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SUMMER 2022

TECHNOLOGY TODAY®

In 2022, Southwest Research Institute completed several new buildings and facilities, including a state-of-the-art, 65,000-square-foot expansion for the Applied Power Division.

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TECHNOLOGY TODAY

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ON THE COVER

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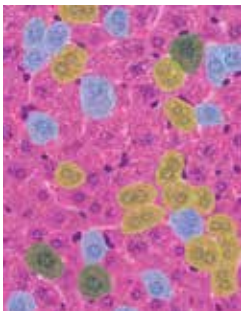

SwRI is using AI algorithms to enhance digital pathology, including identifying treatment-resistant cancer cells in blood samples to help clinicians assess suppression therapies.

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IN THIS ISSUE

Long ago, SwRI placed an ad in a trade journal that summarized our technology development mission as neatly and concisely as I can imagine. It said simply: "We make it work."

Making it work means helping someone with a new idea turn it into a useful product. It also can mean taking a product whose time supposedly has passed and making it relevant for a new future. There's an element of both in the stories of this issue of Technology Today.

Heavy crude oil is traditionally near the back of the line in terms of desirability among petroleum raw materials because it requires extensive refining and is almost impossible to transport via pipeline. But SwRI's EZ Flow™ process cost-effectively allows heavy oil to move via today's pipeline network and could be used to upgrade these raw materials in the future.

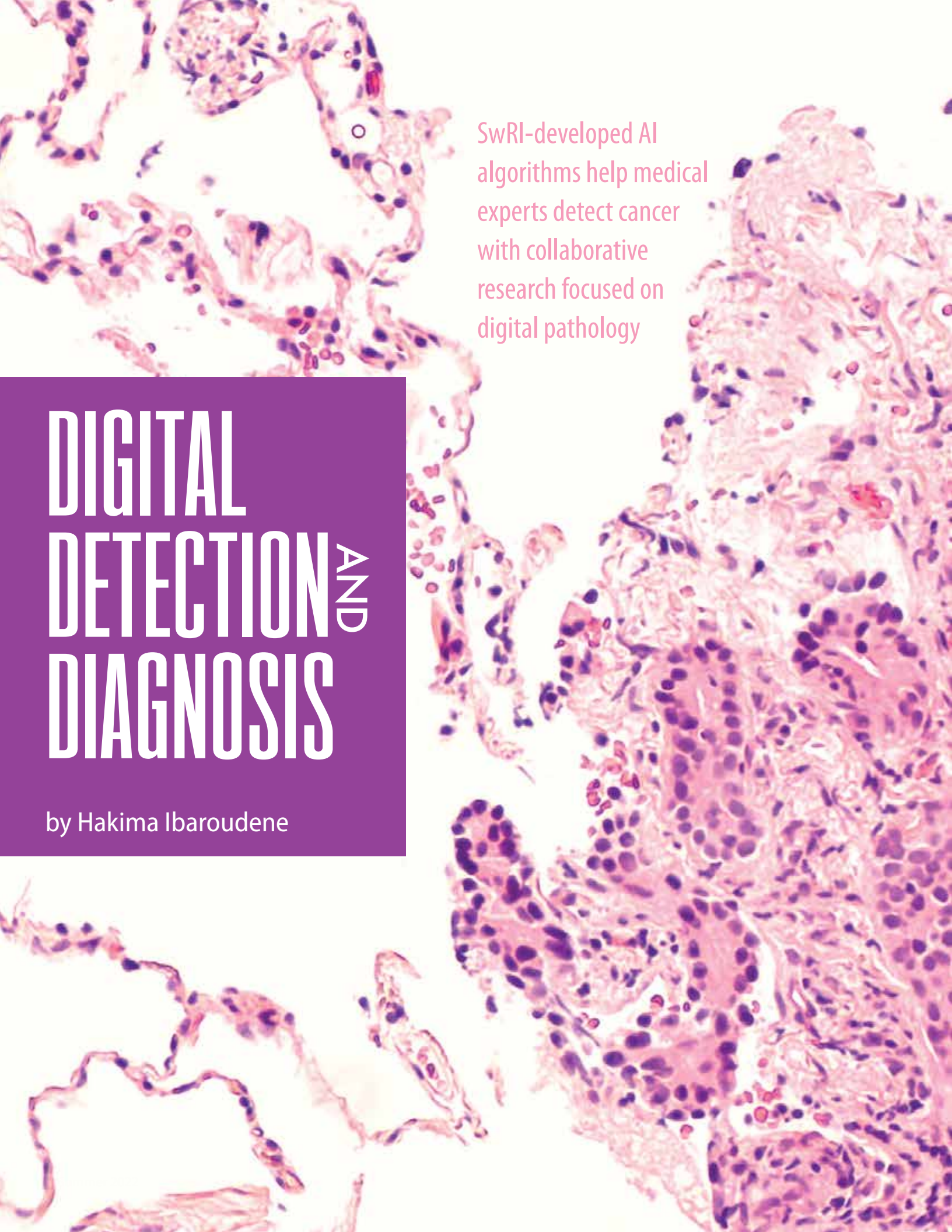
At first glance, one wouldn't link cancer diagnosis with industrial robotics. After all, identifying and quantifying cancer cells in a tissue sample has required not only sharp human eyes but years of specialized training. But with a declining number of board-certified pathologists in recent years, SwRI has been training machine-vision algorithms originally developed for industrial robots and automated vehicles to detect breast cancer cells on digital pathology slides. We've helped "make it work" to the extent of winning a worldwide breast cancer detection competition.

Other technologies highlighted in this issue range from assisting law enforcement with a digital database of specific vehicles to help crack car thefts, bank robberies and kidnappings, to helping solve the worldwide environmental problem of plastic pollution with new recycling processes.

"Making it work" has been making our work relevant to the needs of the world for 75 years, and yet it remains as new as ever.

Sincerely,

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



SwRI-developed AI algorithms help medical experts detect cancer with collaborative research focused on digital pathology

DIGITAL DETECTION AND DIAGNOSIS

by Hakima Ibaroudene

Pathology is a critical part of screening, detecting and staging cancer and other diseases, and yet the number of board-certified pathologists has been declining in recent years.

Over the long term, the demand for disease detection in an aging population has increased pathologists' workloads. In the short term, this growing backlog of work is surging as people who put off cancer screening and other health diagnostics due to the COVID-19 pandemic are once again seeking diagnostic health care services.

These trends are helping to drive research and development of artificial intelligence and other technologies that can speed up analysis of cells for a variety of diseases. Southwest Research Institute is collaborating with several local research institutions and physicians to develop machine vision algorithms that will increase the speed and accuracy of cancer detection and other diagnoses.

DETAIL

An algorithm is a set of steps for a computer program to accomplish a task.

Our work in this space began in 2018, over a year before the onset of the COVID pandemic, when we trained algorithms that had been used in perception systems for industrial robotics and automated vehicles to detect breast cancer from digital pathology slides. The SwRI research with UT Health San Antonio pathologists placed first in the BreastPathQ: Cancer Cellularity Challenge conducted by the American Association of Physicists in Medicine, the National Cancer Institute and SPIE, the international society for optics and photonics.

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ABOUT THE AUTHOR

Hakima Ibaroudene launched and leads the Medical Diagnostic and Prognostic Technologies program area in SwRI's Intelligent Systems Division. The program applies artificial intelligence to solve problems in the medical domain to address challenges in imaging, image processing and electronic health record data. Ibaroudene currently leads research in mental well-being, pathology, radiology, biomechanics and cognitive performance.

By winning that worldwide breast cancer detection competition, the Medical Diagnostic and Prognostic Technologies program at SwRI quickly gained recognition in the world of digital pathology research, but that was only the beginning of a rapidly growing program area and ongoing collaboration with local medical professionals.

DIGITAL DETECTION TRAINING

Algorithms are used in cancer research, especially in the fields of diagnostics and prognostics, using digital image data to increase the speed and efficiency of pathology, while also providing data that can be mined for future treatment options.

Having never worked with medical data or tissue images, SwRI engineers seemingly were at a disadvantage in comparison to the competition. However, they were confident that algorithms for autonomous robots could be adapted to new applications. The team worked with pathologists Dr. Bradley Brimhall and Dr. Edward Medina at UT Health to develop digital diagnostic strategies. The pathologists provided labeled digital files distinguishing between cancer cells and normal cells in hematoxylin and eosin (H&E) stained slides of tissue samples. Then computer scientists set out to automate the process using artificial intelligence techniques, specifically using machine learning.

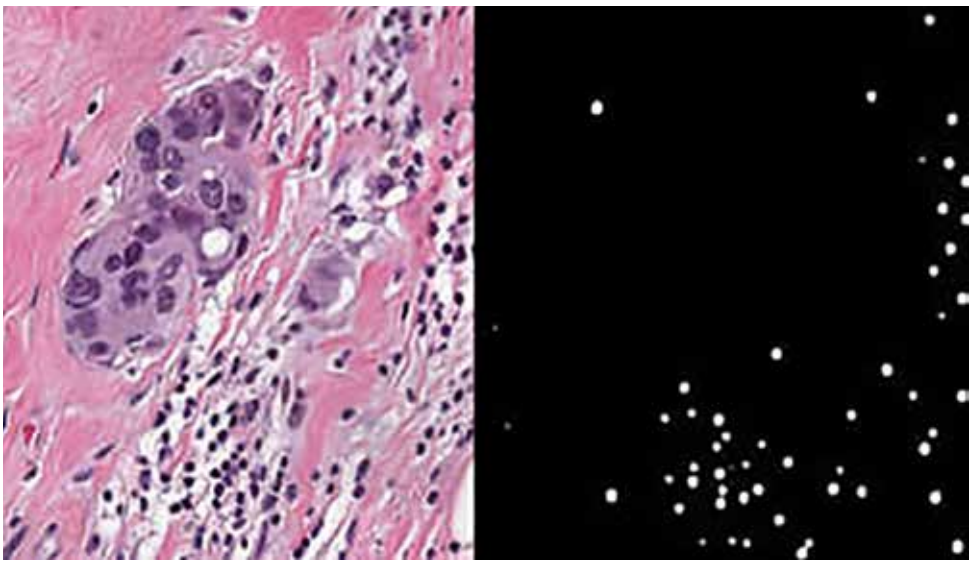
Out of 87 competitors from some of the world's top research institutions, SwRI's algorithm most closely matched the ground truth diagnoses by physicians. With this initial success in applying machine learning to digital pathology, SwRI was eager to tackle more problems in the medical space. First, engineers stepped back and considered the purpose of research efforts. In this case, even the most qualified pathologists are subject to human error. Accuracy can vary depending on factors such as sleep deprivation and clinician experience. Because pathologists perform many other diagnostic, prognostic and research tasks throughout their day, automating one of the most time-consuming tasks allows them to devote more time to advancing cancer treatment in other ways.

MACHINE LEARNING

The team used deep learning techniques, also known as convolutional neural networks, to adapt algorithms to learn from datasets of cancerous and normal cells. These machine learning algorithms automate the processing and interpret large amounts of complex data by extracting and learning patterns.

DETAIL

Digital pathology uses cell imagery from slides scanned into a computer for analysis by a pathologist. Pathologists are physicians who use microscopes and other instruments to study tissues and cells to identify abnormalities and disease. They typically obtain cells via a biopsy or surgery. The process can take several hours to positively identify cancer from a single sample, and multiple samples are often required.



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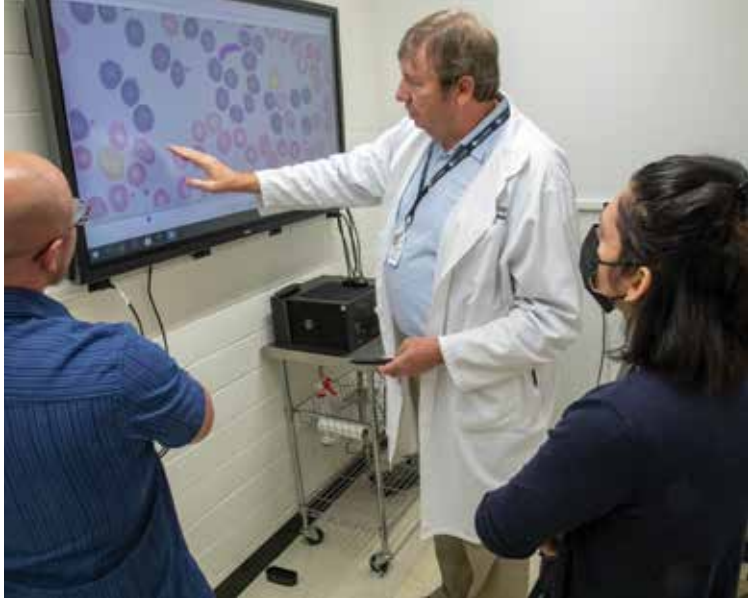
SwRI developed a detection algorithm using breast cancer tumor cell images to compete in BreastPathQ: Cancer Cellularity Challenge. Out of 100 submissions, the SwRI solution placed first in the international challenge to develop an automated method to detect breast cancer tumor cells.



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SwRI analysts David Chambers (left) and Hakima Ibaroudene (right) work with Dr. Bradley Brimhall of UT Health on an AI tool that analyzes stained pathology slides. The purple shapes are irregular blood cells known as follicular lymphoma (FL), a B-cell malignancy, and Philadelphia chromosome (Ph)-negative.

DETAIL

Hematoxylin and eosin (H&E) stain is one of the most widely used tissue treatments for histology, which studies the microscopic anatomy of tissues taken during a biopsy of a suspected cancer.

The team used an artificial neural network (ANN) as a predictive model to classify data. Known inputs are fed into an ANN's top layer, which passes those values through one or more hidden layers. The supervised learning algorithm analyzes the training data and produces an inferred function, which can be used for mapping new examples. An optimal scenario will allow for the algorithm to correctly determine the class labels for new, unlabeled datasets. This requires the learning algorithm to generalize from the training data in a "reasonable" way. ANNs have a high tolerance for noisy data and excel at classifying patterns.

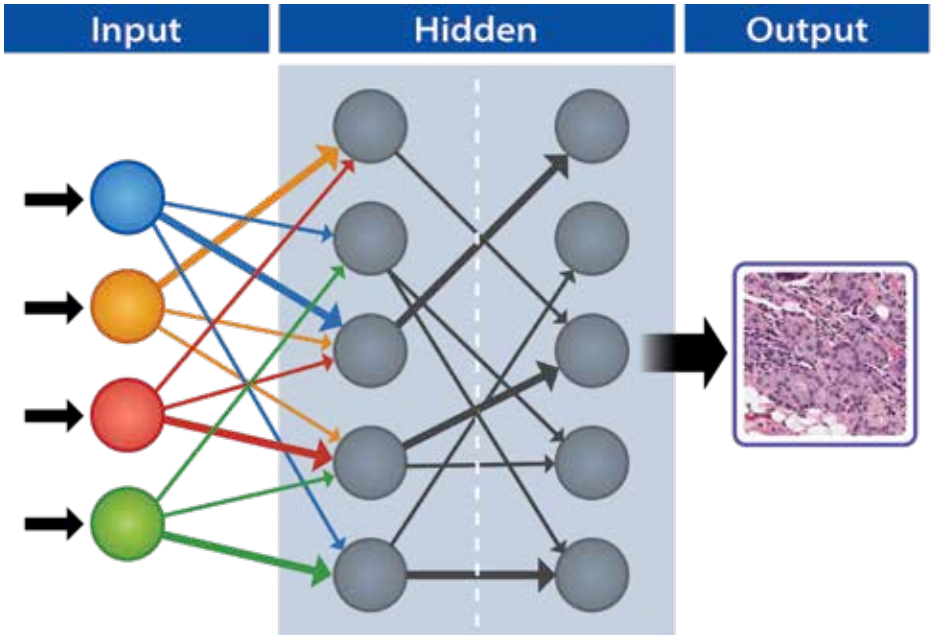
An image recognition neural network breaks down and examines different features. The algorithm is optimized through trial and error and computational back propagation through the various layers of the neural network, eventually narrowing down its predictions to something that is accurate. The learning process takes the inputs and the desired outputs and updates its internal state accordingly, so the calculated output is as close as possible to the desired output.

ADVANCING DIGITAL DIAGNOSTICS

One key to advancing digital diagnostic capabilities is developing and maintaining relationships with collaborators in the medical field. SwRI engineers recognize the importance of consulting medical professionals for their needs and expertise. Since winning the BreastPathQ competition, SwRI has completed projects in collaboration with various local medical professionals. For instance, together with Brimhall and Medina, SwRI developed an algorithm to determine the hormone receptor status of breast cancer cells.

DETAIL

Artificial neural networks are computing systems inspired by biological neural networks in animal brains. Convolutional neural networks are most commonly used to analyze visual imagery.



Convolutional neural networks can be trained to detect features in images. Data are entered at the input layer (far left column) and analyzed in various hidden layers (middle columns) where images are compared to identify cancer or other anomalies based on machine learning inputs. The output layer (right column) identifies images that have cancer cells

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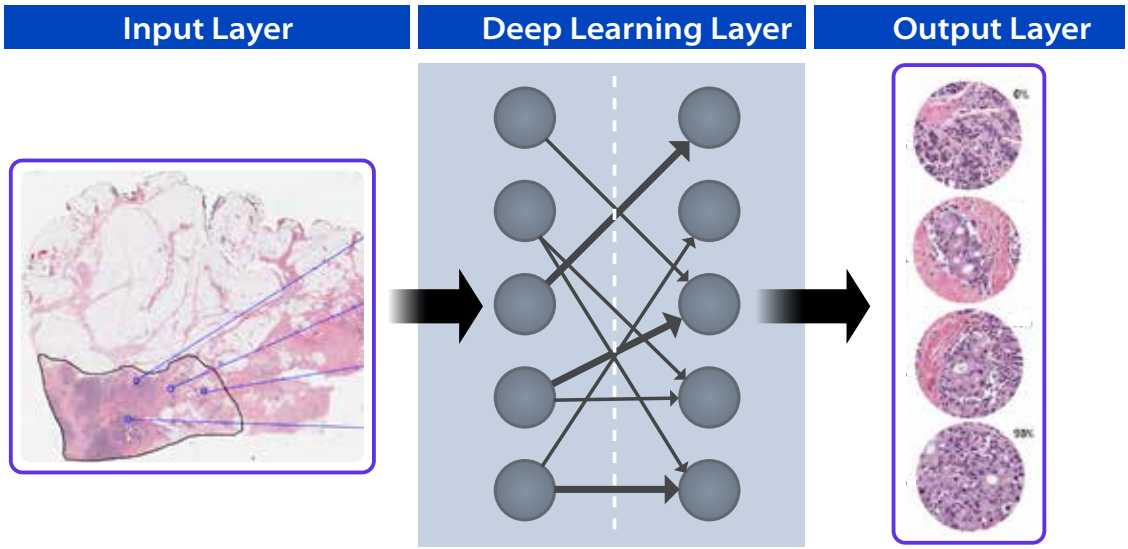


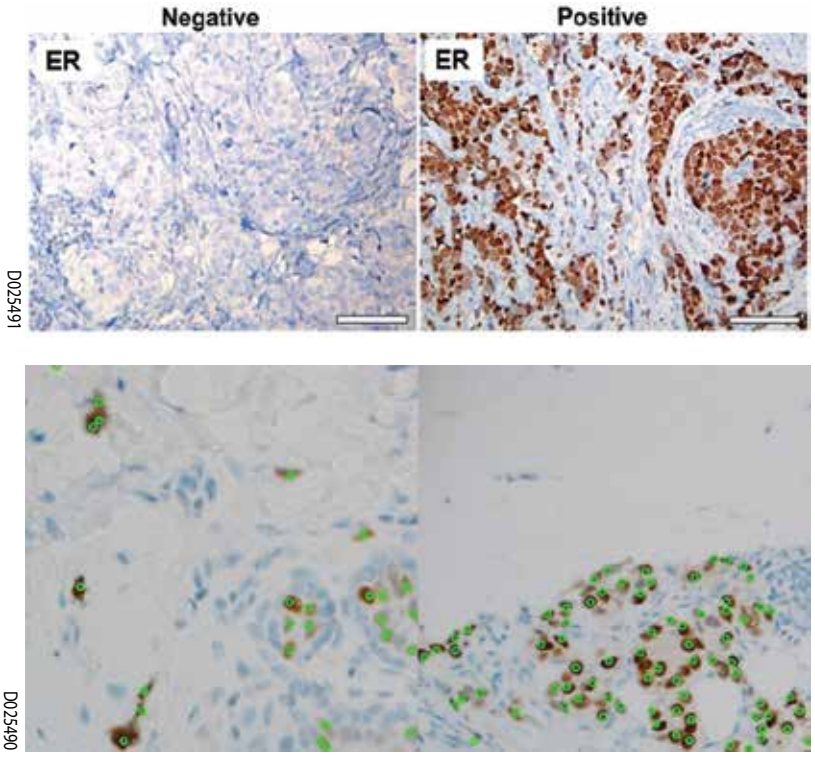
An image of a pathology slide (breast tissue with H&E stain) is digitized and input into a convolutional neural network to train it to differentiate between normal and cancer cells. Most breast cancers arise from epithelial cells (stained purple) that normally line the lobules and ducts that produce milk.

Hidden layers of a neural net use deep learning algorithms to compare input images to thousands of similar images to teach the tool to identify cancer cells. The neural net uses contextual information to identify epithelial cells where they should not occur or arranged in abnormal patterns, indicating cancer.

Training a deep learning algorithm to identify cells with and without cancer improves the accuracy of cancer cell detection. The output layer indicates the percentage of cancerous cells in a sample, depending on the collection site or configuration.

D025529

Hormone receptor status allows doctors to better determine an effective treatment plan, particularly if a cancer is likely to respond to hormonal therapy. However, the current method is susceptible to interpretation and human error, which could be eliminated by automation. This project used estrogen receptor (ER) immunohistochemistry (IHC) staining assay, rather than H&E stains, which presented new challenges. The staining process makes hormone receptors show up in a sample of breast cancer tissue. The assay first identifies a percentage of cells out of 100 that are positive for hormone receptors and their intensity, or how well the receptors show up after staining. The intensity corresponds to how susceptible the cells are to hormonal influences. Because ER IHC slides are drastically different than IHC slides, engineers had to take a new approach that included hand-labeling cells and assessing pixel intensities. This information is then combined to score the sample on a scale from 0 to 8. The higher this "Allred" score, the more receptive the cancer will likely be to hormone therapy.



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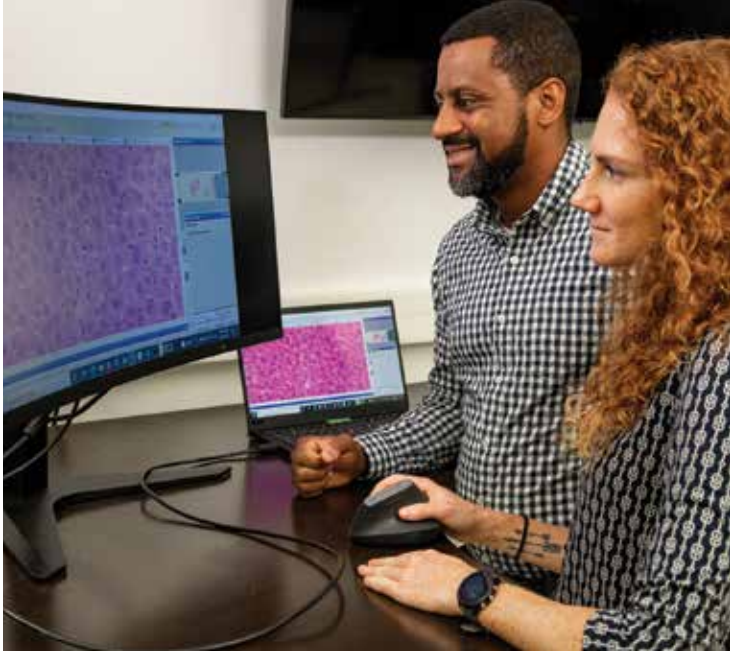
SwRI algorithms accurately determined the hormone receptor status of biopsies at top. Below, the program identified hormone receptor cells (green) while indicating false positives (red) to help pathologists determine if a cancer will respond to hormonal therapy.

DETAIL

The Allred score was named for the doctor who developed the technique for assessing a cancer's hormone receptor status. The technique combines the percentage of positive cells and their intensity to determine the Allred score. Scores from zero to two are considered negative. Scores from three to eight are considered positive and would likely respond to hormone therapies.



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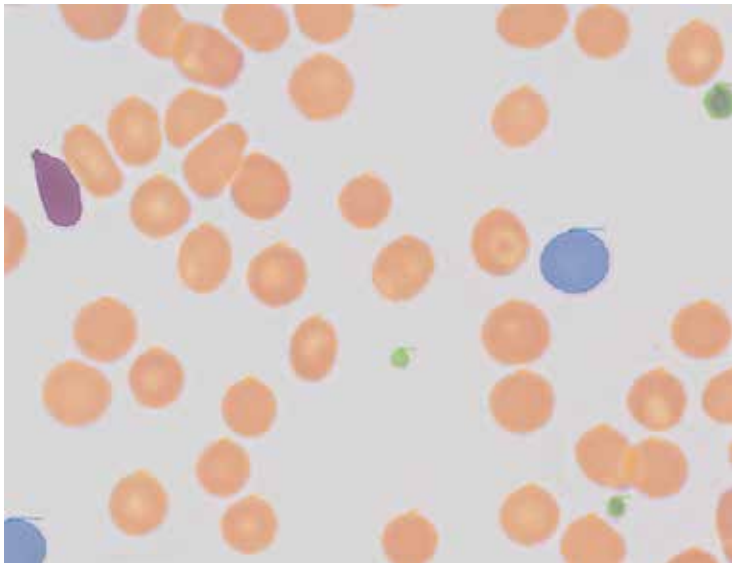
SwRI's Daniel Poole and Dr. Courtney Rouse adapt machine learning algorithms to identify polyploid cells in DLBCL samples to help clinicians assess new polyploid suppression therapies. Chemotherapy-induced polyploid cells become resistant to additional bouts of chemotherapy.

DETAIL

Polyploidy means that cells of an organism have more than one pair of chromosomes. Most species whose cells have nuclei are diploid, meaning they have two sets of chromosomes. Polyploidy may occur due to abnormal cell division.



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SwRI created an AI tool that analyzes stained pathology slides, looking for irregular blood cells that indicate lymphoma.

PREDICTING DRUG RESPONSE

To expand our expertise beyond breast cancers, SwRI needed to expand its network of medical collaborators. The group contacted Dr. Daruka Mahadevan of Mays Cancer Center (part of UT Health San Antonio) after reading an article about his lab's recent drug discovery research for one of the deadliest forms of cancer, Diffuse Large B-Cell Lymphoma (DLBCL).

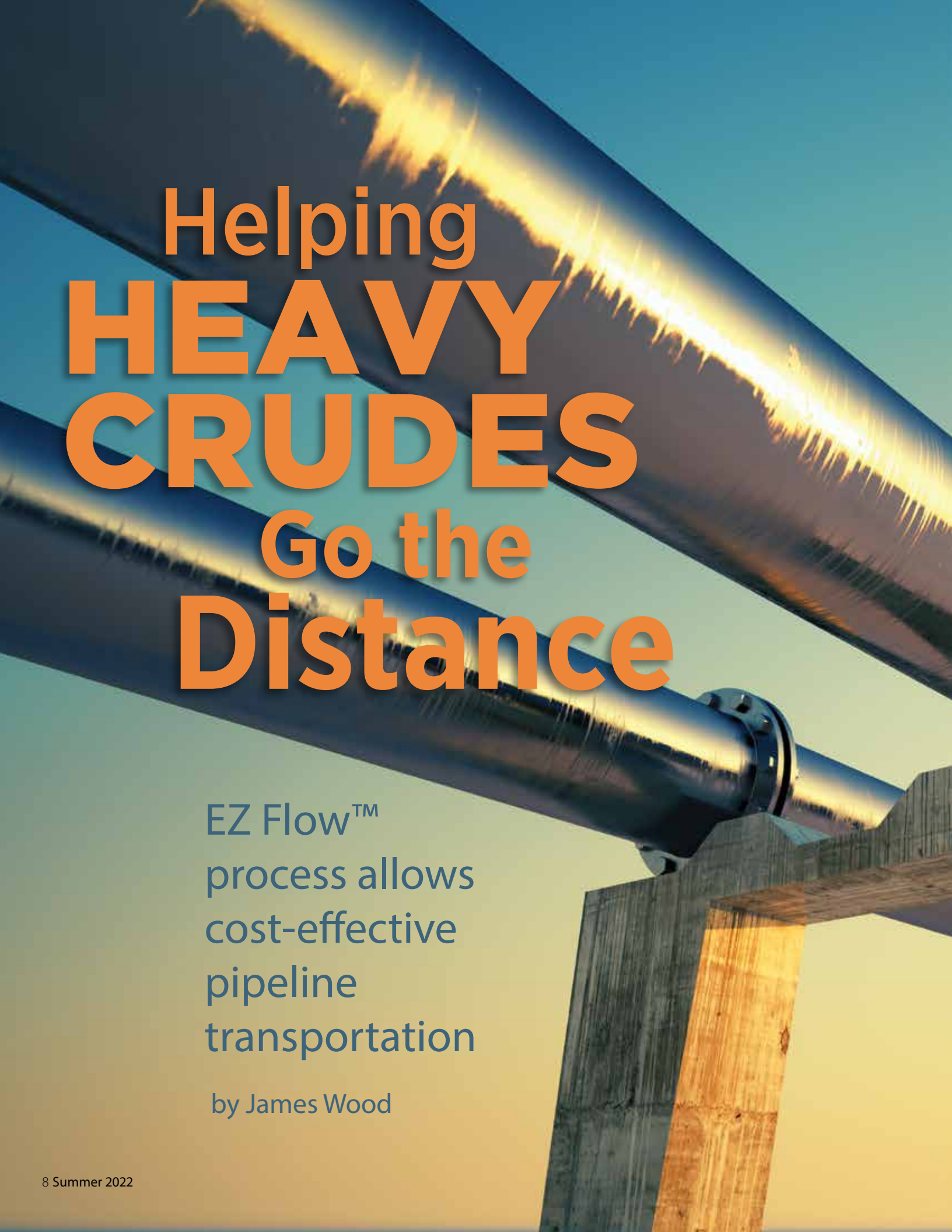
Mahadevan has new evidence that DLBCL becomes resistant to treatment as chemotherapy results in the formation of large polyploid cells with more chromosomes than found in healthy cells. To address this issue, Mahadevan tested the effects of other drugs administered alongside chemotherapy to resist the development of these problematic cells. Unfortunately, there's no methodology for efficiently determining how effective a drug was at eliminating polyploidy. Moreover, because treatment for polyploidy is not yet approved, most pathologists are not trained to identify these cells. Like many other digital pathology projects, the motivation behind automating this process is to eliminate human error and accelerate discovery of therapeutics. A machine learning algorithm was first trained and tested on images of cultured polyploid and normal diploid cells. Currently, the team is adjusting the algorithm to assess images of tissue data.

ADVANCING TOOLS, CAPABILITIES

Throughout their time working on digital pathology research, SwRI engineers have built an image labeling tool that can be used for a variety of data. Project-specific modules can be added as needed, making the tool incredibly versatile, even outside of medical applications. Each project has required a new skillset, which has expanded the capabilities of the group as a whole, enabling the team to apply them to new challenges.

While some of these projects are ongoing, the members of the medical diagnostic and prognostic program area continue to apply for funding, brainstorm with current collaborators and reach out to potential new collaborators. With so many types of cancer and disease, the experience gained from current and past projects will have countless future applications. The group is passionate about improving cancer treatment by developing tools that doctors find useful, timesaving and cost-effective.

Questions about this story? Contact Ibaroudene at hakima.ibaroudene@swri.org or (210) 522-3963.



Helping HEAVY CRUDES Go the Distance

EZ Flow™ process allows cost-effective pipeline transportation

by James Wood

As economic development and populations increase and reservoirs of light conventional crude are depleted, the demand for heavy crude oil as an energy source is expected to grow. Slowly but steadily, unconventional heavy crudes have been gaining on conventional light crude oils as a major energy source. Currently, of more than 80 million barrels of oil produced globally per day, about 11 million barrels are classified as heavy crude oils.[1] In light of today's political and economic challenges in the petroleum marketplace, abundant heavy crude oil reserves in North America offer attractive alternatives.

SwRI is investigating techniques to make thick, highly viscous heavy crude oil easy to transport through existing pipeline networks.

D017427_5620

DETAIL

Viscosity refers to a fluid's resistance to flow, usually measured in centipoise, cP. For liquids, viscosity corresponds to the informal notion of "thickness." For example, honey has a higher viscosity than water.

Producing and transporting heavy crude oil and bitumen, a semisolid form of petroleum, is at least twice as capital- and energy-intensive as producing and transporting conventional oil[2] due to high viscosity at reservoir conditions, as well as the presence of undesirable compounds. These characteristics make heavy crude oils difficult to produce, move by pipeline and refine.

Heavy and extra-heavy crude oils are thick and sludgy, so they resist flow through pipelines and are often transported by truck or rail, adding significant expense and introducing potential hazards. Pipeline transmission is also hindered by asphaltene and paraffin deposition, formation water and salt content, and corrosion issues.[3] However, pipelines are widely regarded as the most attractive option for transporting crude oils. Pipeline transmission offers low costs and relatively low environmental impacts compared to other transport options that require loading and unloading oil in environmentally sensitive places.

Southwest Research Institute scientists and engineers developed the EZ Flow™ process to treat heavy crude oils, making pipeline transportation of the resource and similar viscous commodities more cost-effective and less energy-intensive than current techniques. The EZ Flow process combines mechanical and chemical treatments to reduce the heavy crude oil's viscosity by 60% or more, helping it flow more easily through existing pipelines.

IMPROVEMENT OPPORTUNITY

The production of heavy crude oil is expanding worldwide. For example, at least 50 percent of crude oil reserves in Mexico are heavy and extra-heavy crude oils.[4] Canada currently relies on heavy crude oil to meet production needs, producing about 700,000 barrels per day of synthetic crude oil coming from heavy crude oil, bitumen and tar sands. These synthetic crudes are transported via pipelines to refineries in Canada and the U.S.[2] using heat and chemical additives to facilitate transport by pipeline.

However, the technologies currently used to facilitate transport of heavy crudes are expensive, typically requiring various treatment techniques and tremendous energy resources in the form of heat. The heavy crude oil often requires multiple treatments simultaneously or the addition of large volumes of diluent to allow for pipeline transportation.

Non-pipeline transportation methods, such as rail or tanker trucks, are expensive, incurring fuel costs, transport maintenance and high potential for environmental impacts associated with exhaust emissions, derailment and collision risks. For example, air pollution and greenhouse gas costs associated with moving a fully loaded 100-car train of crude oil from North Dakota to the Gulf Coast are estimated to be about $150,000 one-way. The same transportation to the East Coast would cost about $210,000. The total estimated air pollution and greenhouse gas damages for oil shipped by rail from North Dakota in 2014 exceeded $420 million.[5] And there are many other associated costs making current methods for transporting heavy crudes very expensive. A literature review of

Chemists used heavy crude oil from the Belridge oil field to demonstrate the EZ Flow™ treatment system at bench scales.

D025219_0459

DETAIL

Asphaltenes, molecular substances in crude oil named for their asphalt-like properties, are used as paving materials on roads. Paraffin is a soft, colorless petroleum wax consisting of large hydrocarbon molecules. Bitumen is a sticky black, highly viscous liquid or semisolid form of petroleum.

current heavy crude oil pipeline transportation technologies concluded that to continue the "increasing exploitation of heavy oil and bitumen, it is necessary to develop technology to aid in their transportation through pipelines."[2] Clearly new transport solutions are needed.

Logistically, transporting heavy crude oil and bitumen via pipeline is challenging and often impossible considering the high density and viscosity (≥ 1,000 cP at 40°C) and very low mobility of the commodities at reservoir temperatures.[2] These characteristics are associated with the precipitation of the asphaltene's macromolecules and their subsequent aggregation in the oil, which contributes greatly to its pipeline flow resistance. The intermolecular forces between large, branched molecules and the tendency of the asphaltenes and paraffins to coalesce produces aggregates of heavy hydrocarbons. Those agglomerations can not only cause pipeline deposits and plugging, but also can structurally compress the oil and reduce its relative volume. That, in turn, increases the density of the heavy crude oil. These natural physical and chemical properties make heavy and extra-heavy crudes difficult to transport in general and very difficult to transport via pipeline over long distances.

PROCESS DEVELOPMENT

When developing the EZ Flow process, SwRI chemists used bench-scale screening to determine the best candidate chemical formulations to treat heavy crude oil. The team then used the formulations with the most promising viscosity reduction potential at the bench scale in the pilot-scale system and optimized the chemical treatment of the heavy crude oil by incorporating hydrodynamic cavitation to homogenize the mixture. The hydrodynamic cavitation process froths the fluid, generating and imploding

bubbles in a flowing liquid, which decreases and subsequently increases local pressures to enhance chemical reactions. Chemists considered the properties of the specific heavy material being treated when developing and testing chemical formulations.

SwRI selected Belridge heavy crude oil to demonstrate the EZ Flow process at a bench scale because its properties are well-documented, and it resembles many of the candidate oils targeted for this treatment. Chemists heated the sample to 40°C in a stirred-stainless-steel, conical-bottom vessel while sequentially mixing low-concentration chemicals into the heavy crude oil. They then circulated the sample through the hydrodynamic cavitation mixing device using a specified energy input. For the demonstration, the mixture was circulated in multiple passes. Chemists anticipate that a commercial unit would treat the heavy crude/chemical mixture in a single pass.

A key feature of the overall process is the low volume of added chemicals needed to reduce viscosity. These chemical additives included a water-dispersible mixture integrating an aromatic solvent, at least one base solvent, at least one liquid hydrocarbon and an organic solvent as well as an optional surfactant. Process optimization for various feeds may include additional chemical compounds or classes.

FLOWABLE HEAVY CRUDES

Treatment of Belridge heavy crude oil using the EZ Flow technology reduced kinematic viscosity at 40°C by 60% or more while using low concentrations of added chemicals — 2% or less — and less than 2% water. No heat is required after treatment, allowing for pipeline transportation of the treated heavy crude oil without further heating, dilution or chemical addition.

SwRI evaluated over 30 different chemical formulations during the screening process for the Belridge heavy crude oil treatment. Chemical formulations can be optimized for different feeds, bitumen, extra heavy crude oil and other nonconventional heavy crudes. The results obtained to date have shown promise for the economic transportation of a variety of nonconventional heavy crudes by pipeline. The application of this technology to other heavy and extra-heavy materials seems promising.

The EZ Flow process reduces the intermolecular forces between and inside the agglomerates of the heavy crude oil, promoting dispersion vs. aggregation. The chemical and mechanical treatments of the heavy crude oil work together to reduce viscosity. Chemical additives reduce the interfacial tension in heavy crudes, while hydrodynamic cavitation (HC) provides enough energy to enhance the chemical reaction without requiring bulk heating to break up the aggregates and disperse the asphaltenes. The local thermal treatment does not need to raise the whole mass of oil to the target temperatures for disaggregation.

EZ Flow's proprietary mixture of low-concentration chemical compounds optimizes the hydrodynamic cavitation of the heavy crude oil and can reduce heavy crude oil viscosity by over 60%. The similarities between EZ Flow formulations and refinery chemicals

DETAIL

Belridge heavy crude oil comes from one of the largest oil fields in the country, near Bakersfield, California. The field has been producing oil for more than a century, so the oil's properties are well known.

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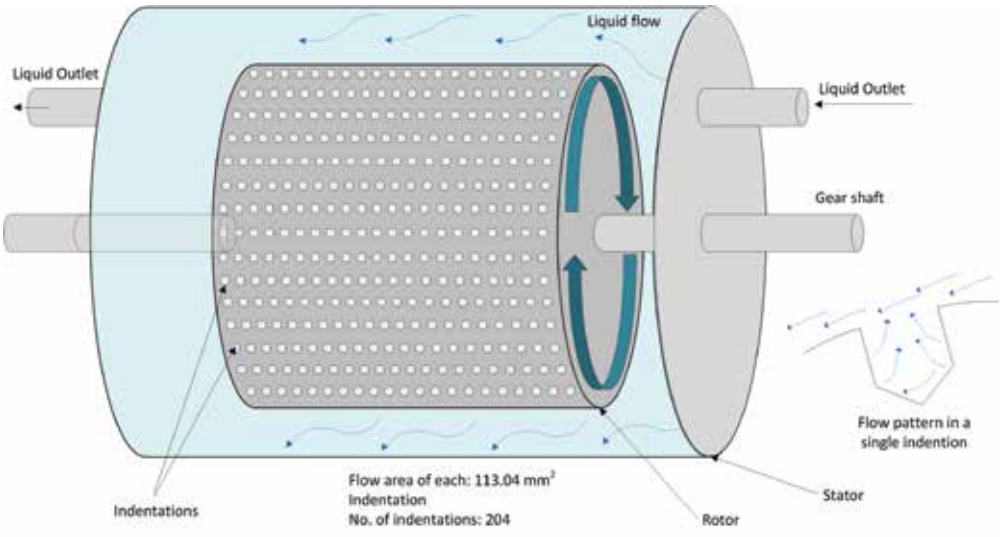
To demonstrate the EZ Flow process at a bench scale, chemists heated a heavy crude sample to 40°C in a stirred-stainless-steel, conical-bottom vessel while sequentially mixing low-concentration chemicals into the heavy crude oil.



The figure at left shows hydrodynamic cavitation, a mechanical process used to froth and homogenize fluids efficiently. The technique enhances chemical reactions, minimizing additives needed to treat heavy crude oils.

D025530

DETAIL

Interfacial tension is the molecular attraction between compounds in fluids.

suggest that these formulations will not interfere with processes nor affect equipment at a refinery. In addition, the chemical formulation composition and hydrodynamic cavitation process can be optimized to lower the viscosity of different types of heavy and extra-heavy crude oils from different regions to make many unconventional crude oils suitable for transport through existing pipelines.

Other advantages of this process include lower costs of chemical additives and more environmentally friendly qualities. The process is not technically demanding, and treated oils can be stored for long periods of time without affecting the viscosity improvements. The process was designed to be scaled up to a commercially viable operation with low upfront and operational costs. In addition to reducing viscosity to allow for pipeline transportation, the EZ Flow technique could be used to upgrade heavy crude oil or possibly to enhance oil recovery. The changes created in the field will facilitate processing in the refinery and will not require special operations or processing.

According to API, the U.S. has more than 190,000 miles of liquid petroleum pipeline that deliver crude oils, including heavy crude oils, to refineries and chemical plants throughout the U.S. Transporting EZ Flow-treated heavy and extra-heavy crude oils over long distances by pipeline is estimated to be more cost-effective than using transportation methods, such as rail car or pipeline distribution of heavily diluted product.

Using the EZ Flow process to upgrade heavy crude oil will require further research and optimization but could produce significant benefits to the oil refining industry in addition to companies that transport the heavy crude oils. The research performed to date has been developmental, but the application of the technology to industry has the potential to change the dynamics of the unconventional crude oil market, bringing transportation costs more in line with those of conventional crude oil. In the next phase of research, chemical engineers will evaluate client-specific applications as well as scale up the EZ Flow process.

Questions about this story? Contact James Wood at james.wood@swri.org or (210) 522-6768.

[1] Gounder, Ramasam, Introductory Chapter: *Heavy Crude Oil Processing — An Overview, Processing of Heavy Crude Oils*, IntechOpen, 2019.

[2] Hart, A., A Review of Technologies for Transporting Heavy Crude Oil and Bitumen via Pipelines, *Journal of Petroleum Exploration and Production Technology*, pp. 327-336, 2014.

[3] Martinez-Palou, R., Transportation of Heavy and Extra Heavy Crude Oil by Pipeline: A Review, *Journal of Petroleum Science and Engineering*, pp. 274-282, 2011.

[4] Investigación y Desarrollo, New Technology Reduces Transportation Costs of Heavy Oil, *Distrito Federal, Mexico: Investigación y Desarrollo*, 2016.

[5] Clay, K., *The External Costs of Transporting Petroleum Products by Pipelines and Rail: Evidence from Shipments of Crude Oil from North Dakota*, National Bureau of Economic Research, 2017.

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ABOUT THE AUTHOR

James Wood is a chemist, microbiologist and project manager. He has performed research and development at SwRI for 16 years. Wood has been published in over 20 technical journals, magazines or national conference proceedings in the fields of engineering, chemistry, microbiology and environmental science.

SECURING CRITICAL INFRASTRUCTURE, INDUSTRIAL SYSTEMS

SwRI has developed technology to help government and industry detect cyber threats to industrial networks used in critical infrastructure and manufacturing systems. SwRI funded the research to address emerging cyber threats in the rapidly evolving ecosystem for industrial automation.

"Business trends and new technology — driven in part by a pandemic push toward automation — are revealing more cyber vulnerabilities across industrial systems," said Dr. Steven Dellenback, vice president of SwRI's Intelligent Systems Division. "We are proud to support government and industry with multidisciplinary expertise in cybersecurity and automation technologies."

The team used algorithms to scan for cyber threats across networks that transmit industrial control data for everything from natural gas pipelines to manufacturing robots. The research led to the development of an intrusion detection system (IDS) for industrial control systems (ICS).

"Historically, industrial control systems were not designed with security in mind," said Ian R. Meinzen, an SwRI intelligent machines engineer who worked on the project. "They had the benefit of an 'air gap' where they could operate securely without a connection to information technology (IT) networks."

Isolating industrial networks from IT networks, however, is no longer an option for modern automation systems that rely on the internet of things (IoT) to transmit vast amounts of data. IoT describes the network of physical objects embedded with sensors and software to connect and exchange data with other devices and systems via communications networks over the internet.

"Connecting IoT devices and other hardware exposes industrial networks to security vulnerabilities," said Peter Moldenhauer, an SwRI computer scientist specializing in cybersecurity. "Attacks can occur through an IoT device, network protocols and outdated software."

The SwRI team focused this research on scanning for cyberattacks over the Modbus/Transmission Control Protocol (TCP). Utilities and industry have used this Ethernet-based networking protocol for decades in supervisory controls and data acquisition (SCADA) systems equipment.

SwRI researchers originally developed the algorithms to scan Controller Area Network or CAN bus networks used in automotive hardware. They customized cybersecurity algorithms to scan a simulated network equipped with industrial devices before evaluating the new algorithms on a real-world industrial network. The test system used the Modbus/TCP protocol to send data packets over a network. The network featured an Ethernet switch that connected personal computers, programmable logic controllers and input/out modules. Such industrial computing devices send commands and record data for automated robots and mechanized equipment.

"We had to customize the previous algorithms to recognize the different ways the Modbus/TCP protocol grouped data packets in sequences and time signatures," said Jonathan Esquivel, an SwRI computer scientist.

The adapted algorithms applied to the test network recognized normal Modbus/TCP traffic and identified cyberattack vectors such as out-of-band timing, address probing and data fuzzing/manipulation. The algorithms classify data packets as "regular" when they come from an uncompromised industrial control device or "attack" when the source is an unexpected or compromised device.

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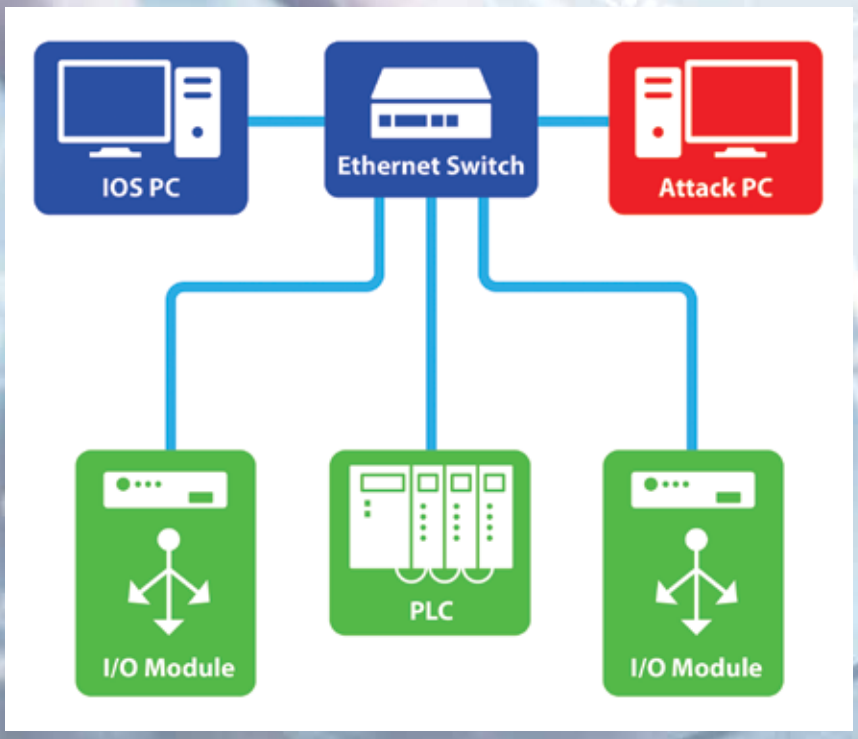
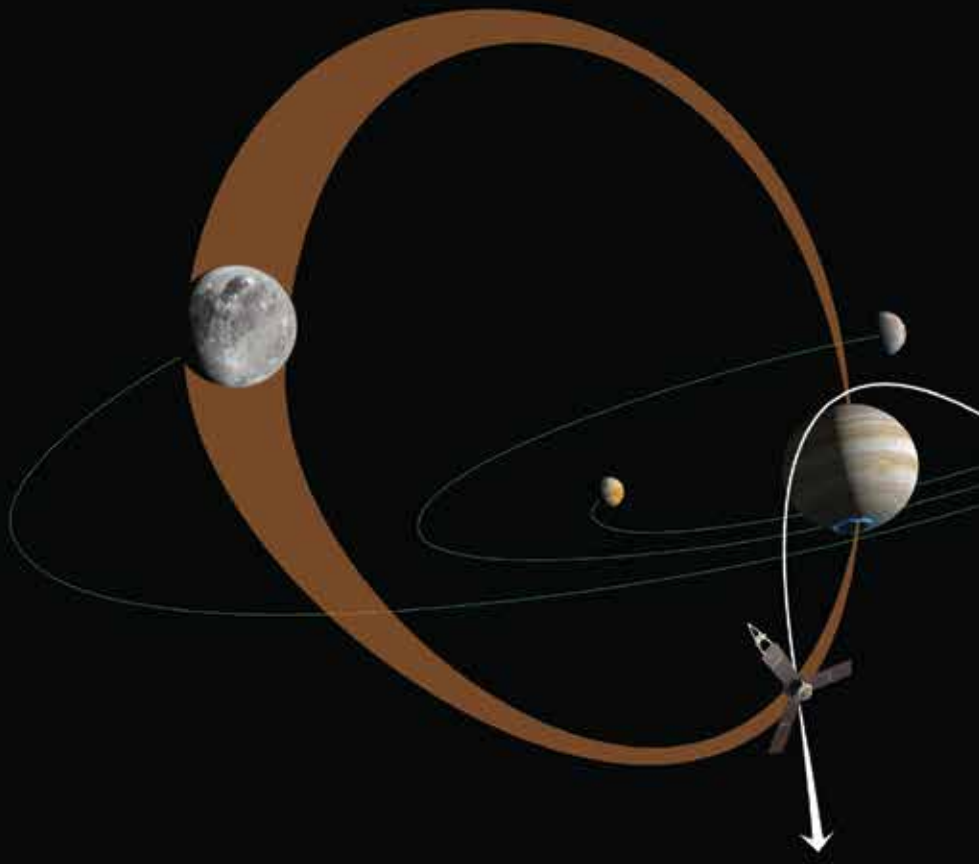


SwRI-designed algorithms detected cyberattacks to an industrial network from a malicious computer. The network utilized the Modbus/TCP protocol to transfer data packets between input/output devices and programmable logic controllers connected via an Ethernet switch.

D025493

Using a bench test network, SwRI-developed algorithms scanned data packets transferred via the Modbus/TCP protocol for cyberattacks.

CONNECTING THE DOTS BETWEEN JOVIAN MOON, AURORAL FOOTPRINTS



On November 8, 2020, NASA's Juno spacecraft flew through an intense beam of electrons traveling from Ganymede, Jupiter's largest moon, to its auroral footprint on the gas giant. SwRI scientists used data from Juno's payload to study the charged particles traveling along the magnetic field connecting Ganymede to Jupiter while, at the same time, recording pictures of Jupiter's auroras.

"Jupiter's most massive moons each create their own auroras on Jupiter's north and south poles," said Dr. Vincent Hue, lead author of a paper outlining the results of this research. "Each auroral footprint, as we call them, is magnetically connected to their respective moon, kind of like a magnetic leash connected to the moon glowing on Jupiter itself."

Like the Earth, Jupiter experiences auroral light around the polar regions. However, Jupiter's auroras are significantly more intense than Earth's, and unlike Earth, Jupiter's largest moons also create their own auroras on Jupiter. The Juno mission to Jupiter is led by SwRI's Dr. Scott Bolton. From its polar orbit, the Juno spacecraft flew through the electron "thread" connecting Ganymede with its associated auroral footprint.

Ganymede is the only moon in our solar system that has its own magnetic field. Its mini-magnetosphere interacts with Jupiter's massive magnetosphere, creating waves that accelerate electrons along the gas giant's magnetic field lines, which can be directly measured by Juno.

Two SwRI-led instruments on Juno, the Jovian Auroral Distributions Experiment (JADE) and the Ultraviolet Spectrometer (UVS) provided key data for this study, which was also supported by Juno's magnetic field sensor built at NASA's Goddard Space Flight Center.

"JADE measured the electrons traveling along the magnetic field lines, while UVS imaged the related auroral footprint spot," said SwRI's Dr. Thomas Greathouse, a co-author on this study.

In this way, Juno is both able to measure the electron "rain" and immediately observe the UV light it creates when it crashes into Jupiter. Previous Juno measurements showed that large magnetic perturbations accompanied the electron beams causing the auroral footprint. This time, however, Juno did not observe similar perturbations with the electron beam.

"If our interpretation is correct, this is a confirmation of a decade-old theory that we put together to explain the morphology of the auroral footprints," said Dr. Bertrand Bonfond of the Liège University in Belgium, a co-author of the study. The theory suggests that electrons accelerated in both directions create the multi-spot dance of auroral footprints.

"The Jupiter-Ganymede relationship will be further explored by Juno's extended mission, as well as the forthcoming JUICE mission from the European Space Agency," Hue said. "SwRI is building the next generation of UVS instrumentation for the mission."

A paper describing this research was published in Geophysical Research Letters and can be accessed at https://doi.org/10.1029/2021GL096994.

NASA's Juno spacecraft flew through the intense beam of electrons traveling from Ganymede, Jupiter's largest moon, to its auroral footprint on the gas giant. SwRI scientists used the resulting data to connect the particle population traveling along the beam with associated auroral emissions to unveil the mysterious processes creating the shimmering lights.

IMAGE COURTESY NASA/SwRI/JPL-CALTECH/MALIN SPACE SCIENCE SYSTEMS/KEVIN M. GILL/ITALIAN SPACE AGENCY/ITALIAN NATIONAL INSTITUTE FOR ASTROPHYSICS/BJÖRN JÓNSSON/ULIÈGE/BERTRAND BONFOND/VINCENT HUE D025513

DAIS

CRIME-BUSTING SOFTWARE SYSTEM

In the mid-2000s, SwRI developed the Digital Automotive Image System (DAIS) to assist in the forensic investigation of crimes, providing automotive images and associated technical specifications of vehicles. The system allows law enforcement personnel to search a database of vehicles to find a particular car or cars and print a high-quality 8x10 image of the vehicle or quickly create a customized be-on-the-lookout (BOLO) poster. The database can be searched by year, make, model, class/type, door number, features and any combination thereof. DAIS has helped solve bank robberies, child abductions, missing persons and various other cases. SwRI provides regular updates to the software to include new vehicles. The FBI provides DAIS free of charge to law enforcement via the Law Enforcement Enterprise Portal (LEEP).

UPDATED EVERY **2** YEARS

DAIS INITIAL RELEASE **2007**

MAKES **70**

MODEL YEARS **1990 to 2021**

AUTOMOTIVE IMAGES **51,000**

MODELS **16,979**

DISTRIBUTED TO

>18,000

LAW ENFORCEMENT AGENCIES IN NORTH AMERICA

COST TO LAW ENFORCEMENT

$0

D024629

- CLASS/TYPE: from passenger cars to SUVs and cargo vans
- FEATURES: from hatchbacks to convertibles and extended-cab pickups
- DOORS: two-door vs. four-door
- FOUR VIEWS: front, rear and driver and passenger sides

A CHEMICAL SOLUTION TO PLASTIC POLLUTION

Advanced chemical recycling using mixed plastics

by Hsiang Yee Hoekstra and Eloy Flores III

Plastics are ubiquitous in modern life. Nearly 400 million tons of plastic are produced annually and found in everything from cell phones to cars, toys, food packaging, home goods and medical products. For decades, consumers have collected and recycled plastics expecting that the material will be reused in the manufacturing process. However, of the piles of plastic waste collected in the United States, more than 90% ends up in our oceans and landfills or incinerated for energy production.

As a result, these plastic pollutants affect wildlife and the environment, take years to decompose at landfills and result in increased greenhouse gas emissions with incineration. For instance, the Ocean Cleanup organization estimates that the Great Pacific Garbage Patch, the largest of five plastics accumulation zones in the world's oceans, occupies nearly a million square miles. Located about halfway between Hawaii and California, it is about twice the size of Texas.

D025029_8964

New SwRI-developed processes are chemically recycling mixed plastics, shown melted together into a cylinder, to target the large number of plastics in our economy that are currently not being recycled.

Today, 71% of the plastic produced is formally collected after use, but less than 15% is actually recycled. The plastics that are recycled use conventional mechanical recycling technologies, which change the physical structure of the material while keeping the chemical structure the same.

The recycling process is initiated by the consumer, who sorts and decides which materials to recycle and which to dispose of as waste. The recyclables are then collected and delivered to a material recovery facility where a combination of automated and manual processes sort the materials into different materials streams: metals, cardboards and paper, glass and waste plastic. The waste plastics are further sorted by polymer type, which are identified by a number between one and seven inside the familiar triangle made of arrows. Each number corresponds to a different type of plastic. After collection and sorting, the materials are washed, dried, ground and regranulated to recycle the materials into like products. For example, plastic water bottles are recycled into more water bottles.

DETAIL

The plastics industry is one of the largest manufacturing industries in the U.S., generating $451 billion per year in shipments and employing nearly a million people directly and more than 1.5 million indirectly.

Southwest Research Institute (SwRI) is developing approaches to solve this plastics challenge using advanced chemical recycling processes to create applications for waste plastics. The goal is to convert mixed waste plastics into light hydrocarbon gases, fuels and commodity chemicals, including precursors for downstream plastic product manufacturing. Advanced chemical recycling will utilize existing waste plastics supply chains and target the recycling of the plastics that would otherwise be sent to landfills or incinerators, complementing the mechanical recycling process.

CHEMICAL PROCESSING

SwRI chemical engineers have a long history helping clients develop chemical processes, from fundamental process design to demonstrating techniques and technology at laboratory and pilot plant scales. With diverse backgrounds in advanced alternative fuels, gas-to-fuels, petroleum and petrochemical processes, SwRI is advancing process development to improve costs, efficiency, environmental impacts and technology advancement.

This diverse experience is critical to recycling mixed plastics, which is complicated by the various types of plastics, their different flow properties and contaminants.

To solve the plastics recycling conundrum, chemical engineers are investigating several approaches for recycling waste plastics, including pyrolysis and gasification. Pyrolysis and catalytic pyrolysis use high temperatures and inert atmospheres to break down material into more basic molecules. A process known as fast pyrolysis has been the go-to technology for converting biomass, or plant-based materials, into biofuels. SwRI is adapting this technology for plastics. Another common technique for processing waste materials into useful chemicals is gasification. Gasification also employs pyrolysis as part of the process, but further processes the feedstock into carbon monoxide and hydrogen.

TODAY'S MECHANICAL RECYCLING

Just because a plastic material has the "chasing arrows" symbol does not mean it is recyclable.

Only plastics labeled #1 and #2 are readily recyclable using mechanical techniques. Recyclable #1 is the most common plastic used for single-serving bottles of water, carbonated drinks, juices, vegetable oil and ketchup. Recyclable #2 can be found in milk jugs, detergent jugs, shampoo bottles and other household cleaner bottles.

Once sorted, these plastics are washed, dried and regranulated to make new plastic products. Mechanical recycling is successful for single-type bulk plastic streams, where water bottles can be recycled into more water bottles.

Anything but #1 and #2 plastics are pulled out and sent to landfills or incinerators. Plastics #3-7 account for more than 90% of waste plastics collected and are found in piping, siding, grocery bags, food containers, plastic bottle caps, takeout containers and polystyrene.

One key feature of pyrolysis is the ability to handle mixed plastics without sorting. SwRI has used pyrolysis to process heavy oil, coal and all types of biomass. Engineers are transferring that experience to accelerate technology development to convert waste plastics into pyrolysis oils. These oils can then be used as feedstocks to produce new plastic products, useful chemicals, and fuels, or they can be integrated into traditional refinery streams.

DETAIL

Pyrolysis is not new. It was used by the ancient Egyptians to extract methanol from wood to create embalming fluids for mummies.

PLASTIC PROCESSING

To begin the recycling process, plastics are dried and shredded into small flakes and fed into a pyrolysis reactor, typically using a heat transfer media such as sand or a catalyst. Pyrolysis begins as the material melts at high temperatures without the presence of oxygen. Through surface interaction with the solid media, the waste plastic chemical bonds start breaking down into smaller and smaller molecular components.

SwRI has more than 25 years of experience creating novel processes to create fuels and chemical products from unconventional sources. We demonstrate these at lab, pilot plant and near commercial scales.

D021646_7678

Gasification also uses pyrolysis, but the process is conducted in a single column. Shredded waste plastic is fed through the top of the column where it is dried and pyrolyzed before air or oxygen is introduced, and the oil is partially combusted to create syngas (carbon monoxide and hydrogen). The syngas is then reduced and piped out, while ash is removed using cyclonic separation to extract particulates.

Conventional pyrolysis of plastics creates mostly hydrocarbons. Gasification allows the introduction of oxygen to create syngas, which can easily be converted into compounds like methanol and isopropyl alcohol.

These simpler compounds can be condensed and used to create fuels or chemical feedstocks. Another byproduct of pyrolysis is carbon, as heavier molecules tend to polymerize and form coke particles. The coke byproducts can be used directly as heat energy by using a circulating fluid bed to introduce air into the process, allowing the coke to burn and provide energy to fuel the pyrolysis process.

Once the plastics have been reduced into their basic components, those components can serve as building blocks for many different types of products. Carbonaceous and ash solids can be used in products like roofing materials, concrete or tires. Some of the liquid products are what might be called "pygas," or pyrolysis gasoline, which has a similar boiling point range as gasoline or naphtha, a flammable liquid hydrocarbon mixture.

Those oils can be further fractionated into chemicals of interest. For instance, pyrolysis oils can be processed in naphtha crackers to produce more plastic feedstocks. A naphtha cracker can process lower boiling point hydrocarbons into ethylene and propylene, the basic building blocks for plastics and subsequent manufacturing.

DETAIL

Coke is a hard, grey, porous substance with a high carbon content that is typically used for iron ore smelting.

Cracking, which breaks heavy hydrocarbon molecules into lighter molecules using heat, often done in a reducing environment (with hydrogen) combined with pressure and catalysts, is the most important process for the commercial production of jet, gasoline and diesel fuel.

Pyrolysis oils made by chemical plastic recycling are versatile and can be processed into a large slate of chemicals. Pyrolysis processing provides a fairly quick response to shifting market demands for different chemical products.

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Post-consumer and post-industrial plastic flakes are heated and pressurized to extrude plastic into a flowable material to feed into SwRI reactors.

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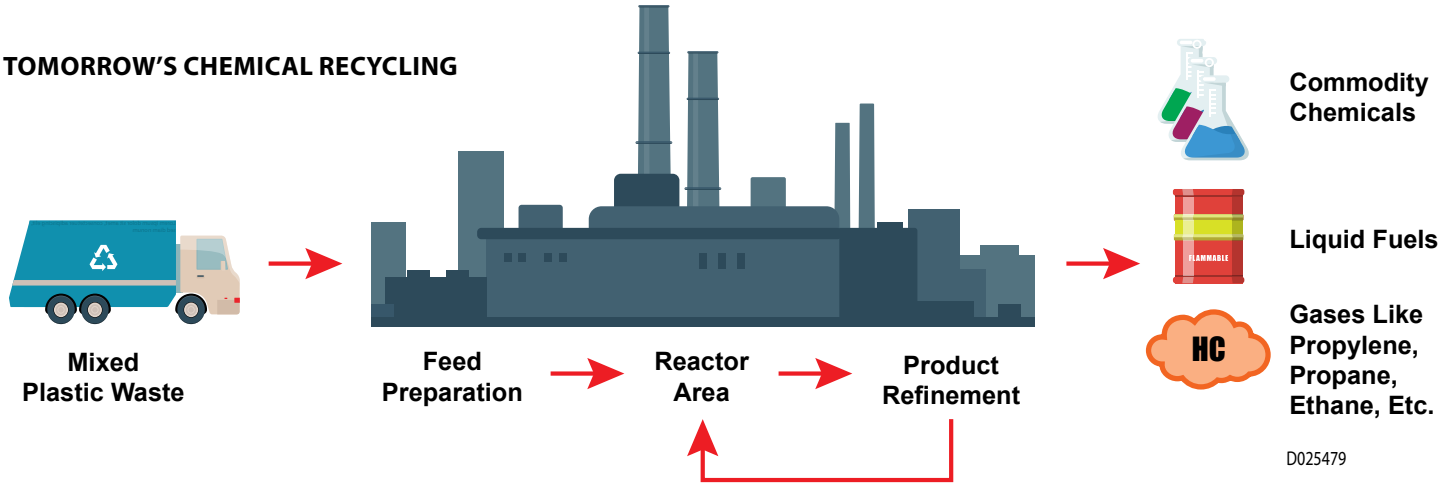

SwRI is exploring new pyrolysis-based chemical processes to use mixed plastics to create a truly cyclic recycling solution for the tremendous amount of plastic waste currently ending up in oceans, landfills or incineration plants.

CIRCULAR ECONOMY

Chemical recycling advances the current state of recycling to allow consumers to use a plastic product, which could then be recycled and reused to make more plastics, to avoid adding new plastics into the environment in what is referred to as a circular economy. The SwRI pyrolysis process could offer a transition to flexible, total recycling. Pyrolysis oils from plastics fed into a naphtha cracker convert them back into the basic building blocks for plastics. The ultimate goal would be net zero new plastics generated. In reality, the increasing demand for plastic products also needs to be addressed as demand is higher than what recycling all waste plastics would supply.

In addition to creating a next generation of plastic products, pyrolysis oils can be mixed with conventional feedstocks in refinery unit operations to make other industrial chemical products, such as benzene, toluene and xylene, which are also used in plastic production and other industries.

Pyrolysis oils are versatile and can be processed into a large slate of chemicals, providing a fairly quick response to market demands for different chemical products. For example, during the COVID pandemic, materials to produce personal protective equipment were in high demand, creating a need for plastics, components and chemical feedstocks. Chemical engineers can tune the pyrolysis process in the reactor to target generation of different product slates depending on market drivers.

While the global plastic waste problem is going to need a multifaceted solution, SwRI is focusing on new ways to expand recycling. Our chemical engineers are working with clients to develop new techniques for producing specific high-value commodities from plastic pyrolysis products. With expertise and facilities developed over the last quarter century working with heavy oils, biomass and other alternative feedstocks, the Institute offers lab-scale, pilot scale and demonstration units to test, tune and validate processes. We recently completed and have started commissioning a new facility to support this research on a large demonstration scale, particularly to address mixed plastic wastes ending up in our oceans and landfills.

Questions about this story? Contact Hoekstra at hsiangyee.hoekstra@swri.org or (210) 522-3448 or Flores at eloy.flores@swri.org or (210) 522-2547.

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ABOUT THE AUTHORS
Hsiang Yee Hoekstra leads efforts to develop and scale up chemical processes to generate renewable fuels and chemicals from alternative and challenging feedstocks, such as waste plastics, Fischer-Tropsch products, biocrudes and pyrolyzed biomass. Eloy Flores directs operations of the Chemical Engineering Department while continuing to manage process development projects and support staff in troubleshooting, buildup and operation of chemical and petroleum process pilot plants.

MULTIPLE ERUPTIONS LIKELY BEHIND PLUTO'S GIANT ICE VOLCANOS

SwRI scientists led a New Horizons mission team that determined multiple episodes of cryovolcanism may have created interesting surface structures on Pluto, the likes of which are not seen anywhere else in the solar system. Material expelled from below the surface of this distant, icy planet could have created a region of large domes and rises flanked by hills, mounds and depressions.

"The particular structures we studied are unique to Pluto, at least so far," said SwRI's Dr. Kelsi Singer, New Horizons deputy project scientist and lead author of the paper published in Nature Communications. "Rather than erosion or other geologic processes, cryovolcanic activity appears to have extruded large amounts of material onto Pluto's exterior and resurfaced an entire region of the hemisphere New Horizons saw up close."

Singer's team analyzed the geomorphology and composition of an area located southwest of Pluto's bright, icy "heart," Sputnik Planitia. The cryovolcanic region contains multiple large domes, ranging from about one-half to 4 miles tall and 18 to 60 miles across, that sometimes merge to form more complex structures. Irregular interconnected hills, mounds and depressions, called hummocky terrain, cover the sides and tops of many of the larger structures. Few, if any, craters exist in this area, indicating it is geologically young. The largest structures in the region rival the Mauna Loa volcano in Hawaii.

Even with the addition of ammonia and other antifreeze-like components that lower the melting temperature of water ices — a process similar to the way road salt inhibits ice from forming on streets and highways — the extremely low temperatures and atmospheric pressures on Pluto rapidly freeze liquid water on its surface.

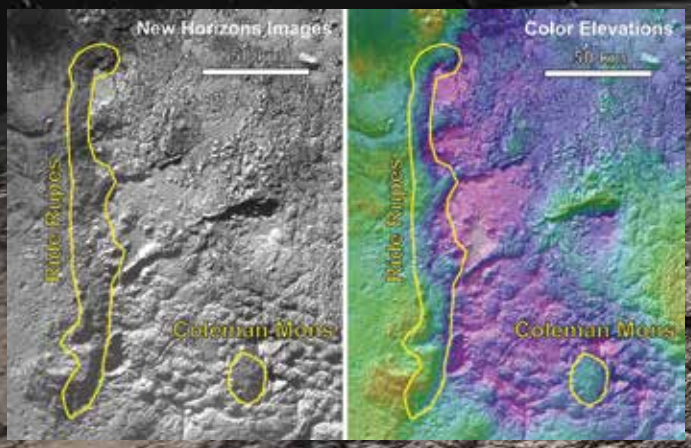
Because these are young geologic terrains and large amounts of material were required to create them, it is possible that Pluto's interior structure retained heat up until the relatively recent past, enabling water-ice-rich materials to be deposited onto the surface. Cryovolcanic flows capable of creating the large structures could have occurred if the material had a toothpaste-like consistency, flowing somewhat like solid ice glaciers on Earth or creeping from beneath a frozen shell.

"One of the benefits of exploring new places in the solar system is that we find things we weren't expecting," said Singer. "These giant, strange-looking cryovolcanoes observed by New Horizons are a great example of how we are expanding our knowledge of volcanic processes and geologic activity on icy worlds."

Images obtained in 2015 by the New Horizons spacecraft revealed diverse geological features populating across Pluto, including mountains, valleys, plains, and glaciers. They were particularly intriguing because the frigid temperatures at Pluto's distance were expected to produce a frozen, geologically inactive world.

"This newly published work is truly landmark, showing once again how much geologic personality Pluto has for such a small planet, and how it has been incredibly active over long periods," said New Horizons Principal Investigator Dr. Alan Stern of Southwest Research Institute. "Even years after the flyby, these new results by Singer and her coworkers show that there's much more to learn about the marvels of Pluto than we imagined before it was explored up close."

New Horizons was NASA's mission to make the first exploration of Pluto and its system of five moons. The paper "Large-scale cryovolcanic resurfacing on Pluto" by Singer and the New Horizons team is available in Nature Communications.



The New Horizons team proposed names for two structures in the cryovolcanic region honoring aviation pioneers Bessie Coleman, the first African American and Native American woman to earn a pilot's license, and Sally Ride, the first American woman in space.

Cryovolcanic activity most likely created these unique structures on Pluto. The surface and atmospheric hazes of Pluto are shown here in greyscale, with an artistic interpretation of how past volcanic processes may have operated superimposed in blue.

IMAGES COURTESY NASA/JOHNS HOPKINS UNIVERSITY APL/SwRI/ISAAC HERRERA/KELSI SINGER D025512 D025512

D025495

SwRI's MRF flare, above, will play a central role in a new ARPA-E project to create an advanced burner that will eliminate 99.5% of the methane in gas flares used by the oil and gas industry.

D025496

SwRI's Metering Research Facility will serve as a testbed for a collaborative project with the University of Michigan to create an advanced burner that will eliminate virtually all the methane vented during oil and gas production.

CREATING ADVANCED BURNER TO REDUCE METHANE EMISSIONS

In collaboration with the University of Michigan (UM), SwRI is using additive manufacturing and machine learning to create an advanced burner capable of eliminating virtually all the methane vented during oil production. Burners currently used in the field typically perform below target specifications, especially under crosswind conditions, which results in a significant portion of this powerful greenhouse gas escaping into the atmosphere.

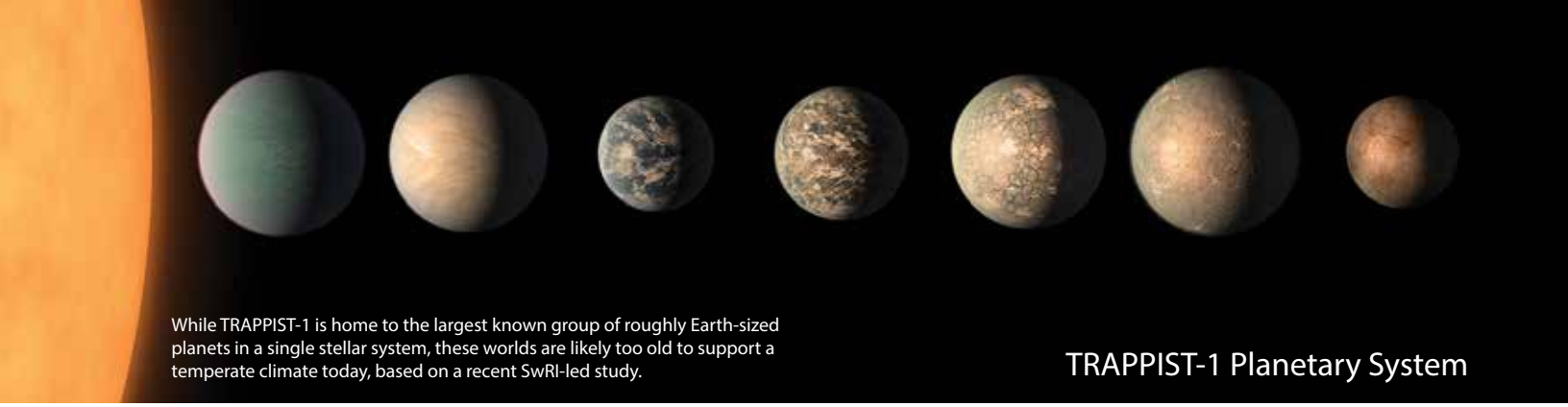
During oil production, producers encountering pockets of methane typically use flare stacks to burn off the vented gas. However, when winds blow across conventional open flame burners, 40% or more of the gas escapes into the air. Methane's global warming effect is significantly greater than that of carbon dioxide on a per-unit basis, so flaring reduces overall climate change potential.

"We are working to create a burner capable of achieving high methane destruction efficiency and combustion stability, eliminating 99.5% of vented methane, even in challenging field conditions," said SwRI Research Engineer Luis Gutierrez, one of the project's leaders. "This burner will be a vast improvement over today's conventional flare technology."

Gutierrez is working with Dr. Margaret Wooldridge, an Arthur F. Thurnau Professor of Mechanical Engineering at UM and leader of the Wooldridge Combustion Laboratory. She has extensive experience in using advanced engineering methods such as machine learning to optimize combustion systems and reduce emissions. Additive manufacturing supports the development of burners with complex geometries to enhance the efficacy and robustness of the combustion process in gas flares. Using computational fluid dynamics, machine learning and multiscale testing, the team will explore less conventional solutions to optimize fluid dynamics and gas mixing in a novel burner design that lowers methane emissions.

The project will take advantage of SwRI's Metering Research Facility (MRF), a world-class, natural gas flow measurement testbed, with the most accurate, controllable and flexible research capabilities in the industry. MRF provides the realistic conditions needed to test the effectiveness of the burner's geometry. Additionally, engineers will fabricate the burners in SwRI's metal additive manufacturing facilities.

The three-year, $2.9 million project is funded by the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) Reducing Emissions of Methane Every Day of the Year (REMEDY) program. It is one of several projects funded in support of the U.S. Methane Emissions Reduction Action Plan, announced at the 2021 United Nations Climate Change Conference. The plan seeks to reduce methane emissions and promote American innovation and manufacturing of new technologies to achieve climate goals.



While TRAPPIST-1 is home to the largest known group of roughly Earth-sized planets in a single stellar system, these worlds are likely too old to support a temperate climate today, based on a recent SwRI-led study.

TRAPPIST-1 Planetary System

IMAGE COURTESY NASA/JPL-CALTECH D025514

IN SEARCH OF OTHER EARTHS

As the scientific community searches for worlds orbiting nearby stars that could potentially harbor life, new SwRI-led research suggests that younger rocky exoplanets are more likely to support temperate, Earth-like climates.

In the past, scientists have focused on planets situated within a star's habitable zone, where it is neither too hot nor too cold for liquid surface water to exist. Today, we know sustaining temperate climates also requires a planet have sufficient heat to power a planetary-scale carbon cycle. A key source of this energy is the decay of the radioactive isotopes of uranium, thorium and potassium.

"We know these radioactive elements are necessary to regulate climate, but we don't know how long these elements can do this, because they decay over time," said Dr. Cayman Unterborn, lead author of an Astrophysical Journal Letters paper about the research.

Studying exoplanets is challenging. Today's technology cannot measure the composition of an exoplanet's surface, much less that of its interior. Scientists can, however, measure the abundance of elements in a star spectroscopically by studying how light interacts with the elements in a star's upper layers. Using these data, scientists can infer what a star's orbiting planets are made of using stellar composition as a rough proxy for its planets.

"Using host stars to estimate the amount of these elements that would go into planets throughout the history of the Milky Way, we calculated how long we can expect planets to have enough volcanism to support a temperate climate before running out of power," Unterborn said. "Under the most pessimistic conditions we estimate that this critical age is only around 2 billion years for an Earth-mass planet and reaching 5–6 billion years for higher-mass planets under more optimistic conditions."

REVITALIZING CLEAN, EFFICIENT HYDROGEN ENGINE CONCEPTS

In pursuit of zero carbon emissions, SwRI is investigating four concepts for converting existing internal combustion (IC) engine designs to burn hydrogen cleanly and efficiently.

Government and industry researchers are working to transition transportation energy usage away from fuels that emit carbon dioxide (CO_2) — a greenhouse gas (GHG) that contributes to climate change — to hydrogen and other alternative fuels that emit less CO_2 on a well-to-wheel basis. According to the U.S. Environmental Protection Agency, transportation alone produced 29% of total U.S. GHG emissions in 2019, the largest share.

In the late 2000s, the U.S. Department of Energy and numerous automakers funded hydrogen IC engine development. To build on this earlier research, SwRI ran simulations of four novel approaches for using spark-ignited (SI) combustion of hydrogen to fuel an IC engine. That research demonstrated a hydrogen-fueled SI engine that could achieve 45% brake thermal efficiency (BTE) in the laboratory, which was competitive with diesel engines at the time. Today's gasoline engines typically have BTEs of 30–43% and modern diesel engines have BTEs from 42–50%. By comparison, each of SwRI's simulated approaches shows a development path to achieve at least 50% BTE.

"Higher brake thermal efficiency translates to lower fuel consumption," said Dr. Thomas Briggs, part of the SwRI research team, which includes Dr. Graham Conway (pictured). "None of the simulations we completed represent fully optimized calibrations for a combustion system, but they all show thermal efficiencies comparable to a baseline diesel engine, with nitrogen oxides (NOx) emissions consistent with diesel combustion, but no carbon monoxide, hydrocarbon, soot or CO_2 emissions. It is very promising."

SwRI recently patented technology that improves hydrogen fuel injection management, optimizing air-fuel mixtures and minimizing the risk of pre-ignition. The team is working with engine suppliers to acquire a suitable fuel injector to move into the second phase of their research and is well positioned to lead a shift to cleaner hydrogen-fueled vehicles.

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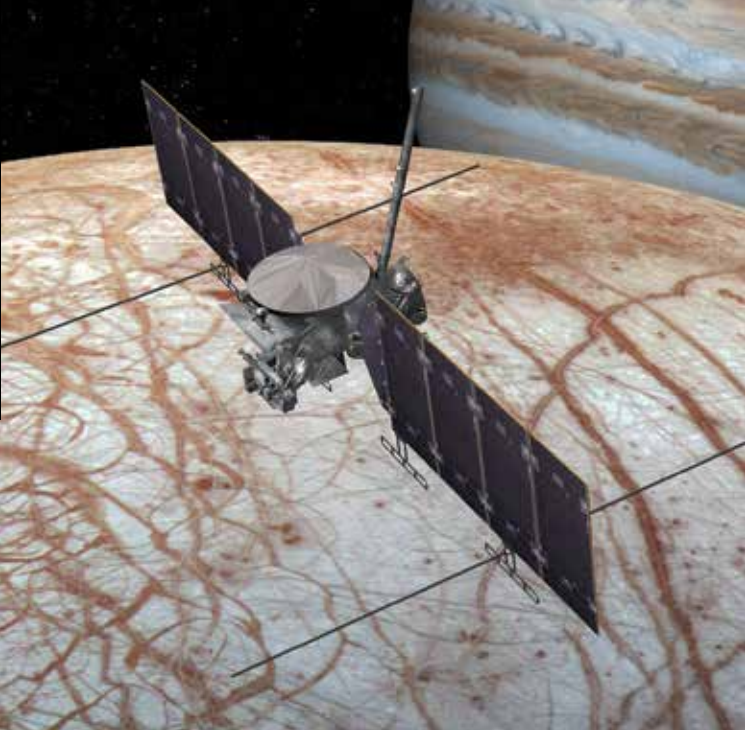


IMAGE COURTESY NASA/JPL-CALTECH D025509

Ultraviolet Instrument to Play Integral Part in NASA's Europa Clipper Mission

An ultraviolet spectrograph (UVS) designed and built by SwRI was the first scientific instrument to be delivered for integration onto NASA's Europa Clipper spacecraft. Scheduled to launch in 2024 and arrive in the Jovian system by 2030, the Europa Clipper spacecraft will conduct a detailed reconnaissance of Jupiter's moon Europa and investigate whether it harbors conditions suitable for life.

Europa-UVS is one of nine science instruments in the mission payload. The instrument collects UV light and creates images to help determine the composition of Europa's atmospheric gases and surface materials. The Europa Clipper spacecraft will orbit Jupiter and perform repeated close flybys of the icy moon. Previous observations show strong evidence for a subsurface ocean of liquid water that could host conditions favorable for life.

"It has been a huge team effort to get Europa-UVS built, tested and delivered," said Matthew Freeman, project manager for Europa-UVS and a group leader in SwRI's Space Science and Engineering Division. "Europa-UVS is the sixth in a series of SwRI-built ultraviolet spectrographs, and it benefits greatly from the design experience gained by our team from the Juno-UVS instrument, which is currently operating in Jupiter's harsh radiation environment."

In addition to performing atmospheric studies, Europa-UVS will also search for evidence of geysers erupting from within Europa.

"Europa-UVS will hunt down potential plumes erupting from Europa's icy surface and study them," said SwRI's Dr. Kurt Retherford, principal investigator for the UVS instrument. "Europa-UVS will search for and characterize plumes in terms of activity and the nature of subsurface water reservoirs. We will study how the plumes behave — when they start, stop and expand outward far into space."

NEW SPACE INTEGRATION FACILITY SUPPORTS SMALLSAT DEVELOPMENT

SwRI has added a 74,000- square-foot Space System Integration Facility to its San Antonio headquarters. The SwRI facility supports the rapid design, assembly and testing of spacecraft, particularly small satellites for emerging "new space" applications, including support for commercial clients and the U.S. Department of Defense.

According to one industry forecast, nearly 12,000 small satellites — defined in this case as satellites with masses under 500 kilograms — will be placed in orbit between 2018 and 2030, an average of nearly 1,000 small satellites annually. SwRI serves as a trusted leader for this rapidly advancing industry, providing technology development and innovation.

"After 40 years as one of the leading space science and engineering programs, SwRI now offers a new state-of-the-art spacecraft assembly, integration and test facility, designed for working with the latest launch providers," said Steve Diamond, a senior program manager in SwRI's Space Science and Engineering Division. "Using digital design and design-to-manufacturing (D2M) processes, we can rapidly field mission prototypes, then collaborate with industry to meet low-Earth orbit constellation production requirements. Our work with emerging launch providers allows us to create a unique capability for deploying smallsat assets using launch campaigns measured in days instead of months."

The new building includes nearly 20,000 square feet of integration space, including a range of cleanroom facilities. In addition, the new building houses a nearly 11,000-square-foot environmental testing facility that includes a thermal vacuum chamber capable of testing multiple spacecraft at once, a shielded electromagnetic interference enclosure and a high-decibel acoustic test chamber.

"Our digital design ethos supports the integration of mobile launch capabilities and scaled serial production," Diamond said. "The building design supports multiple levels of security, accommodating multiple programs and customers in parallel."

SwRI offers comprehensive vertical mission capabilities in a single organization, including design, fabrication, test, launch and operations support.

D025480

Evidence for an Internal Ocean in Small Saturn Moon

An SwRI scientist set out to prove that the tiny, innermost moon of Saturn was a frozen inert satellite and instead discovered compelling evidence that Mimas has a liquid internal ocean. In the waning days of NASA's Cassini mission, the spacecraft identified a curious libration, or oscillation, in the moon's rotation, which often points to a geologically active body able to support an internal ocean.

"If Mimas has an ocean, it represents a new class of small, 'stealth' ocean worlds with surfaces that do not betray the ocean's existence," said SwRI's Dr. Alyssa Rhoden, a specialist in the geophysics of icy satellites.

One of the most profound discoveries in planetary science over the past 25 years is that worlds with oceans beneath layers of rock and ice are common in our solar system. Such worlds include the icy satellites of the giant planets, such as Europa, Titan and Enceladus, as well as distant planets like Pluto. Worlds like Earth with surface oceans must reside within a narrow range of distances from their stars to maintain the temperatures that support liquid oceans. Interior water ocean worlds (IWOWs), however, are found over a much wider range of distances, greatly expanding the number of habitable worlds likely to exist across the galaxy.

"Because the surface of Mimas is heavily cratered, we thought it was just a frozen block of ice," Rhoden said. "IWOWs, such as Enceladus and Europa, tend to be fractured and show other signs of geologic activity. Turns out, Mimas' surface was tricking us, and our new understanding has greatly expanded the definition of a potentially habitable world in our solar system and beyond."

Evaluating Mimas' status as an ocean moon would benchmark models of its formation and evolution.

"This would help us better understand Saturn's rings and mid-sized moons as well as the prevalence of potentially habitable ocean moons, particularly at Uranus," Rhoden said. "Mimas is a compelling target for continued investigation."

IMAGE COURTESY NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE D025510

An SwRI scientist has discovered that Saturn's small moon Mimas (top) likely has something in common with its larger neighbor Enceladus: an internal ocean beneath a thick icy surface.

CAT-DEF Reduces NOx, CO_2 Emissions

SwRI's patented and award-winning CAT-DEF™ technology successfully reduces heavy-duty diesel engine nitrogen oxide (NOx) emissions to meet California Air Resources Board (CARB) 2027 standards. SwRI's novel technology decreases NOx and carbon dioxide emissions for diesel engines by significantly reducing undesirable deposit formation in exhaust systems.

CAT-DEF, which stands for Catalyzed Diesel Exhaust Fluid, is an SwRI-developed catalyst- and surfactant-modified diesel exhaust fluid (DEF) solution. Today's diesel engines use selective catalytic reduction (SCR), an advanced emissions control system, to abate NOx emissions. DEF is injected into the exhaust stream and ideally decomposes to form ammonia, which reacts with NOx on the catalyst to form N_2 and H_2O.

"Although DEF technology has been utilized for more than a decade, the highest emissions control efficiencies could never be realized because DEF can create potentially harmful deposits in the exhaust system, particularly when the engine is operated at low loads and temperatures," said Dr. Charles E. Roberts Jr., director of SwRI's Commercial Vehicle Systems Department. "A combination of surface-active agents and heterogenous catalysts blended into CAT-DEF reduces deposits by 90% with potential reductions up to 98%."

At temperatures below 250°C, deposits forming in aftertreatment systems can severely limit low-temperature NOx conversion and increase fuel consumption as high-temperature engine operations are required to remove the deposits.

SwRI's CAT-DEF technology is currently available to license. The novel innovation is backwards-compatible and can be used in existing engines as a deposit reduction solution. For future applications required to meet more stringent regulatory requirements, the award-winning CAT-DEF solution competes with higher-cost engine hardware modifications currently being considered by the diesel engine industry and DEF manufacturers.

D025478

SLUSH BRINES POSSIBLE ON MARS

An SwRI scientist measured the properties of ice-brine mixtures as cold as -145 degrees Fahrenheit to help confirm that salty water likely exists between grains of ice or sediment under the ice cap at Mars' south pole. Laboratory measurements conducted by SwRI geophysicist Dr. David Stillman support theoretical explanations for bright reflections detected using subsurface sounding radar aboard ESA's Mars Express orbiter.

Conventional models assumed the Mars south polar cap experiences temperatures much lower than the melting point of water. Clay, hydrated salts and saline ices have been proposed as potential explanations for the source of the bright basal reflections, but Stillman's findings may suggest a different explanation altogether.

"Lakes of liquid water actually exist beneath glaciers in Arctic and Antarctic regions, so we have Earth analogs for finding liquid water below ice," said Stillman, a co-author of a paper describing these findings. "The exotic salts that we know exist on Mars have amazing 'antifreeze' properties allowing brines to remain liquid down to -103 degrees Fahrenheit."

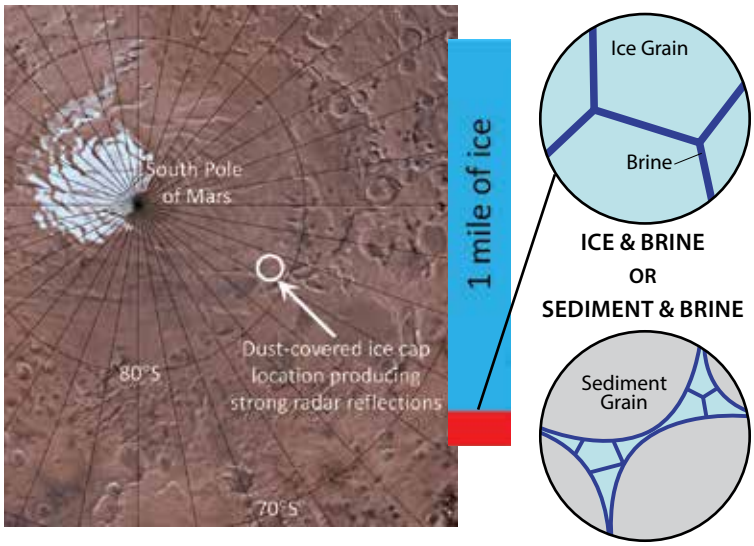
For this project, Stillman measured the properties of perchlorate brines in an SwRI environmental chamber that produces near-liquid-nitrogen temperatures at Mars-like pressures.

"The research showed that we don't have to have lakes of perchlorate and chloride brines, but that these brines could exist between the grains of ice or sediments and are enough to exhibit a strong radar reflection," Stillman said. "This is similar to how seawater saturates grains of sand at the shoreline or how flavoring permeates a slushie, but at -103 degrees Fahrenheit and below a mile of ice near the South Pole of Mars."

The search for water in the cosmos is rooted in searching for potential habitability, because all known life requires water.

"In this case 'following the water' has led us to places so cold that life as we know it couldn't flourish," Stillman said. "But it's still interesting, and who knows what evolutionary paths extraterrestrial life may have taken?"

An SwRI scientist studied the antifreeze properties of exotic salts that exist on Mars, which could allow brines to remain liquid down to -103 degrees Fahrenheit. The studies show how a mile below the Martian south polar cap, brines between the grains of ice or sediments could produce the strong reflections detected by the radar instrument aboard ESA's Mars Express orbiter.



SwRI, UT Austin Energize Collaboration

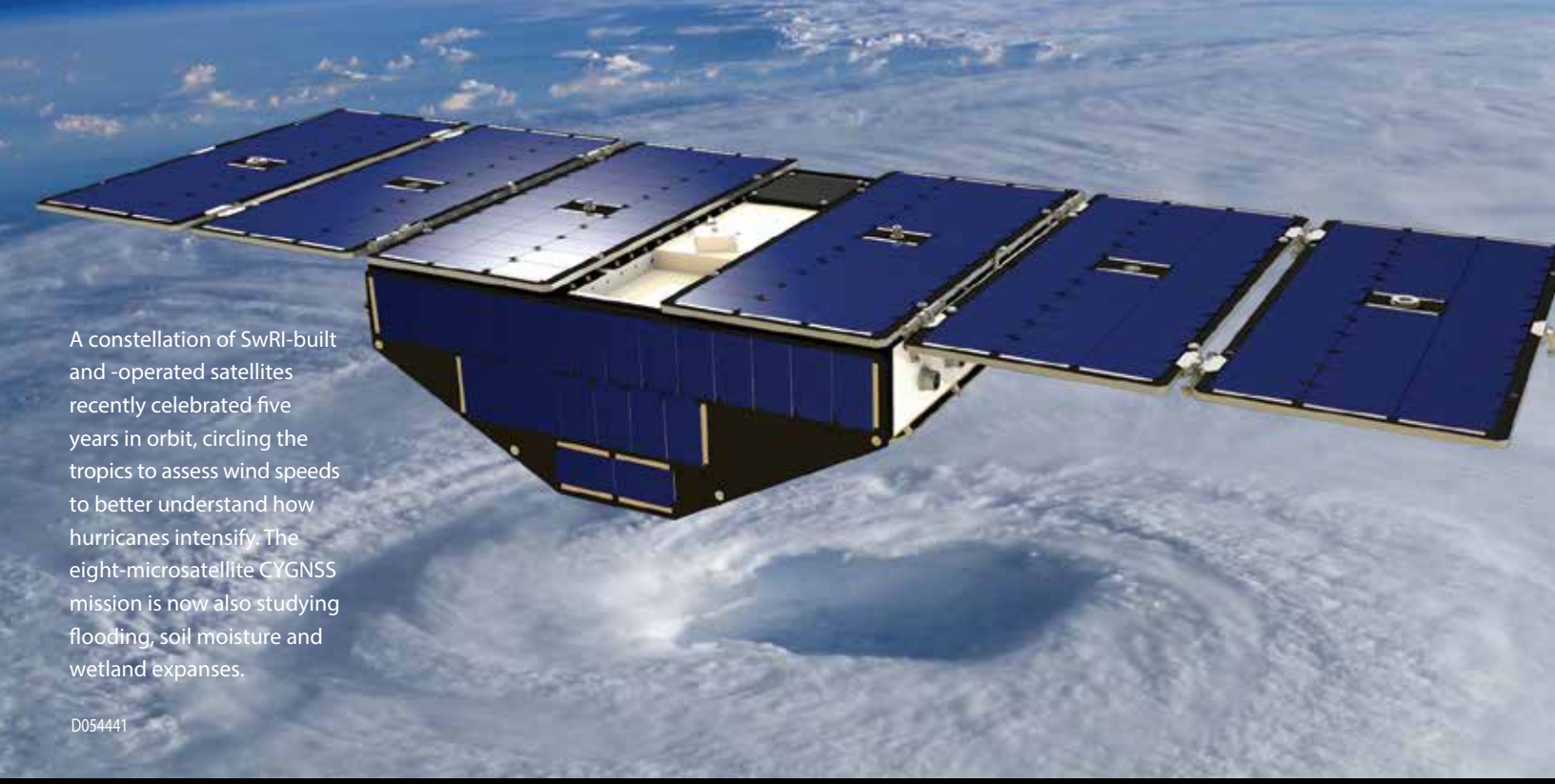
Southwest Research Institute and The University of Texas at Austin have created The Energize Program, a new opportunity to enhance greater scientific collaboration between the two institutions.

"The Energize Program will bring together the capabilities, facilities and expertise from SwRI as well as UT Austin's Energy Institute and Hildebrand Department of Petroleum and Geosystems Engineering in an effort to strengthen research efforts that benefit humankind," said SwRI Executive Vice President and COO Walt Downing. "This is a tremendous opportunity for our two institutions to work together to solve some of the most challenging energy issues we face today."

Two programs are available, with funds provided by SwRI and UT. Some can include contributions from industry affiliates or institutions. Energize projects will include at least one principal investigator from each institution.

One program will fund up to three two-year projects in any field of energy research focused on decarbonization and climate security. The other will fund up to two two-year projects in any field of energy-related research, including oil and gas, renewable resources, hydrogen, carbon storage and geothermal energy.

SwRI is a leader in energy research solutions that improve the efficiency, performance and safety of energy across fuel cycles and supply chains. Institute researchers are working to improve the efficiency of conventional power generation and aid the integration of renewable resources. SwRI's work in battery chemistries and electric vehicles has developed new and improved grid-scale energy storage systems. The Institute's San Antonio campus is home to the Supercritical Transformational Electric Power (STEP) Pilot Plant, a 10-megawatt supercritical carbon dioxide (sCO_2) facility designed to demonstrate the next generation of higher-efficiency, lower-cost electric power technology.



A constellation of SwRI-built and -operated satellites recently celebrated five years in orbit, circling the tropics to assess wind speeds to better understand how hurricanes intensify. The eight-microsatellite CYGNSS mission is now also studying flooding, soil moisture and wetland expanses.

D054441

SIMULATION SHOWS SOLAR SYSTEM FORMING FROM RINGS

IMAGE COURTESY ALMA (ESO/NAOJ/NRAO) D025475

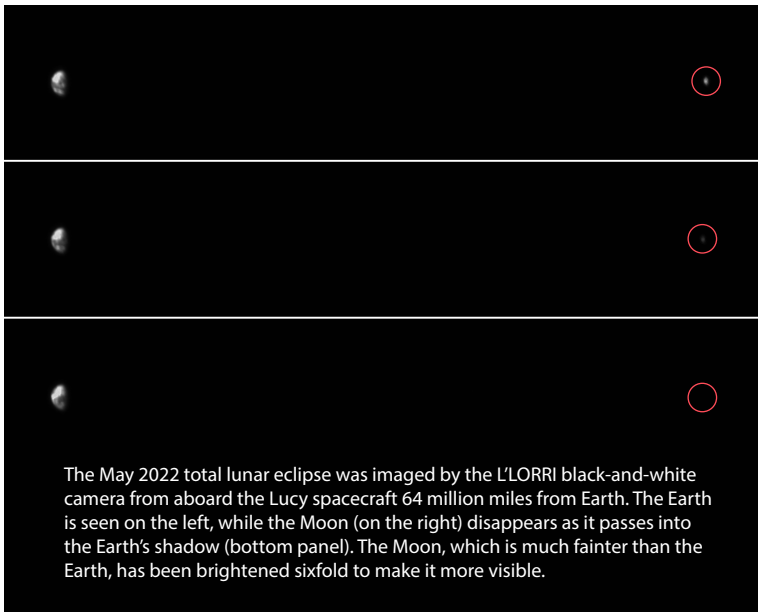
An SwRI scientist contributed to a new solar system formation model that explains the existing inner planets and asteroid belt. Dr. Rogerio Deienno, who specializes in celestial mechanics and dynamical astronomy, and his colleagues developed a model where three rings of planetesimals, the building blocks for planets, would form from the swirling disk of gas and dust around the Sun known as the solar nebula.

"As dust particles move slightly faster than the gas around them, they feel a headwind, lose energy and drift very quickly toward the star," said Deienno, who contributed to a Nature Astronomy paper discussing this research. "At 'pressure bumps' — regions in the disk usually associated with localized changes in disk composition and the size of dust grains — gas pressure increases, gas molecules move faster and solid particles stop feeling the headwind. That allows dust particles to accumulate at these pressure bumps forming rings separated by gaps."

The three rings in the Sun's natal disk are associated with three pressure bumps at different sublimation fronts, corresponding to temperatures and distance from the star. Sublimation fronts are regions in the disk where materials of a given chemical composition become vapor.

"As time goes by, the disk temperature cools," Deienno said. "This cooling process causes the pressure bumps to migrate toward the Sun, with the first planetesimals forming at the outer edge of each ring."

Using supercomputers, the researchers performed a variety of simulations that captured how our inner solar system formed right down to the slightly different chemical compositions and masses of Venus, Earth and Mars. They formed from the innermost of the three rings, with Earth and Venus analogs collecting the most materials forming the bulk from the center of the ring, whereas Mars was built from materials in the more sparsely populated regions from the edge of the ring.



The May 2022 total lunar eclipse was imaged by the L'LORRI black-and-white camera from aboard the Lucy spacecraft 64 million miles from Earth. The Earth is seen on the left, while the Moon (on the right) disappears as it passes into the Earth's shadow (bottom panel). The Moon, which is much fainter than the Earth, has been brightened sixfold to make it more visible.

IMAGE COURTESY NASA/GODDARD/APL/SwRI D025533

LUCY'S LONG-DISTANCE LUNAR ECLIPSE OBSERVATION

The NASA Lucy mission, led by SwRI's Dr. Hal Levison, observed the May 2022 total lunar eclipse from a unique vantage point 64 million miles (100 million km) from the Earth.

For a few hours on May 15, the Earth cast its shadow over the Moon. This total lunar eclipse was visible over much of the United States, but it was also visible from deep space. Despite being so far away, the Lucy spacecraft was able to use its high-resolution imaging instrument to watch the Moon pass into the shadow of the Earth, disappearing from view.

"While total lunar eclipses aren't that rare — they happen every year or so — it isn't that often that you get a chance to observe them from an entirely new angle," said Levison. "When the team realized Lucy had a chance to observe this lunar eclipse as a part of the instrument calibration process, everyone was incredibly excited."

The Lucy spacecraft launched on October 16, 2021. The spacecraft trajectory has it traveling back toward the Earth for a gravity assist to help propel it on its journey to the Trojan asteroids. This previously unexplored population of asteroids that lead and follow Jupiter in its orbit around the Sun are "fossils" of planet formation; they likely hold important clues to help us understand the history of our Solar System.

Lucy's L'LORRI instrument, a high-resolution, black-and-white camera, took 86 one-millisecond exposures to create a time-lapse video of the first half of the total lunar eclipse. A movie made from these images has been viewed more than 72,000 times on SwRItv, the Institute's YouTube channel. See https://youtu.be/0c3ak2_JVts.

"Capturing these images really was an amazing team effort," said SwRI's Dr. John Spencer. "And all this had to be done while operating the spacecraft in a very tricky environment."

Designed to operate at the Trojans more than five times farther from the Sun than the spacecraft is now, the spacecraft only viewed the first half of the eclipse to avoid the risk of overheating.

Powerful Microscope Expands Characterization Capabilities

SwRI is now home to a field emission scanning electron microscope, a powerful characterization tool to study a wide range of materials, including thin films and nanomaterials. The microscope's powerful magnification capabilities can produce clear, sharp images of objects magnified over a million times. Additionally, an onboard energy-dispersive X-ray spectrometer enables localized chemical analysis of the materials being imaged.

"This exceptional new tool will allow us to image and chemically characterize materials at much higher magnifications than we could previously," said John Macha, manager of SwRI's Materials Science and Failure Analysis Section.

The microscope will be especially useful to SwRI's Surface Engineering Laboratory, where engineers use various processes to modify the surface of materials for improved properties. The microscope will support a broad range of programs including graphene synthesis research, allowing visualization of the material's unique structure. The microscope will also support the evaluation of thin films composed of high entropy alloys, which are formed by mixing equal or relatively large proportions of five or more elements.

"This new microscope will serve researchers across many different disciplines," Macha said. "For instance, our space scientists will use it to evaluate ultrathin films and other coatings for spacecraft instrumentation. Hypersonics researchers can evaluate how different coating technologies protect objects traveling extremely fast, to prevent them from deteriorating."

This powerful microscope will also expand SwRI's failure analysis capabilities, which include studying the root cause of equipment failures for the power generation, aerospace and transportation industries. Engineers will use the instrument to zoom in on extremely fine fracture features to assess the damage mechanisms that led to failure.

"We're excited about the new applied research opportunities this instrument will bring — the ones we've identified as well as potential new ones waiting to be discovered," he said.

D055891

UPCOMING

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

NASGRO Course, Aug. 2, 2022. Live virtual training.

SwRI Machinery Test Facilities, Aug. 10, 2022. Free webinar.

Manufacturing Supervisor Certification Program, Aug. 16, 2022. In-person training.

Rotordynamics Fundamentals, Aug. 24, 2022. Free webinar.

Lateral & Torsional Rotordynamics Course, Aug. 24, 2022. In-person training.

Penetration Mechanics Short Course, Sept. 12, 2022. Hybrid in-person/virtual training.

Avoiding Lateral Rotordynamic Instabilities in Turbomachinery, Sept. 14, 2022. Free webinar.

Introduction to CFD for Turbomachinery, Sept. 28, 2022. Free webinar.

Introduction to Microencapsulation, Oct. 3, 2022. Two-day workshop.

CONFERENCES/MEETINGS:

36th Annual Small Satellite Conference, Logan, Utah, Aug. 6, 2022, Booth No. 550.

IMAGE International Meeting for Applied Geosciences & Energy, Houston, Aug. 28, 2022, Booth No. 1707.

IEEE AUTOTESTCON, National Harbor, Maryland, Aug. 29, 2022, Booth No. 327.

Texas Groundwater Summit, San Antonio, Aug. 30, 2022.

Turbomachinery & Pump Symposia, Houston, Sept. 13, 2022, Booth No. 2626.

Intelligent Transportation World Congress, Los Angeles, Sept. 18, 2022, Booth No. 1123.

International Refining and Petrochemical Conference Americas, Houston, Sept. 26, 2022, Booth No. 1.

GMRC Gas Machinery Conference, Fort Worth, Oct. 2, 2022, Booth No. 407.

Association of the United States Army Annual Meeting and Exposition, Washington, Oct. 10, 2022, Booth No. 4116.

IEEE

Southwest Research Institute received the IEEE Region 5 2021 Outstanding Large Company Award. SwRI Executive Vice President and Chief Operating Officer Walt Downing, P.E., and Defense and Intelligence Solutions Division Vice President Nils Smith, P.E., accepted the award at the region's 2022 annual meeting in Houston.


D025487

Dr. James Burch, vice president of the Space Science and Engineering Division, has received NASA's highest honor for nongovernment employees, its Distinguished Public Service Medal. Burch is recognized for his visionary science mission leadership in investigating the interaction of the solar wind with the magnetospheres of Earth and Saturn as well as the environments of comets.


D025287_0311

James R. Keys Jr. has been named vice president of Southwest Research Institute's Applied Power Division. He previously served as the division's executive director. Keys will oversee a staff of more than 175, working in three research departments: Electrical Systems, Kinetics and Industrial Technology.


D025500

Dr. Peter Lee of SwRI's Tribology Research and Evaluations Section has been promoted to Institute engineer, the highest technical level at SwRI. Lee established SwRI's tribology laboratory in 2011, which, under his leadership, has become a center recognized for its cutting-edge research and testing.


D025486

Dr. Hal Levison has been awarded the 2022 Dirk Brouwer Career Award by the American Astronomical Society's Division on Dynamical Astronomy (AAS DDA). Levison is the co-author of the premier model used to predict the dynamical evolution of the outer solar system and currently serves as the principal investigator of NASA's Lucy spacecraft mission to the Trojan asteroids, which launched in October 2021.


D019449

Dr. Simone Marchi was among three editors of a new book titled "Vesta and Ceres: Insights from the Dawn Mission for the Origin of the Solar System." The text covers the NASA mission to the two most massive protoplanets in the main asteroid belt, comparing them to better understand their formation and evolution and what that tells us about the overall solar system.


D022503

Matt Robinson was honored as an Advanced Robotics for Manufacturing Institute champion for his role in strengthening U.S. manufacturing. The ARM Institute fosters robotics and workforce development, providing a safe collaborative framework between tech vendors, automation end-users, academia and the government.


D0253442_5160

Kelly Smith has been promoted to Institute engineer, the highest technical level at SwRI. Since joining SwRI's Space Science and Engineering Division in the 1990s, he has contributed to several space missions and programs, specializing in designing and testing space structures, instruments and electronics.


D025497

Dr. Natalie Smith of SwRI's Mechanical Engineering Division has won the 2022 Dilip R. Ballal Early Career Award from the American Society of Mechanical Engineers (ASME). The award honors an individual who has made significant contributions in the gas turbine industry within the first five years of their career.

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