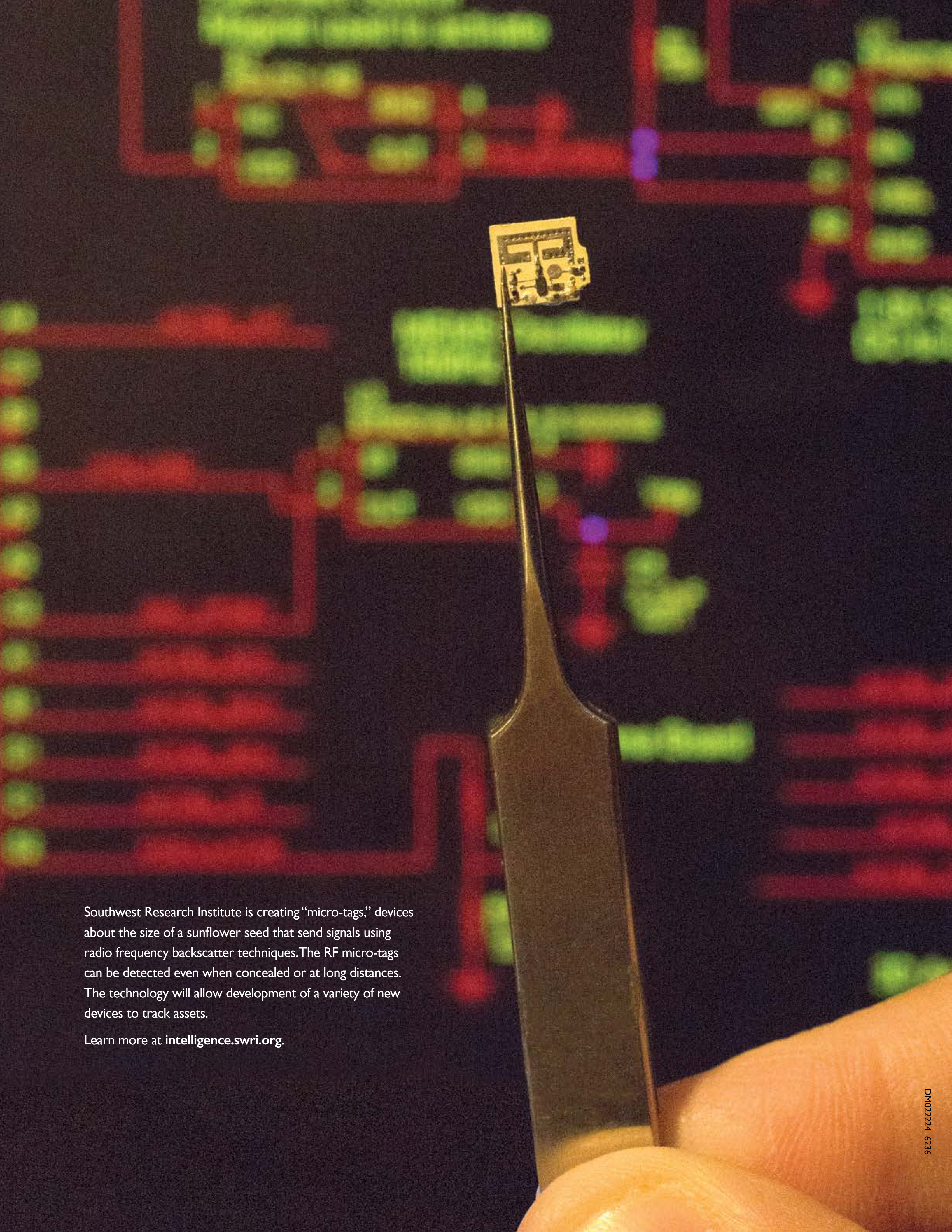
Southwest Research Institute®

Spring 2017

# Technology Today®

## Spurring $sCO_2$ Power Cycles



Southwest Research Institute is creating "micro-tags," devices about the size of a sunflower seed that send signals using radio frequency backscatter techniques. The RF micro-tags can be detected even when concealed or at long distances. The technology will allow development of a variety of new devices to track assets.

Learn more at **intelligence.swri.org**.

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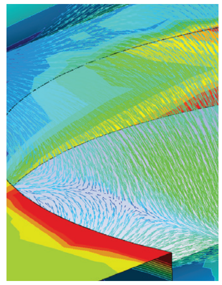
ABOUT THE INSTITUTE

Southwest Research Institute is a premier independent, nonprofit research and development organization. With nine technical divisions, we offer multidisciplinary services leveraging advanced science and applied technologies. Since 1947, we have provided solutions for some of the world's most challenging scientific and engineering problems.

**swri.org**



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## ON THE COVER



## EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of nearly 2,700 employees pursues activities in the areas of communication systems, modeling and simulation, software development, electronic design, vehicle and engine systems, automotive fuels and lubricants, avionics, geosciences, polymer and materials engineering, mechanical design, chemical analyses, environmental sciences, space science, training systems, industrial engineering, and more.

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Thomas Edison saw electricity as the "field of fields" to "reorganize the life of the world." And since his invention of the incandescent light bulb in the late 1870s, access to light and power has revolutionized the world. Today, affordable, reliable electricity powers our way of life.

# ELECTRIFYING ADVANCES

## SwRI researchers are leading the charge for next-generation power systems

By Klaus Brun, Ph.D.

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ABOUT THE AUTHOR

Dr. Klaus Brun, a program director in SwRI's Mechanical Engineering Division, is internationally recognized as an expert in turbomachinery. His contributions to electric power and the gas turbine industry include developing next-generation technology to improve the efficiency and decrease the emissions associated with generating electricity.

Most power plants in the United States today are more than 30 years old and operate well below 35 percent efficiency. Because about 60 percent of all power in North America comes from fossil fuels, these inefficient plants burn huge quantities of expensive hydrocarbon fuels, creating significant amounts of greenhouse gas emissions. While alternative energy sources such as wind, solar, and hydropower are making great inroads into the power generation spectrum, they will not replace fossil fuels as the principal U.S. energy source in the near future. Even with continued improvements in alternative energy technology, we will likely require a diverse electricity portfolio with many plants utilizing fossil fuels for a long time. If the U.S. continues to rely on fossil fuels, it is imperative to decrease the emissions produced by these plants while increasing their efficiency.

For the past 10 years, SwRI has worked with the U.S. Department of Energy (DOE) to develop novel technologies to generate cleaner electricity more efficiently using both conventional fuels and alternative techniques. Thermal power plant research to reduce greenhouse gas emissions starts with increasing plant efficiency by producing more megawatts for the same amount of fuel, which at the same time can reduce the amount of carbon emissions produced. Another approach is to separate the carbon dioxide in the exhaust stream and sequester it underground. SwRI also researches low or no-carbon power production.

In late 2016, DOE awarded SwRI clean energy projects that will advance novel supercritical carbon dioxide ($sCO_2$) technology to improve the efficiency of electric generation by as much as 10 percent. While it may seem modest, that increase alone would drastically reduce greenhouse gas emissions as well as capital costs.

### CONVENTIONAL POWER CYCLES

Electricity is generated by converting resources such as water, sun, coal, oil, natural gas, and wind into electrical currents that can power everything from lightbulbs to factories.

For instance, in a natural gas power plant, the gas is combusted, creating hot gas pressure that pushes the blades of a turbine, causing it to spin. A shaft connects the gas turbine to the generator, which spins magnets within wire coils to produce electricity. The hot combustion gas is then piped to a heat recovery steam generator where it heats pipes of water, turning the water to steam. The high-pressure steam spins a steam turbine. A shaft connects the steam turbine to the generator, which converts the turbine's mechanical energy into additional electricity.

In the U.S., most power plants are thermal conversion plants, which heat a fluid — either a liquid or gas — to drive a generator. The type of process, the process fluid, and the cycle's pressures and temperatures drive the efficiency of these cycles. Most commercial power plants are either air-breathing single-phase Brayton cycles using gas turbines, or Rankine cycles, which use water/steam as the phase-change working fluid. Each plant type has a wide range of potential configurations that vary in size and complexity.

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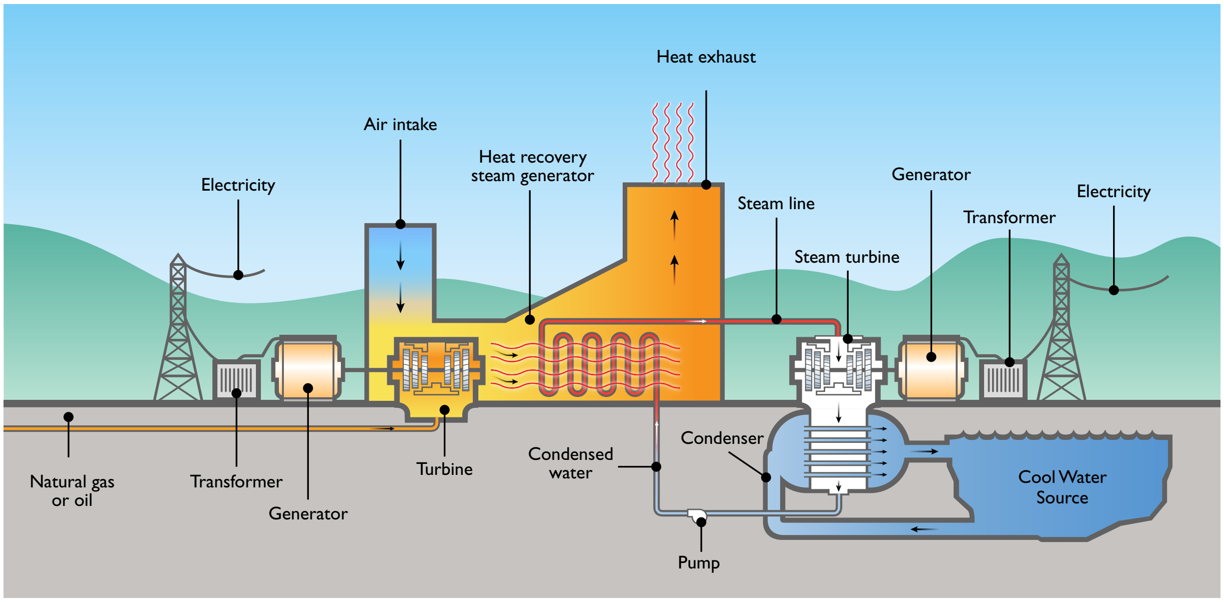


This illustration shows how a typical commercial power plant uses natural gas to create electricity.

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The optimum thermal power cycle is a function of the application and the heat source. For example, most pulverized coal power plants and all nuclear power plants use a Rankine heat engine cycle with steam/water as the process fluid. Similarly, modern natural gas electric plants use a coupled air Brayton and steam Rankine combined cycle. These heat engine cycles are not novel; James Watt patented the modern steam engine in 1781. However, these technologies have evolved, optimizing the efficiency, reliability, and operability of today's power plants while reducing emissions. Unfortunately, in the last decade or so, conventional heat engine cycles have reached the point where few efficiency improvements are possible. SwRI and other research organizations are exploring novel power cycles to allow for game-changing improvements in power generation efficiency and environmental performance.

## NEXT-GENERATION POWER CYCLES

Replacing steam or gas with $sCO_2$ in the power cycle is an option that offers improved power generation efficiency. And $sCO_2$ power cycles can be used in coal, natural gas, nuclear, geothermal, and concentrated solar power plants. Using $sCO_2$ offers high efficiency in a compact footprint using a range of heat sources. Increased cycle efficiency will decrease fuel costs, lower water use, and in the case of fossil-fueled plants, lower greenhouse gas emissions.

But what is supercritical $CO_2$? It is a fluid state of carbon dioxide. In this state, high pressures and temperatures create a phase where it acts as both a liquid and a gas simultaneously. It is non-toxic and non-flammable and is used in relatively ordinary processes such as decaffeinating coffee or dry cleaning clothing. Replacing steam or air with $sCO_2$ as the working fluid in a power plant will improve plant efficiency and allow for easy separation and sequestration of $CO_2$. These power cycles use equipment one-tenth the size of conventional equipment, requiring a significantly smaller facility.

Achieving the full benefits of the $sCO_2$ cycle, however, will depend on solving a number of engineering challenges that affect the technical feasibility of the cycle as well as its economic viability. These include developing optimized thermodynamic cycles, turbomachinery, low-cost heat exchangers, and control systems. SwRI is addressing these challenging technology gaps, creating enabling technology as steppingstones to bridge these gaps. Among these challenges are identifying the best materials to handle the elevated temperatures and pressures in turbomachinery and related components.

## TECHNICAL ADVANCES

SwRI is a world leader in $sCO_2$ power cycles. In the last decade, SwRI has conducted 22 DOE projects with total funding of about

SwRI's machinery program develops and utilizes novel power plant technology for a variety of applications. For instance, engineers developed a hot gas expander and recuperator for a 1 MW $sCO_2$ demonstration loop located at SwRI.

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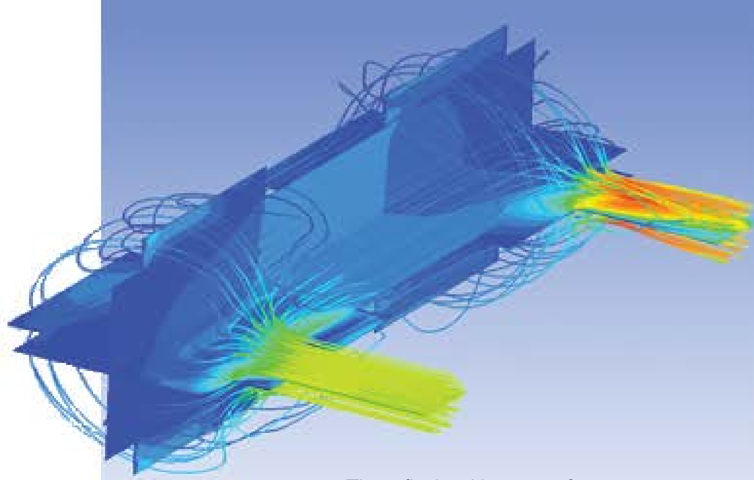
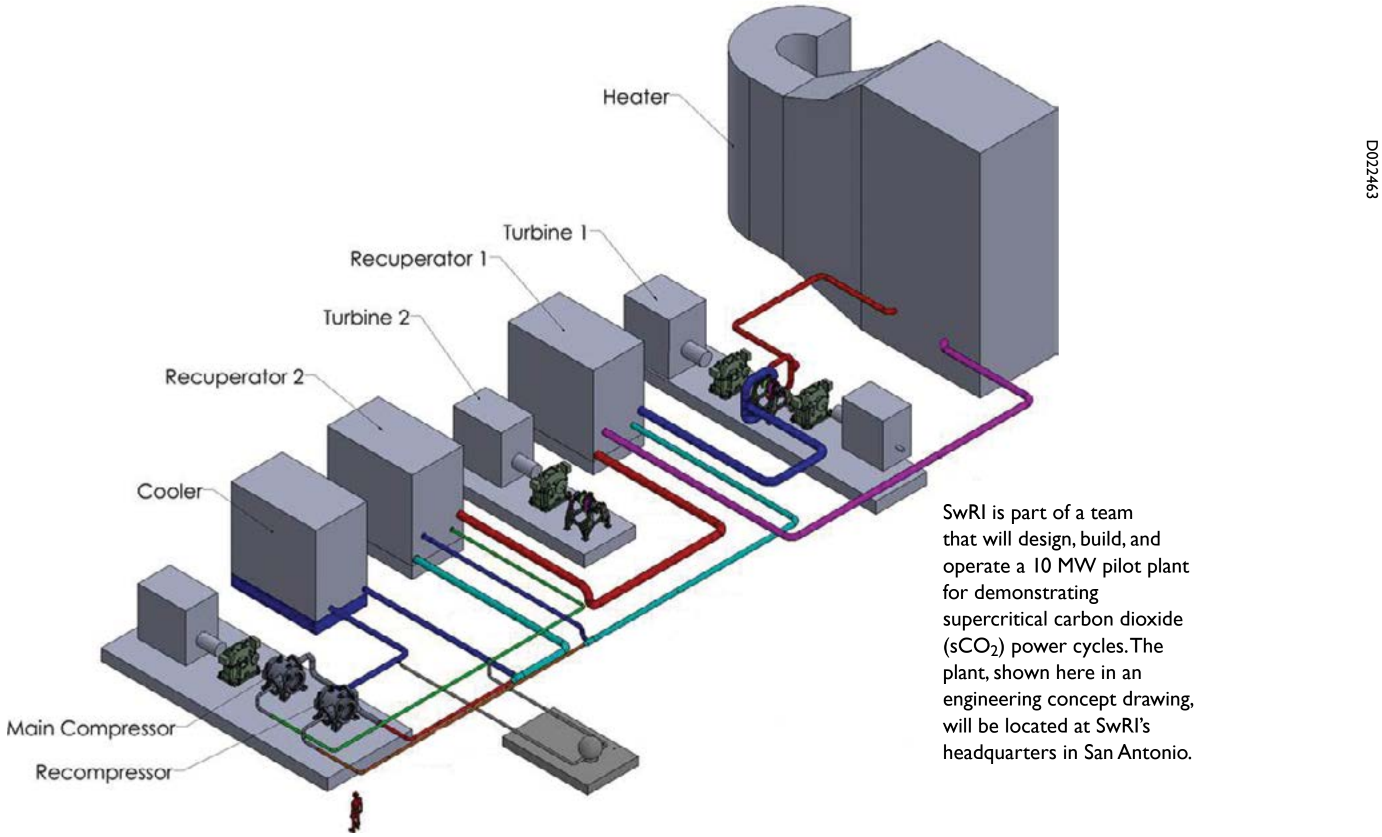
## DETAIL

### SwRI's Patented $sCO_2$ Power Cycle

SwRI researchers have developed the Cryogenic Pressurized Oxy-combustion Cycle, or CPOC, a novel, highly efficient $sCO_2$ power cycle. In this patented thermodynamic heat-to-mechanical energy conversion process, a hydrocarbon fuel (such as natural gas) is fired at elevated pressure with the $sCO_2$ gas. The resulting combustion products, $CO_2$ and water vapor, can easily be removed in a concentrated form. The process eliminates the need for a heat exchanger, simplifying the equipment design. It also is more efficient and provides a concentrated stream of pressurized $CO_2$, which can be sequestered or used to enhance oil recovery, reducing the plant's overall carbon footprint. SwRI researchers are currently working with DOE to advance this cycle's combustor design and expect to have a functioning prototype within the next three to four years.



These fluid and heat-transfer computational analysis data show the flow field through an $sCO_2$ heat exchanger.




SwRI is part of a team that will design, build, and operate a 10 MW pilot plant for demonstrating supercritical carbon dioxide ($sCO_2$) power cycles. The plant, shown here in an engineering concept drawing, will be located at SwRI's headquarters in San Antonio.

$119 million to address technology challenges, developing individual cycle components as well as demonstrating feasibility of the entire power cycle. Currently, SwRI engineers are developing two $sCO_2$ demonstration plants.

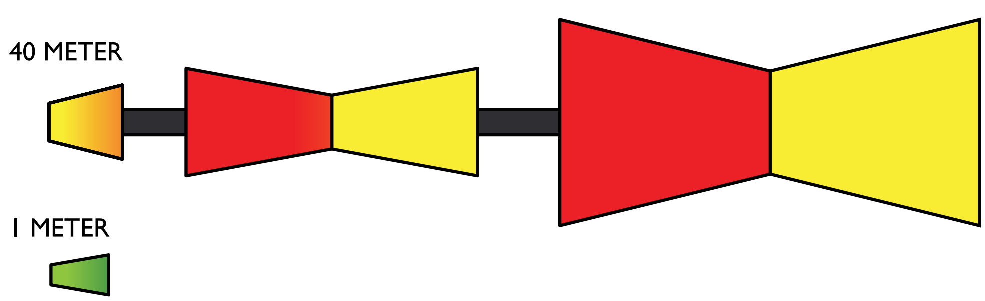
The first plant will include a high-efficiency 1 MW $sCO_2$ hot gas expander to demonstrate cycle efficiencies of nearly 50 percent, 20 percent above today's industry average. This project includes designing and constructing a 1 MW $sCO_2$ test loop at SwRI to demonstrate the performance and durability of the expander as well as critical equipment for $sCO_2$ power plant technology. The loop will be operational by mid-2017, with all testing completed by the end of 2017.

Similarly, SwRI is advancing compressors, heat exchangers, heaters, valves, instrumentation, combustors, and other components of the $sCO_2$ power cycle under various DOE and industry contracts. In addition to contributing to key $sCO_2$ plant technology, SwRI has developed and patented its own proprietary $sCO_2$ power cycle, the Cryogenic Pressurized Oxy-Combustion Cycle.

In a separate DOE project, SwRI will work with GTI, GE Global, and other industry team members to design, build, and operate a commercial scale $sCO_2$ power pilot plant to demonstrate the next generation of higher-efficiency, lower-cost electric power. The planned 10 MW facility, to be located at SwRI, will house first-of-its-kind equipment to demonstrate the use of $sCO_2$ as the working fluid in power system components. The facility will allow researchers to demonstrate turbomachinery, recuperators, and process configurations operating at turbine inlet temperatures up to 700°C. DOE is providing up to $80 million for the six-year program. The system will be connected to the San Antonio electric grid and is expected to produce efficient electricity for SwRI well beyond the project duration. The 15-acre facility is scheduled to be operational in 2020.

Locating the pilot plant at SwRI's technology-focused headquarters offers DOE the best value and an industry-neutral site. The plan leverages SwRI's existing utility infrastructure and on-site subject matter expertise as well as grid connectivity through the

SwRI is developing technology that will reduce the size of power plants. This diagram compares the equipment sizes needed for a 250 MW plant using a steam-driven turbine (red) versus an $sCO_2$-driven turbine (green).



local utility, CPS Energy. In anticipation of future re-use, the location will offer a flexible and reconfigurable facility design using a modular approach to component integration. The facility also can be configured to provide on-site user training and operations experience to accelerate commercial adoption of $sCO_2$ technology. At the conclusion of this program, $sCO_2$ Brayton cycle technology will advance to a near-commercial level, and the facility will continue to serve as a testbed for $sCO_2$ plant technology.

## THE NEXT STEP

The holy grail of $sCO_2$ research is developing oxy-fuel combustion for highly efficient, carbon-free fossil fuel plants. SwRI has four of these projects underway. Oxy-combustor technology integrates the combustion process into the $sCO_2$ cycle itself. These direct-fired coal or natural gas processes produce almost no carbon emissions or a concentrated stream of $CO_2$ that can be sequestered easily without additional separation or compression.

## BRIGHT FUTURE

Power plants using $sCO_2$ cycles offer many advantages. A single-phase working fluid simplifies overall processes and avoids other concerns associated with steam cycles. Because the U.S. has over 250 years of coal and more than 40 years of natural gas reserves, $sCO_2$ would allow the nation to exploit these resources more efficiently and with fewer greenhouse gas emissions as part of an integrated electric power portfolio for decades to come. The power cycle also lends itself to streamlined carbon capture and sequestration. With more than 50 years of experience in design, analysis, and troubleshooting of energy industry machinery, SwRI sees a bright future ahead for tomorrow's clean $sCO_2$ power cycles.

*Questions about this article? Contact Brun at (210) 522-5449 or klaus.brun@swri.org.*

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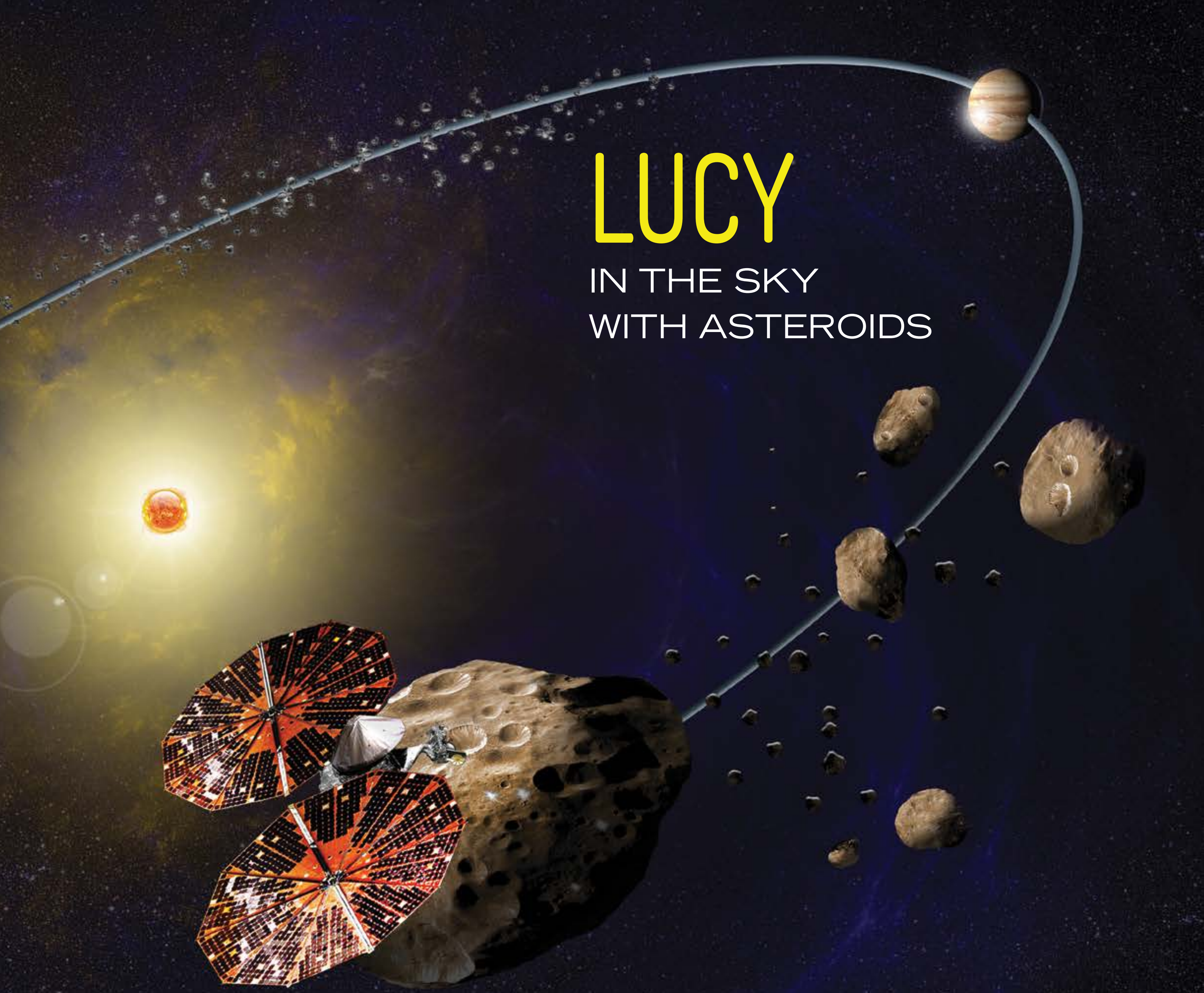
SwRI researchers use this 700 hp electric motor driven $sCO_2$ pump for the 1 MW $sCO_2$ demonstration plant. The plant is expected to be operational by mid-2017.



# LUCY

## IN THE SKY WITH ASTEROIDS

SwRI has been selected to lead NASA's Lucy mission to perform the first reconnaissance of the Trojans, a population of primitive asteroids orbiting in tandem with Jupiter. The Lucy spacecraft will launch in 2021 to study six of these exciting worlds.

"This is a unique opportunity," said Dr. Harold F. Levison, a program director and chief scientist in SwRI's Boulder office and the principal investigator of the mission. "Because the Trojans are remnants of the primordial material that formed the outer planets, they hold vital clues to deciphering the history of the solar system. Lucy, like the hominid fossil for which it is named, will revolutionize the understanding of our origins."

Lucy has an amazing trajectory. The spacecraft will circle around the Sun twice getting gravity boosts from Earth before it visits a main belt asteroid — designated DonaldJohanson in a nod to the paleoanthropologist who discovered the fossil Lucy — before looping back around the Earth for a final gravity assist to slingshot the spacecraft out to Jupiter orbit.

"One of the most puzzling characteristics of the Trojans is that they are very different from one another," said Levison. "This diversity was caused by the evolution of the outer planets and, as such, can be used to detangle their history."

According to the Nice planetary evolution model, a shakeup in the outer solar system caused the outer planets to move significantly farther from the Sun, disturbing various populations of smaller bodies, many of which were then captured in Jupiter's orbit. They stabilized into two swarms of objects known as the Trojan asteroids, one in front of and another trailing the gas giant, offering a rich range of targets for discovery.

Lucy will visit both swarms, first encountering Eurybates, a C-type asteroid and the largest remnant of a disruptive collision, followed by Polymele, a small, dim, reddish fragment. The spacecraft will also visit D-type asteroids, Orus and Leucus. Interestingly, Leucus rotates on its axis very slowly. Then Lucy will move to the second swarm to visit the near-equal mass binary system of Patroclus and Menoetius, pristine objects thought to be locked in an orbital dance since their formation.

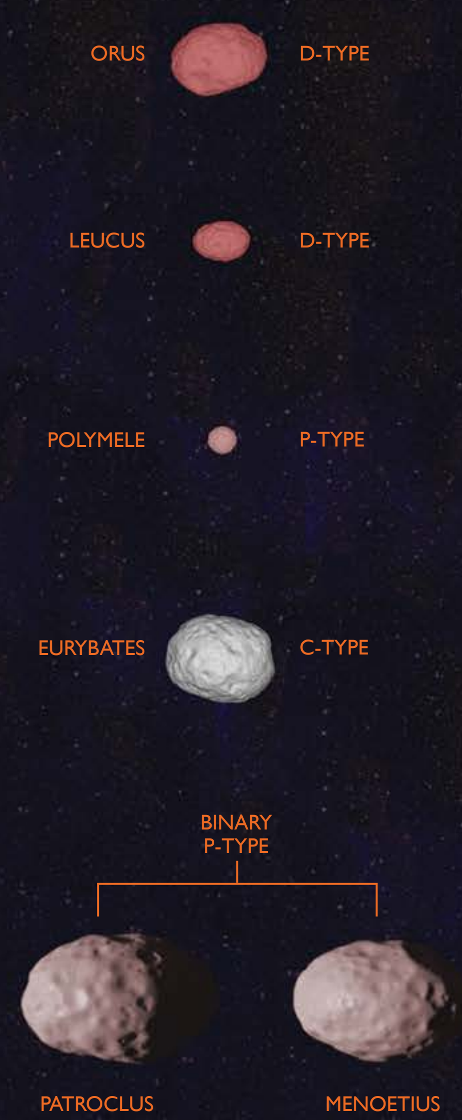
"Understanding the causes of the differences between the Trojans will provide unique and critical knowledge of planetary origins, the source of volatiles and organics on the terrestrial planets, and the evolution of the planetary system as a whole," said Dr. Catherine Olkin, the mission's deputy principal investigator. "Lucy will also transform our understanding of the Trojans."

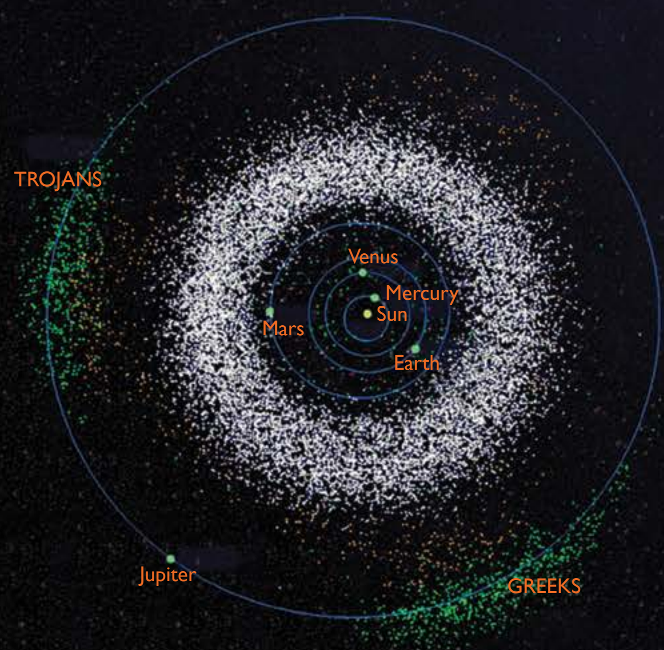
Right now, the best Hubble images are little more than pixelated blobs. Lucy will tell us about their surface geology, color, and composition. Its payload is designed to determine if they are solid, fractured, a rubble pile covered in dust, or a conglomeration of gravel. Lucy will also look for satellites and rings around the objects.

"The Lucy mission is one of those rare moments where a single mission can have a major impact on our understanding of such fundamental questions," added Dr. Keith Noll, chief of the NASA's Goddard Space Flight Center (GSFC) Planetary Systems Laboratory and a project scientist for the mission.

Lucy will use a proven spacecraft and remote-sensing instrument suite to study the geology, surface composition, and bulk physical properties of these bodies at close range. The payload includes three complementary imaging and mapping instruments, including a color imaging and infrared mapping spectrometer from GSFC, a high-resolution visible imager from the Johns Hopkins University Applied Physics Laboratory, and a thermal infrared spectrometer from Arizona State University. In addition, Lucy will perform radio science investigations using its telecommunications system to determine the masses and densities of the Trojan targets.

Lucy is scheduled to launch in October 2021 and fly by its targets between 2025 and 2033. In all, Lucy will study six Trojans and one main belt asteroid. SwRI is the principal investigator institution and will lead the science investigation. GSFC will provide overall mission management, systems engineering, and safety and mission assurance. Lockheed Martin Space Systems of Denver will build the spacecraft.



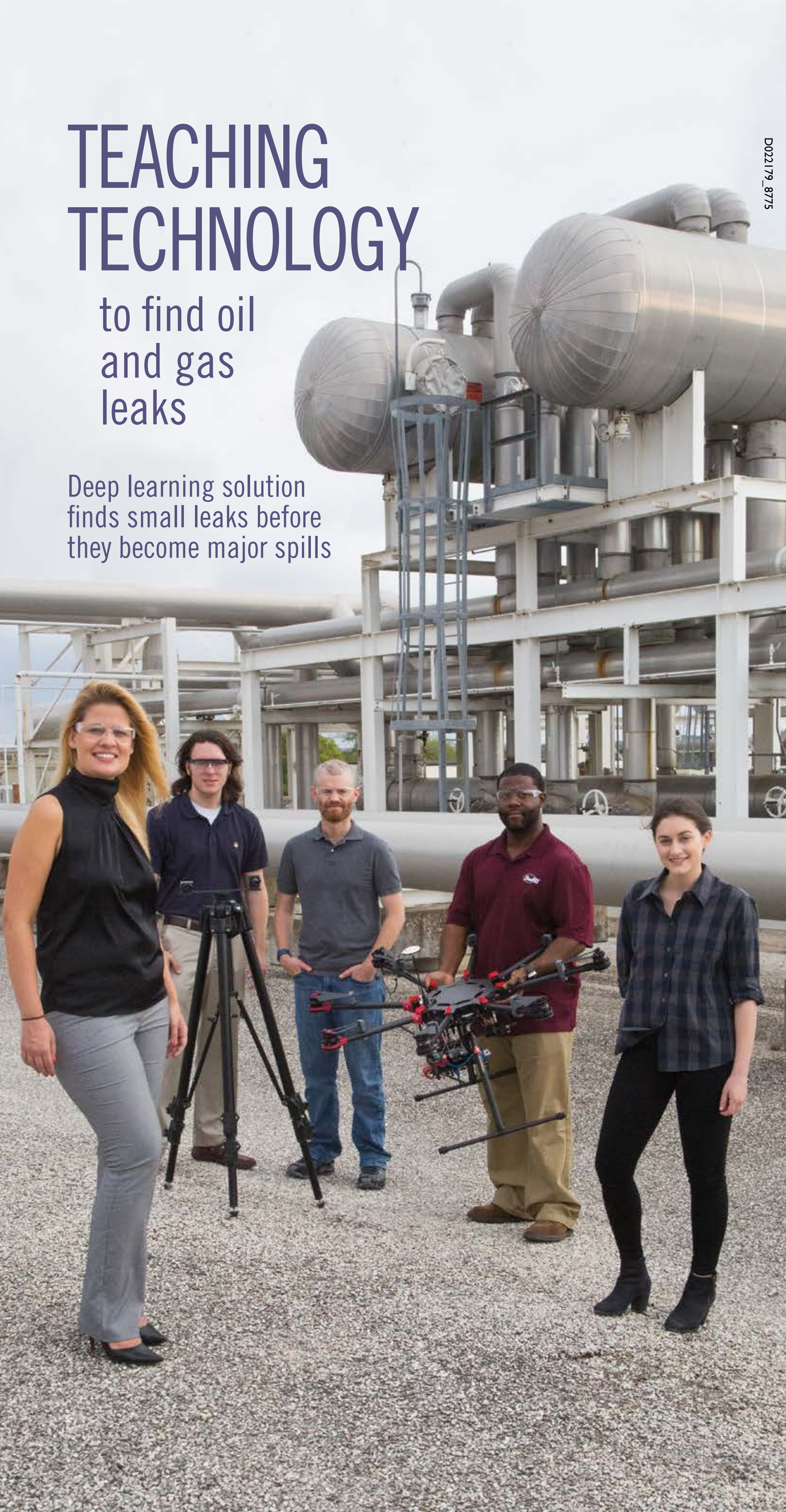

COURTESY NASA

Opposite: In this artist's concept (not to scale), the Lucy spacecraft flies by Eurybates, one of the six diverse and scientifically important Trojans to be studied. The diverse targets shown above include Eurybates, Polymele, Leucus, Orus, and the binary Trojans Patroclus and Menoetius. The figure on the left shows the two swarms of Trojan asteroids in green, named after characters from the Trojan War of Greek mythology (one swarm for the Greeks, the other for the Trojans). These swarms travel in front of, and trailing behind, Jupiter as the gas giant orbits the Sun.

# TEACHING TECHNOLOGY

## to find oil and gas leaks

Deep learning solution finds small leaks before they become major spills




The domestic boom in oil and gas production helped the U.S. increase energy independence in the past decade, but the benefits have come with environmental challenges. Among those are increased risks of hazardous chemical spills and methane gas leaks, which contribute to climate change by trapping heat in the atmosphere.

Between 2007 and 2012, leaks in the U.S. liquid pipelines network exceeded 100,000 barrels a year; that's a pool of petroleum the size of the Lincoln monument's reflecting pool every two years. This volume is a 3.5 percent increase from the previous five-year period.

Southwest Research Institute is attacking the issue, developing technology that can autonomously pinpoint small liquid and gas leaks before they become major problems.

Maria Araujo (left), manager of SwRI's High Reliability Systems Section, led a multidivisional team to address gaps in technology for detecting small leaks in liquid pipelines. The team included (from left) Daniel Davila, Shane Siebenaler, Dr. Edmond DuPont, and Samantha Blaisdell from the Intelligent Systems and Mechanical Engineering divisions.

"It makes both environmental and economic sense to identify the smallest oil and gas leaks as early as possible to help ensure environmental safety and pipeline system reliability," said Maria Araujo, a manager in SwRI's Intelligent Systems Division. "With sensor fusion and machine learning techniques, we are using a branch of artificial intelligence to trigger rapid responses."

## SMALL LEAK DETECTION

Working with SwRI's Mechanical Engineering Division, Araujo led an internal research project that addresses gaps in technology for detecting small leaks in liquid pipelines. The Smart LEak Detection (SLED) system uses algorithms to process images from sensors scanning the infrastructure. These sensors can be positioned at sensitive pipeline junctures or deployed on drones to cost-effectively fly over pipeline networks.

Current practices in hazardous liquid leak detection include visual monitoring and external and internal leak detection systems (LDS). Visual monitoring can entail pilots surveying infrastructure from a small plane. This technique is somewhat effective, but expensive and time-consuming, and cannot distinguish a puddle of water from a hydrocarbon spill. Existing external leak detection systems do offer some benefits, including the ability to locate a leak, continuous operation, significantly better sensitivity than computational methods, and the ability to estimate the size of a leak, among others. However, several drawbacks in existing LDS include high costs and difficulty in retrofitting existing pipelines to support these technologies. Some of these technologies are not effective for both under- and above-ground pipelines or when a very large number of sensors are required. And both visual techniques are less likely to find a leak the smaller it is.

Today, the predominant internal leak detection systems used by the oil and gas industry rely on computational pipeline monitoring, or CPM, which looks for anomalies in flow volume and pressure. This process works well when identifying large leaks, but often fails to detect leaks of less than 1 percent of the pipeline flow volume. To put that into perspective, 1 percent of the Keystone XL Pipeline volume is about 8,000 barrels per day; today's standard technology is neither accurate nor effective at pinpointing such leaks.

The crux of the problem is CPM leak detection systems tend to trigger false alarms with leaks of less than 1 percent. Historically, high false alarm rates have led system operators to ignore those alarms. Consequently, that means energy companies often don't find out about leaks until property owners, or the media, report significant spill incidents. Nearly half of all leaks today are found by accident, not by leak detection technology.

SLED sensors can be deployed on drones to fly over long stretches of pipelines and look for leaks efficiently. D022203_9227

Project lead Maria Araujo sets up stationary sensors for the SLED system. Using machine learning techniques, the system analyzes sensor data to autonomously identify hydrocarbon leaks in real time.

## DETAIL

SwRI is modifying SLED to find methane gas leaks. Methane doesn't remain in the Earth's atmosphere as long as carbon dioxide. But its initial effect on climate change is more intense, because it absorbs heat very effectively. In the first two decades after release, methane is considered 84 times more "warming" than carbon dioxide. Scientists at the Environmental Defense Fund estimate that 25 percent of current manmade global warming is caused by methane emissions.

"It's too late at that point; the damage is already done, so we need more reliable leak detection," Araujo said. "With more than 2.5 million miles of existing pipelines, this is a major challenge for our energy infrastructure."

## SENSING LEAK SIGNATURES

The SwRI solution is multiplatform; it can be deployed on stationary platforms at pumping stations, located about every 50 miles along the pipelines. These are high-risk areas for leaks because valves and other specialized equipment can fail. But the technology can also be deployed on drones, to fly over long stretches of pipelines between stations. The SwRI solution fuses inputs from low-cost optical sensors and applies machine learning techniques to reliably detect the chemical "fingerprints" of small hazardous liquid leaks.

The technique for fingerprinting chemicals uses the reflectance response of typical hydrocarbons using infrared and visual sensors. Cameras have been used to detect leaks before, but the SwRI team used artificial intelligence techniques to vastly improve the accuracy. The team then used feature extraction and classifier training techniques to teach computers to identify unique features across the full range of environmental conditions. It not only provides a more reliable fingerprint of small liquid leaks, but also characterizes a variety of non-leak events over the full range of operating conditions. This substantially reduces false positive rates.

## DEEP LEARNING TECHNIQUES

Accuracy is paramount. Consider if a system identifies a pipeline leak in rural Alaska. To send a team of technicians out in the field to repair the leak is costly, even more so if they arrive and determine that it was a false alarm. Artificial intelligence is key to the accuracy of SLED. Using machine learning, a computer can learn without explicit programming, by consuming copious amounts of data. The team collected thousands of images of mineral oil, crude oil, gasoline, diesel, and water on various surfaces, including gravel, grass, and concrete. These images were shot at various angles and under all conditions, from bright sunshine to cloudy skies, under a full range of temperatures. All those data were fed into an algorithm to identify patterns that differentiate one liquid from another.

In addition to standard conventional machine learning approaches, the team applied advanced deep learning neural network techniques. Deep learning refers to the depth of layers that make up a neural network. The depth of these networks has traditionally made training and classification impractical. However, recent mathematical discoveries combined with rapid improvements in multi-core processing hardware have brought the potential of deep learning techniques into the mainstream. In computer vision, one of the primary deep learning techniques is called convolutional neural network (CNN). This flexible technique dynamically addresses the standard battery of computer vision challenges, such as detection, classification, and tracking. SwRI developed and applied a deep convolutional neural network to process the data and identify hazardous liquids. Initially, the plan was to differentiate hazardous liquids from a puddle of water, but the system proved powerful enough to distinguish between the various petroleum products, identifying a gasoline leak versus a pool of diesel.

The result is a fully autonomous system that can be used with no human intervention, Araujo said. The system identifies leaks of crude oil, diesel, gasoline, and mineral oil under different lighting and weather conditions, accurately characterizing the signatures of leak and non-leak events.

### TECHNOLOGY TRANSFER

The success of the internal research project helped SwRI land a U.S. Department of Energy award to apply the same technology to detect small gaseous leaks, specifically methane. Methane, a primary component of natural gas, is considered a greenhouse gas because it absorbs the sun's heat and warms the atmosphere. The SwRI team will develop an autonomous, real-time methane leak-detection system for the National Energy Technology Laboratory.

"Historically, it has been challenging to effectively detect and mitigate small methane leaks in real time unless you have inspection personnel with sensor devices stationed 24/7 across energy infrastructure," Araujo said.

The Smart LEak Detection/Methane technology, also known as SLED/M, will be designed to automate small leak detection across the entire natural gas supply chain from extraction and storage to transportation and distribution. The two-phase DOE project will take place over 18 months. In Phase I, SwRI will adapt its hazardous liquid spill detection capabilities to develop the methane detection system. Using integrated optical sensors and a GPU-based embedded processing unit, the new technology will create algorithms that learn to recognize patterns and trigger alarms during leak events.

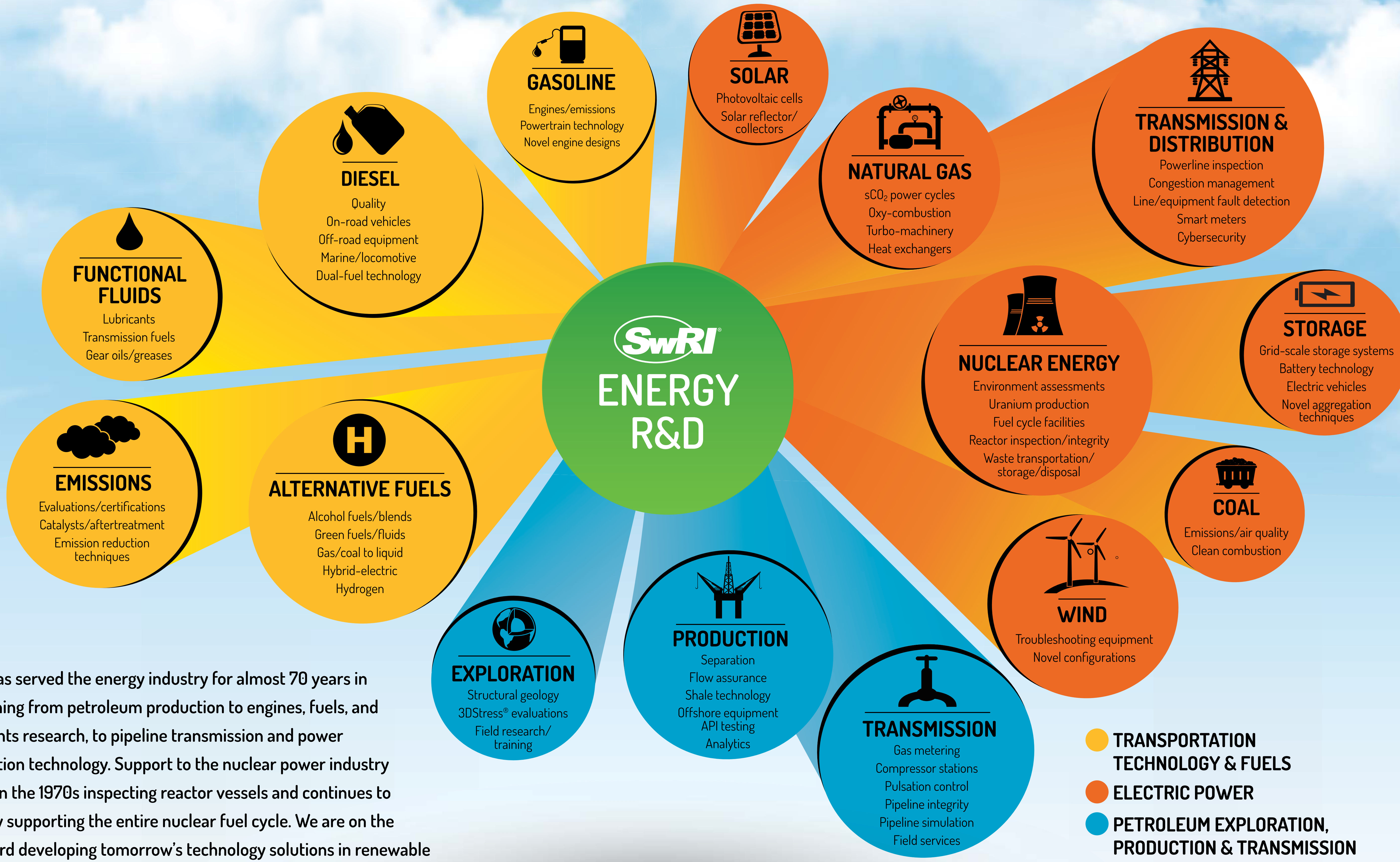
Beyond the DOE project, Araujo's team is developing new applications for the technology, including remote satellite sensing to identify oil spills in places like the Gulf of Mexico.

*Questions about this article? Contact solutions@swri.org.*

### DETAIL

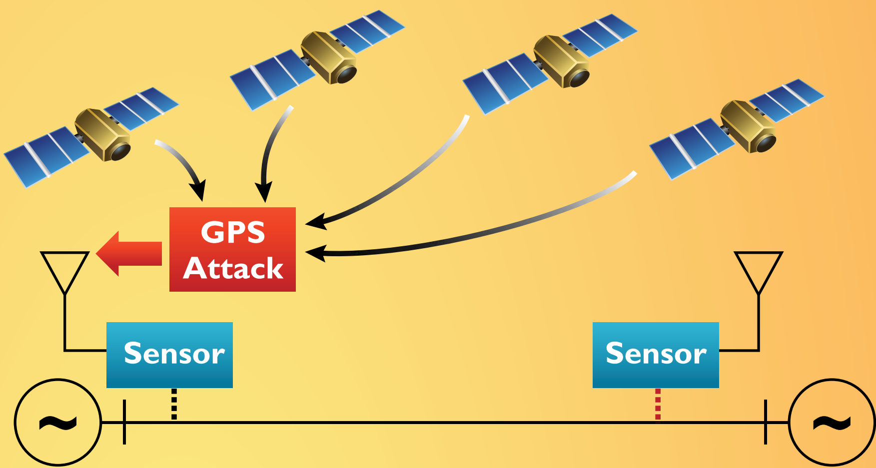
A convolutional neural network (CNN) is a computational approach inspired by the organization of the animal visual cortex. CNNs have proven very effective in areas such as image recognition and classification. They successfully identify faces, objects, and traffic signs, powering vision in robots and self-driving cars, and now detecting hazardous leaks, including methane leaks.


For the internal research program, sensors collected thousands of images of liquids "spilled" on various surfaces from different angles and under a range of conditions. All those data were fed into an algorithm to identify patterns and learn to differentiate one liquid from another. Based on machine learning, SLED can identify a range of hydrocarbons, shown in red.




SwRI has served the energy industry for almost 70 years in everything from petroleum production to engines, fuels, and lubricants research, to pipeline transmission and power generation technology. Support to the nuclear power industry began in the 1970s inspecting reactor vessels and continues to this day supporting the entire nuclear fuel cycle. We are on the vanguard developing tomorrow's technology solutions in renewable energy, supercritical carbon dioxide power cycles, and clean coal.

# SwRI WINS 41ST "OSCAR" OF INVENTIONS




TRES detects and fights through GPS disruption events, including cyberattacks, to maintain time synchronization in critical energy infrastructure applications.

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SwRI's Time REsilient System (TRES), designed to safeguard energy applications from cyberattack, was named one of the top 100 inventions of 2016 by R&D Magazine. Gerardo Trevino and Dr. Ben Abbott, both of SwRI's Intelligent Systems Division, accepted the award at ceremonies held in Washington, D.C.

"The U.S. Department of Homeland Security has identified cyberattacks as a high risk to critical infrastructure, particularly the electric power grid," said Trevino, who led the development of TRES. "The system protects critical infrastructure from GPS jamming and spoofing to maintain the precise time synchronization needed for operations."

In addition to longitude, latitude, and altitude, GPS provides a critical fourth measurement — time. Using onboard atomic clocks, GPS satellites have become a vital "invisible utility," providing precise time information to users ranging from the financial and transportation industries to the electric utility sector.

Working with San Diego Gas & Electric, SwRI developed TRES to identify and fight through GPS disruption events to maintain time synchronization in critical energy infrastructure applications. TRES uses inexpensive, commercial-off-the-shelf hardware modified to monitor GPS time signals used by the energy sector.

"The daunting concept of trying to weed through all currently known — and future — malicious GPS signal-based attacks drove us to use the consistency of time itself in the TRES approach," said Abbott, the technical expert who developed this technique.

Using novel algorithms and methodologies, TRES detects anomalies in time information by looking back at sources of time that have proven trustworthy and comparing them to current GPS time transmissions. TRES continuously monitors time data, waiting to adjust time until it is assured that the GPS signal is from a trustworthy source.

"While GPS has tremendous benefits for society, we have to be worried about the implications of cyber intrusions into GPS receivers," said Division Vice President Dr. Steve Dellenback. "The TRES tool provides a sophisticated approach to monitor the reliability of GPS time data."

Since 1971, SwRI has won 41 R&D 100 Awards, which, in the R&D industry, are considered the "Oscars of invention." R&D 100 Awards are selected by an independent panel of judges and editors of R&D Magazine to honor the top technology products of the year.

# CYGNSS SATELLITES SURVEY THE TROPICS

NASA's Cyclone Global Navigation Satellite System (CYGNSS) constellation of eight spacecraft — the first engineered and fabricated by SwRI — made its first data measurements of the ocean surface on Jan. 4, 2017. The mission has successfully completed the development and commissioning phase and began the operations phase. The microsatellites have now started orbit instrument calibration and validation and are on track for the first science data to be delivered in May.

"With CYGNSS, we're doing real science with a satellite small enough to literally sit on your desk," said John Scherrer, who oversaw satellite construction. "While these satellites might be small, they provide big returns with data that we expect to one day help weather forecasters make important weather-related recommendations, such as evacuations."

The CYGNSS microsatellites launched Dec. 15, 2016, into a low-inclination, low-Earth orbit over the tropics. This proof-of-concept mission will make frequent measurements of ocean surface winds in and near a hurricane's inner core. The regions beneath the eye and intense inner rain bands previously could not be measured accurately from space.

"Over the years, forecasters have improved hurricane path prediction significantly, but the ability to predict the intensity of storms has lagged behind," said Susan Pope, director of SwRI's Space Instrumentation Department. "We know where the storm is going, we just don't know what it's going to do when it gets there. For example, with Hurricane Katrina, forecasters predicted a 10-foot storm surge. It was actually three times that."

The satellites look at GPS signals reflected by the ocean and can determine the wind speed based on qualities of those reflections. Consider how a mountain is reflected with almost mirror-like clarity on a calm lake. When windy, waves on the lake blur the reflection of the mountains. CYGNSS measures the amount of "scatter" in the reflected GPS signals, allowing scientists to correlate that to wind speeds and better understand a storm's intensity.

"Per CYGNSS Principal Investigator Chris Ruf, the first light data were 'rock solid,'" Pope said. And that's good news for the multidisciplinary SwRI team involved in the project. The space sciences staff built the spacecraft, but three different Institute divisions were involved in the testing and evaluation of the hardware. SwRI signal intelligence specialists helped characterize the satellite antennas and an intelligent systems team developed the flight software.

Another first: SwRI's Boulder office is managing the mission operations center — the MOC — which commands the spacecraft, collects the telemetry, and transmits the data to the science operations center at the University of Michigan.

The CYGNSS mission is led by the University of Michigan. SwRI led the engineering development and manages the operation of the constellation. The University of Michigan Climate and Space Sciences and Engineering department leads the science investigation, and the Earth Science Division of NASA's Science Mission Directorate oversees the mission.

> "With CYGNSS, we're doing real science with a satellite small enough to literally sit on your desk.
>
> – John Scherrer

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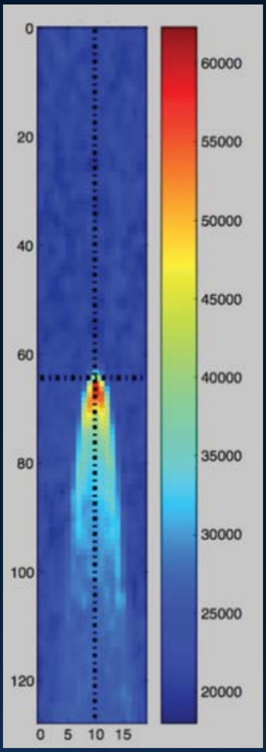



The "first light" data from NASA's CYGNSS mission shows a peak representing a scattered GPS signal reflected from the ocean surface. These data will allow scientists to discern near-surface wind speeds, to better understand how hurricanes form and intensify.


COURTESY NASA/LAURIE LOSEY

After flying to high altitude attached to the underbelly of an Orbital-ATK L-1011 Stargazer jumbo jet, the CYGNSS microsatellites were boosted into low-Earth orbit by a Pegasus XL rocket system Dec. 15, 2016.

# EVALUATING ENVIRONMENTAL IMPACTS

## SwRI assesses hazards across the nuclear fuel cycle

By Miriam Juckett

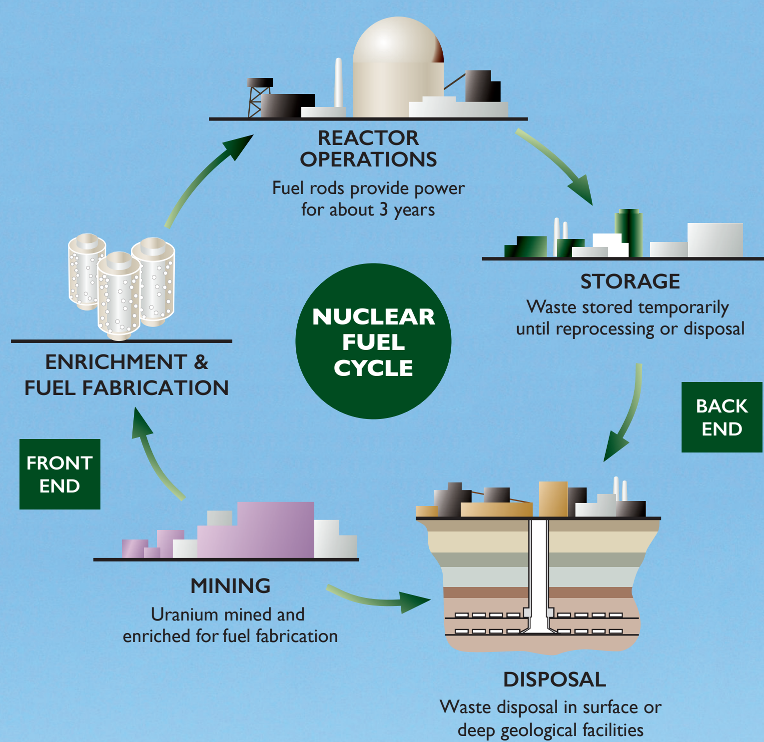
Nuclear power is a significant source of the electrical energy used in homes and industries in the U.S. and around the world. In fact, in the U.S. one-fifth of all electric power is generated by 100 nuclear reactors located in 30 states. After a decades-long lull, the U.S. nuclear power industry is poised for growth with five new reactors scheduled to come online by 2021 and more are under pre-construction regulatory review. Part of the growing demand for nuclear power stems from public interest in low carbon-emitting energy sources in place of coal, oil, and natural gas.

With this renewed activity, the U.S. Nuclear Regulatory Commission (NRC) is busy evaluating new reactor facilities and their potential environmental impacts on local communities and surrounding areas. New plants also will drive additional uranium fuel production as well as spent-fuel transportation, storage, and disposal operations. These areas are known in the nuclear industry as the "front end" and "back end" of the nuclear fuel cycle, bookending the actual operation of nuclear reactors to produce electricity. Close regulatory oversight of all three segments arises from the unique and extremely long-term health and environmental hazards associated with uranium, a naturally occurring radioactive element that is the primary ingredient of nuclear fuel.

Geoscientists and nuclear engineers at Southwest Research Institute

### DETAIL

**NUCLEAR FUEL CYCLE:** Before a nuclear reactor produces energy, uranium is mined or extracted by leaching and further processed to create fuel at the "front end." The next step is reactor operation, followed by short-term storage of the used fuel on-site at a reactor while it cools down. Ultimately, spent nuclear fuel is either stored on-site long term, prepared for consolidated storage off site, or disposed in an underground geologic repository in the "back end."




Yucca Mountain is located about 100 miles northwest of Las Vegas, Nevada.

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ABOUT THE AUTHOR
Miriam Juckett, program manager of environmental protection and external hazards assessment at the Center for Nuclear Waste Regulatory Analyses, is an environmental scientist with specialization in geochemistry. As a principal investigator, she supports the U.S. Nuclear Regulatory Commission (NRC) environmental and public outreach projects and serves as the stakeholder relations expert for NRC programs.

(SwRI) assist the NRC in its regulation of the entire nuclear fuel cycle. For more than 40 years, SwRI engineers have developed new technologies to safely inspect important components of nuclear power plants, including the reactor pressure vessel and associated piping systems. And since 1987, engineers and scientists with the Institute's NRC-sponsored Center for Nuclear Waste Regulatory Analyses (CNWRA®) have provided expertise in geology, hydrology, natural hazards, material sciences, and civil, mechanical, and nuclear engineering to evaluate interim storage facilities and a potential federal facility for disposal of high-level nuclear waste. Today, SwRI's experts are also helping NRC evaluate environmental and safety aspects of uranium extraction and nuclear fuel enrichment facilities.

The National Environmental Policy Act (NEPA) drives all these activities, requiring federal agencies to assess the environmental impact of their actions. NEPA reviews are not confined to the nuclear industry; they also are triggered by other federal actions such as applications for construction of railroads, power plants, and other large projects. The reviews tend to parallel a complementary safety review, and include opportunities for public comment on a formal document that lays out a proposed project's potential impacts, as well as alternatives to what is proposed.

## AIMING FOR A TRANSPARENT PROCESS

NEPA provides different levels of review for projects that require permits or licenses. Those with no significant effect on the environment qualify for a Categorical Exclusion. Projects determined to pose potential impacts move on to the next level and require an Environmental Assessment (EA). This assessment can result in either a "Finding of No Significant Impact" or a requirement for additional review.

If additional review is required, an Environmental Impact Statement (EIS) is the third and most rigorous level in the process. Although it can take years to complete, this evaluation enables federal agencies to work with the public to define issues and determine alternatives. An EIS details the entire process for a proposed project under review. It considers reasonable alternatives, analyzes potential impacts resulting from the alternatives, and demonstrates compliance with applicable environmental laws and executive orders. The EIS process includes preparation of a draft EIS, a final EIS, and a Record of Decision, the public document that outlines the project and its ramifications as well as any alternatives or mitigation and monitoring plans.

To develop either an EA or an EIS for a client, SwRI typically examines hundreds of pages of license application materials, and compares the information against available literature. In the process, the SwRI team also may conduct independent evaluations of aspects of the proposed project that are uncertain, higher risk, or controversial. Environmental impact evaluations cover a broad range of resource areas, ranging from geology and water to the


Congress in the late 1980s chose Yucca Mountain as the location to be characterized for potential geological disposal of high-level radioactive waste.

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Miriam Juckett studies Pacific Northwest regional geology features that can affect seismic probabilistic risk assessment. Geologic features can show evidence of tectonic processes, which are important for understanding the potential hazards at nuclear power plants, fuel cycle facilities, and disposal sites.

scenic resources. Also examined are environmental consequences from accidents and management of waste, as well as environmental justice.

## URANIUM EXTRACTION: THE "FRONT END"

At the very front end of the nuclear fuel cycle, SwRI assists the NRC in its evaluation of proposed uranium mining facilities. Most recently, SwRI helped prepare an environmental impact statement for a proposed *in-situ* recovery uranium facility in Campbell County, Wyoming. The Reno Creek Project, if constructed, would recover uranium from underground deposits by injecting fluids to dissolve the uranium ore and then recovering the ore-containing fluid, without need for open-pit mining. Regulators determined that an EIS was warranted because of potential impacts to the landscape and subsurface geology. The SwRI team spent two years helping the NRC gather input about the plan from the company planning the facility (the license applicant), Native American tribes, nearby residents, local government leaders, and other stakeholders. From that input, a 630-page draft document, covering potential environmental impacts from construction, operation, aquifer restoration, and decommissioning of the facility, was developed and published in July 2016. SwRI and the NRC evaluated public comments on the draft for inclusion in the final document, which was published in December 2016. The goal of this and all EIS documents is a robust and transparent analysis that helps protect the environment and the affected community.

## YUCCA MOUNTAIN: THE "BACK END"

SwRI's qualification for assisting the NRC is enhanced by nearly 30 years of experience preparing for and evaluating a U.S. Department of Energy (DOE) application to dispose spent nuclear fuel at Yucca Mountain in a Nevada desert about 100 miles northwest of Las Vegas. Within the framework of the Nuclear Waste Policy Act in the late 1980s, the U.S. Congress chose Yucca Mountain as the location to be characterized for deep geological disposal of spent nuclear fuel and high-level radioactive waste.

The DOE bored and mined miles of tunnels inside the mountain while evaluating potential hazards ranging from seismic activity and hydrological processes to material integrity and climate. Meanwhile, SwRI's CNWRA provided technical assistance and research support to the NRC in preparation for evaluating the license application for Yucca Mountain. In 2016, SwRI supported NRC activities related to Yucca Mountain, such as development of a supplemental EIS that was published in March 2016. SwRI helped evaluate potential groundwater flow patterns, geochemical interactions, and potential ecological and radiological impacts.

With Yucca Mountain on hold, the U.S. nuclear industry is relying on interim facilities to store spent nuclear fuel and high-level radioactive waste. To continue providing full support at the back end of the nuclear fuel cycle, SwRI also assists NRC in assessing potential impacts of current and proposed interim storage facilities both at and away from nuclear power plant sites.

## EVERY NEPA PROJECT EXPANDS SWRI'S EXPERTISE

SwRI's subject matter experts are versed in federal, state, and local regulations associated with the NEPA evaluation. Each project also presents an opportunity to develop additional knowledge about industries and processes that could play a role in environmental impacts. Interrelationships among various parts of the biosphere — that is, impacts from other activities in the surrounding area — can also make a big difference in results.

D022462

For example, one of the more complicated sites SwRI has investigated was Jefferson Proving Ground located near Madison, Indiana. This legacy Army testing facility contains depleted uranium projectiles spread across land encumbered by more than a million rounds of unexploded ordnance. The site presented many technical challenges and regulatory complexities as a result of its historical activities and the potential for overlapping impacts. Another unique project involved a proposed food irradiator facility in Pa'ina, Hawaii. Proximity to the Honolulu airport required the SwRI team to gather information about air traffic patterns, as well as hurricane storm surge scenarios.

**DETAIL**

*IN-SITU* RECOVERY: Nearly half of worldwide uranium — a leading fuel source for nuclear power — is produced via *in-situ* recovery. This mining process uses a liquid solution to dissolve minerals underground. It generally takes place in confined geological reservoirs to avoid contamination of nearby drinking water supplies. The solution is pumped to the surface, where uranium is recovered and converted to a "yellowcake" product in preparation for subsequent enrichment and processing to make nuclear fuel.

There is no "cookie cutter" process for environmental analyses. Each project is unique, from the activities to be conducted to site characteristics, to the communities affected, to applicant data that may be limited or less than ideal. This means SwRI often must take additional steps to gather information to ensure that evaluations are both technically and legally sufficient to support the conclusions.

### STAKEHOLDER ENGAGEMENT

Meeting stakeholders through site visits and scoping meetings is one of the more difficult, but also more rewarding, aspects of the job. Interacting with residents and community leaders serves as a reminder that this work is an important analysis of how a proposed project can affect a community for generations to come.

Engaging with the public also can be one of the most unpredictable aspects of NEPA reviews. The stakeholder community is different for every project, but often includes state or local governments and Native American tribes, as well as the nuclear industry, advocacy groups, nonprofit organizations, workers, and private citizens. Stakeholders can present a wide diversity of opinions. The old-fashioned "town hall" meeting is a tried-and-true way to learn more about stakeholders' concerns while they learn more about a proposed project. The attendees can talk one-on-one with agency and SwRI staff and may record oral comments about a proposed action.

SwRI helps to ensure that stakeholder engagement is effective at every stage of the process. After identifying potentially interested groups and designing a communications plan, SwRI trains its staff to interact with the public and creates educational materials. Perhaps most importantly, the team develops forward-looking "frequently asked questions" documents to help distill and explain complicated technical issues.

Every NEPA review is subject to significant public and governmental scrutiny, so it is critical that analyses are carefully thought out and defensible. Many NEPA actions eventually go through formal litigation. For these cases, SwRI can provide expert testimony to support NRC's positions.

A recent example of stakeholder engagement involved an EA for the license renewal application of a spent-fuel storage facility at the Prairie Island Nuclear Generating Station in Minnesota. The Prairie Island Indian Community near the plant expressed concerns over environmental impacts. In response, SwRI, which assisted the NRC in the development of the draft EA, hosted a writing session attended by NRC staff and tribal representatives to ensure that the final document properly addressed their concerns.

SwRI and NRC also worked closely with the Prairie Island Indian Community to learn about the history of the tribe and the surrounding area. The SwRI team gained a new appreciation for the importance of public involvement in the NEPA process — as well as the effective role stakeholders play in the final outcome — when no contentions were filed against the final version of the EA.

### NEXT STEPS IN A CHANGING INDUSTRY

Many trends will affect the nuclear power industry in the next several decades. Those factors include federal and state policy decisions, the price of competing fuels, and advancements in renewable energy. But whatever direction the trends take, SwRI will continue serving the NRC and engaging stakeholders in new projects while extending its expertise to other federal agencies in need of robust and transparent environmental analyses.

*Questions about this article? Contact Juckett at (210) 522-3266 or miriam.juckett@swri.org.*

SwRI helped prepare an environmental impact statement for the proposed Reno Creek Project. If constructed, the newly licensed facility in Campbell County, Wyoming, would recover uranium from underground deposits.

# PROJECT METEOR

As we look up in amazement at meteors streaking across the sky, a small instrument aboard the International Space Station (ISS) is delivering a closer look at these phenomena. Peering down from ISS, the Project Meteor camera observes the dust and rocks entering Earth's atmosphere in a fiery show.

"The Meteor team proves that persistence and patience pay off," said SwRI's Michael Fortenberry, Meteor's payload developer, who ended up building three versions of the instrument. The first two were lost when launch vehicles failed in 2014 and 2015. A third camera was launched in March 2016 and began collecting data in June of that year.

Meteors are relatively rare and difficult to monitor from the ground due to interference created by Earth's atmosphere. The Meteor investigation takes high-resolution video looking down at Earth from ISS. Its wide aperture lens allows Meteor to capture video of minuscule meteors. Researchers analyze the images to determine the physical and chemical properties of meteoroids, namely their size, density, and chemical composition.

As meteors enter the atmosphere, they burn at different temperatures, depending on their composition. As elements burn, they emit different frequencies of light. The Meteor camera is equipped with a removable diffraction grating, a piece of glass etched with a series of prisms. These break incoming light into different wavelengths, allowing scientists to detect emissions from four elements — iron, calcium, magnesium, and sodium.

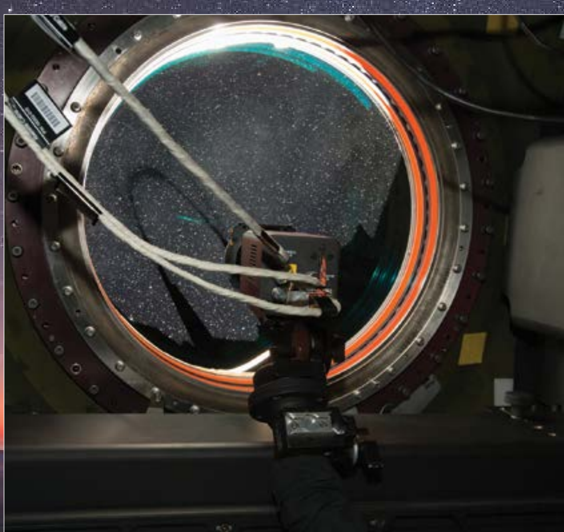
While the camera has been collecting data since shortly after launch, astronauts just recently started using the diffraction grating to collect spectral data. Determining the chemical composition of meteors will provide insight into how the planets in our solar system formed.

"By studying meteors, rocks, and particles streaking through our atmosphere, we can learn more about their parent bodies, the ancient comets and asteroids left over after the formation of the planets," Fortenberry said.

Meteor generates copious amounts of data, filling a 750-gigabyte hard drive each week. While some data are downlinked from the ISS directly, the lion's share was recently delivered on 15 hard drives via the SpaceX Dragon spacecraft.

"We're basically getting to catch a little piece of dust and rock that has been traveling around the sun for millions of years," Fortenberry said. By studying their composition and properties, scientists get a glimpse of what the early solar system was like before the planets formed, which helps them better understand the origin of our solar system. "There have been several space missions out to comets and asteroids, but this is a way of doing it closer to Earth and a lot more cheaply."

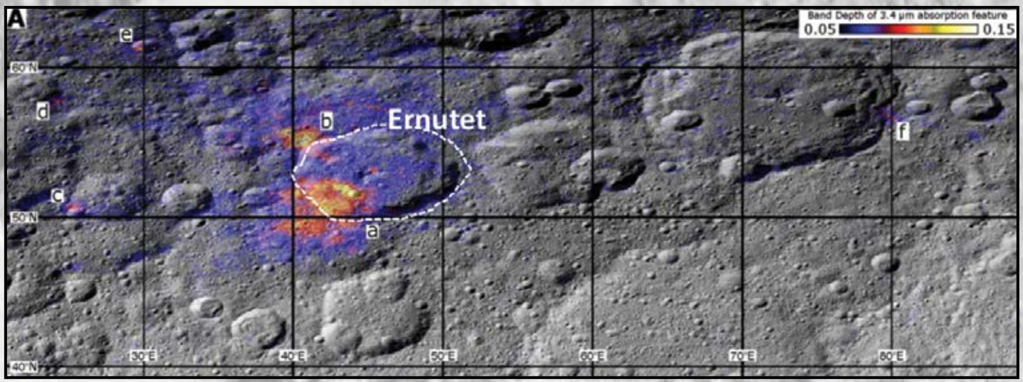
The project is a collaboration between SwRI and Japan's Planetary Exploration Research Center at the Chiba Institute of Technology. The Meteor team, located in Chiba, Japan, performs mission planning and coordinates with the Payload Operations Center at the Marshall Space Flight Center.



The Meteor camera peers out of the Window Observational Research Facility in the Destiny module of ISS. The two-year mission will collect data during the night portion of each ISS orbit, operating during periods of predicated and well-known meteor showers.

Project Meteor imaged this meteor over Africa during the Perseid meteor shower on Aug. 11, 2016.

COURTESY NASA/CASIS/SWRI/CIT AND YURI BELETSKY (LAS CAMPANAS OBSERVATORY, CARNEGIE INSTITUTION) AND NASA/ISS




Dawn spacecraft data show a region around the Ernutet crater where organic concentrations have been discovered. The color coding shows the strength of the organics absorption band, with warmer colors indicating the highest concentrations.

COURTESY NASA/JPL-CALTECH/UCLA/ASI/INAF/MPS/DLR/IDA AND NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

# Are Organics Native to Ceres?

NASA's Dawn spacecraft recently detected organic-rich areas on Ceres. Scientists evaluated the geology of the regions to conclude that the organics are most likely native to the dwarf planet. Data from the spacecraft suggest that the interior of Ceres is the source of these organic materials, as opposed to arriving via impacting asteroids or comets.

"This discovery of a locally high concentration of organics is intriguing, with broad implications for the astrobiology community," said SwRI's Dr. Simone Marchi. "With this new finding, Dawn has shown that Ceres contains key ingredients for life."

Ceres is believed to have originated at the dawn of our solar system about 4.5 billion years ago. Studying its organics can help explain the origin, evolution, and distribution of organic species across the solar system. Data from Dawn's visible and infrared mapping spectrometer show an unusually high concentration of organic matter close to the 50-km-diameter Ernutet crater in the northern hemisphere of Ceres.

"The overall region is heavily cratered and appears to be ancient. However, the rims of Ernutet crater appear to be relatively fresh," Marchi said. "The organic-rich areas include carbonate and ammoniated species, which are clearly Ceres' endogenous material, making it unlikely that the organics arrived via an external impactor."

Ceres shows clear signatures of pervasive hydrothermal activity, aqueous alteration and fluid mobility, so the organic-rich areas may be the result of internal processes. Dawn scientists will continue to study the dwarf planet to identify a viable method for transporting such material from the interior to the surface in the pattern observed.

These findings appear in the paper "Localized aliphatic organic material on the surface of Ceres" published in the Feb. 17, 2017, edition of the journal Science.

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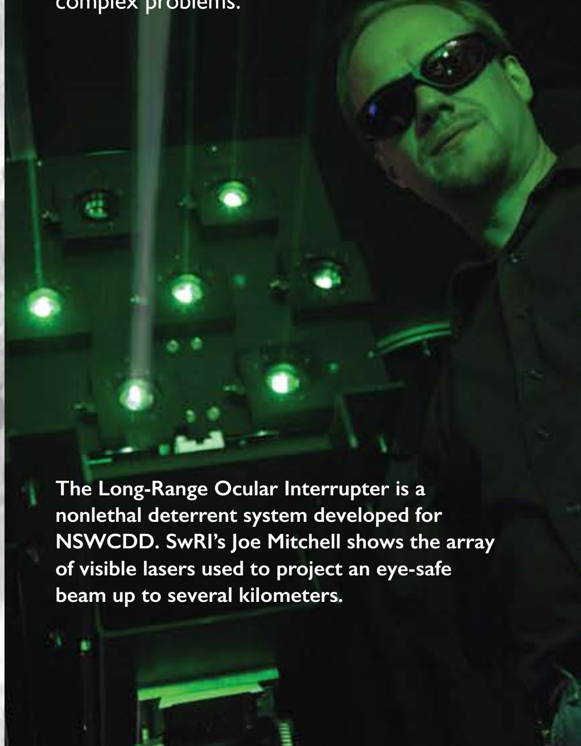
## $39 MILLION MILITARY CONTRACT

A contract valued at up to $39 million over the next five years will allow SwRI to continue to support the Naval Surface Warfare Center Dahlgren Division (NSWCDD).

"NSWCDD is an extremely important customer," said Errol Brigance, a director in SwRI's Applied Physics Division. "We have served this client over the past eight years and remain committed to providing effective technical solutions that meet contractual, schedule, and customer satisfaction requirements."

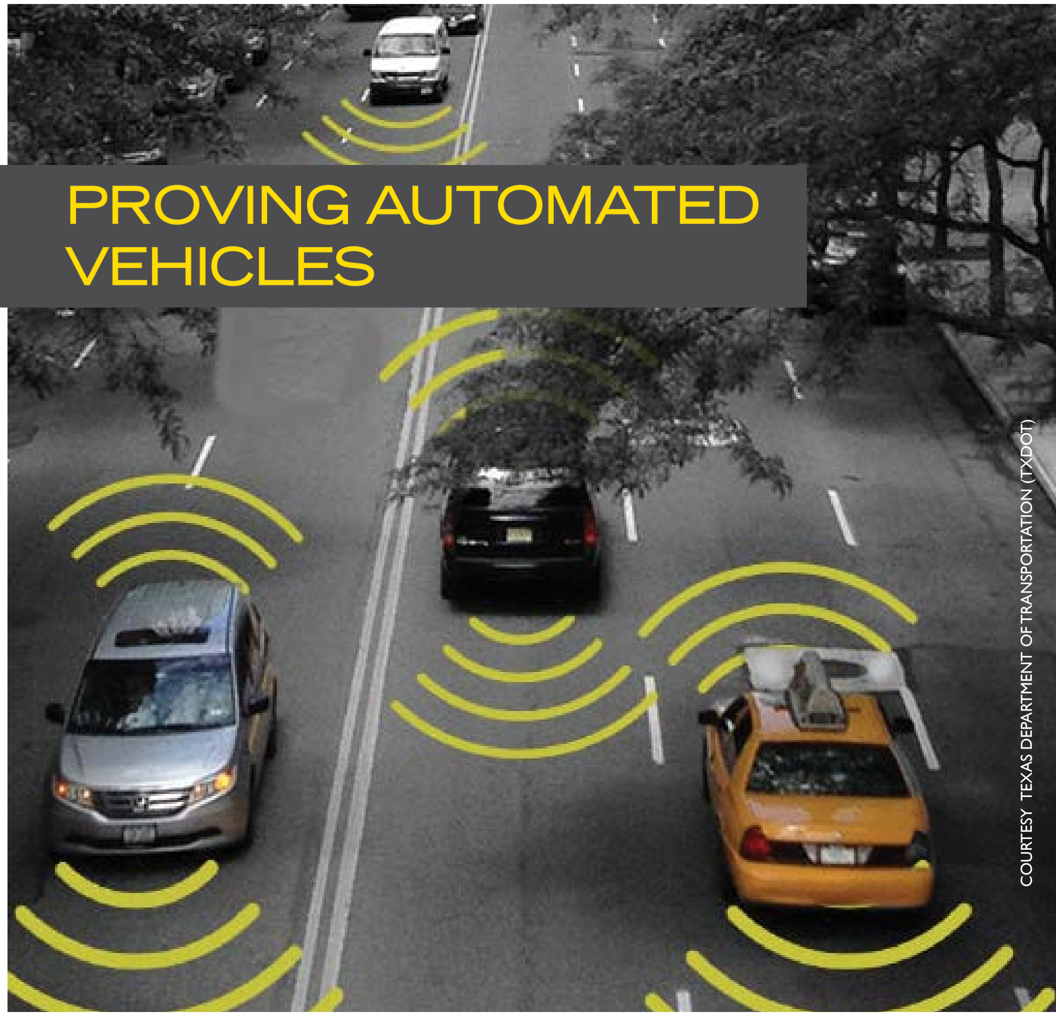
For example, previous developments include a device that projects an eye-safe laser beam up to several kilometers. SwRI also has developed biometric technology to collect various physiological characteristics and rapidly identify or screen individuals for comparisons to watch lists.

Staff members will perform research, development, technical, and test activities under this contract. SwRI will address emerging needs in tactical and non-tactical systems associated with homeland security, anti-terrorism, mission assurance, force protection, unmanned systems, and related programs. This indefinite delivery, indefinite quantity contract allows SwRI to provide flexible and innovative solutions to complex problems.



**The Long-Range Ocular Interrupter is a nonlethal deterrent system developed for NSWCDD. SwRI's Joe Mitchell shows the array of visible lasers used to project an eye-safe beam up to several kilometers.**

# PROVING AUTOMATED VEHICLES



COURTESY TEXAS DEPARTMENT OF TRANSPORTATION (TXDOT)

The Institute is a key member of an alliance that helped the U.S. Department of Transportation (USDOT) designate Texas a national proving ground for testing connected and automated vehicle technologies.

The Texas Automated Vehicle (AV) Proving Ground Partnership includes SwRI, the Texas Department of Transportation, Texas A&M Transportation Institute, The University of Texas at Austin's Center for Transportation Research, and 32 municipal and regional partners. The alliance has a shared interest in mobility and safety challenges related to connected vehicles on public roadways.

"We fully expect to see more automated driving capabilities on Texas roads in the next few years," said Dr. Steve Dellenback, vice president of SwRI's Intelligent Systems Division. "As these systems move out of laboratories like the ones at Southwest Research Institute, we want to ensure that our engineers are working closely with municipalities, transportation agencies, and universities to create the best infrastructure in terms of networks and roadways."

Selected from an applicant pool of more than 60, the Texas AV Proving Ground Partnership is one of 10 groups nationwide that will help USDOT advance safe automated vehicle technologies.

# SwRI BRINGS OUT ITS BIG GUN

A new 7,050-square-foot facility houses a two-stage light-gas launcher featuring a 38-mm-diameter launch tube (1.5 caliber) with the ability to achieve velocities close to 15,600 miles per hour. This hypervelocity launcher augments SwRI's capabilities in armor and anti-armor technology, impact and penetration events, and spacecraft protection from orbital debris. With sophisticated diagnostic and analysis tools, ballistics engineers can explore new designs and concepts for armor to protect land, sea, air, and space vehicles.

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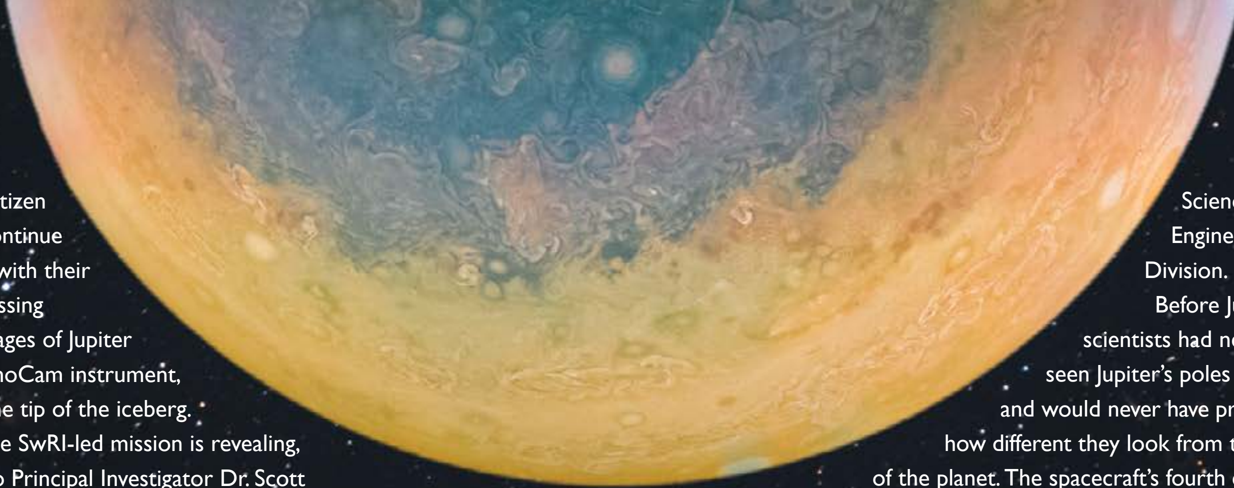

COURTESY NASA/C LEVITAN

# JUPITER SURPRISE

While citizen scientists continue to astound with their work processing stunning images of Jupiter from the JunoCam instrument, that's just the tip of the iceberg.

What the SwRI-led mission is revealing, according to Principal Investigator Dr. Scott Bolton, "is earth-shattering. Or should I say, Jupiter-shattering." Discoveries about its core, composition, and magnetosphere are revolutionizing what is known about Jupiter and giant planets in general.

"We don't know as much about the gas giants as we thought we did," continued Bolton, an associate vice president in SwRI's Space Science and Engineering Division.

Before Juno, scientists had never seen Jupiter's poles close up and would never have predicted how different they look from the rest of the planet. The spacecraft's fourth close encounter revealed again the bluish tinge of the Jovian south pole pictured above.

NASA recently concurred with the team to keep Juno in a 53-day orbit, and that's proving fortuitous. The longer orbit provides more data and unique geometries, supplying scientists with the information they need to better understand the surprises Juno has revealed.

## Multiphase Flow Facility Online

A new 5,460-square-foot facility will support the development and evaluation of turbomachinery exposed to multiphase flow conditions. The Multiphase Machinery Test Facility accommodates large-scale turbo-machinery and testing using a variety of fluids.

"This facility greatly expands our capabilities for evaluating machinery under a range of conditions," said David Ransom, who oversees SwRI propulsion and energy machinery programs. "We now can evaluate much larger equipment and perform tests with hydrocarbons in addition to inert fluids."

While built primarily to support the oil and gas industry, the facility can accommodate propulsion and other energy development and evaluation programs.

"We're currently testing natural gas foam for hydraulic fracturing research and evaluating compressor performance in wet gas conditions," Ransom said. "Wet gas compression system research is a growing area for the oil and gas industry."

The facility's 3,000-square-foot high bay includes a 10-ton bridge crane and a climate-controlled work space. An outside concrete pad accommodates fluid storage tanks. A separate building houses a control room, conference room, client office space, and other amenities.

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# CONNECTED AUTOMATION TO FUEL EFFICIENCY

An SwRI-led team will receive up to $2.9 million from the Department of Energy to develop connected and automated vehicle technologies aimed at improving vehicle fuel economy by more than 20 percent.

The three-year project, "Model Predictive Control for Energy-Efficient Maneuvering of Connected and Automated Vehicles," calls for the team to develop optimal control algorithms for a plug-in hybrid vehicle. The project will leverage vehicle-to-vehicle, vehicle-to-infrastructure, and other vehicle- to-everything technologies to optimize the vehicle's route, speed profile, and power flows from the hybrid system. These developments could help define future powertrain performance requirements and enable more efficient control of powertrain and vehicle dynamics.

"This is an important research step in furthering the development of powertrains for connected and automated vehicles," said Scott Hotz, who heads SwRI's Ann Arbor, Mich., office. "Our team's collective expertise in vehicle powertrain development and connected and automated vehicle technologies will help optimize vehicle efficiency."

To improve fuel efficiency, the team will develop and integrate components that assist in automated eco-driving, informing the vehicle about approaching traffic signals, preferred routes, and optimal vehicle speed profiles. Given this connected "look ahead" at conditions, SwRI engineers will optimize powertrain operation to achieve the goal of 20 percent improvement in fuel economy.

The project is part of NEXTCAR, a DOE Advanced Research Projects Agency–Energy program.

# SwRI Flips LAMP Switch

An SwRI team successfully opened a "fail-safe" door on the Lyman-Alpha Mapping Project (LAMP) instrument in lunar orbit, improving the quality of ultraviolet (UV) data it collects. The door, one of LAMP's few moving parts, operated flawlessly even after orbiting the moon for seven years onboard NASA's Lunar Reconnaissance Orbiter (LRO). The new configuration provides LAMP more UV exposure for LRO's extended mission.

"Opening this door gives us six times better quality data when mapping the lunar dayside," said SwRI's Dr. Kurt Retherford, principal investigator of LAMP. Lyman-alpha emissions are produced by nearby space and stars and bathe all bodies in a soft glow of UV light. UV frequencies are invisible to human eyes and cameras, but visible to LAMP as they reflect off the moon. On the nightside, LAMP "sees" the moon's surface using this soft UV glow. On the dayside, LAMP measures light reflected from the Sun as well.

LAMP discovered water frost in the permanently shaded craters near the lunar south pole and collected evidence that a surprising number of water molecules travel across the dayside surface of the moon. It is these dayside measurements that are most affected by the new operating parameters. Prior to opening the fail-safe door, scientists averaged the data collected over multiple orbits to characterize the dayside surface.

"The amount of water measured appears to be influenced by the time of day," said SwRI's Dr. Kathleen Mandt. "In this new mode, we will get much higher resolution data from every orbit, allowing us to see how water on the surface increases and decreases over shorter time periods than before."

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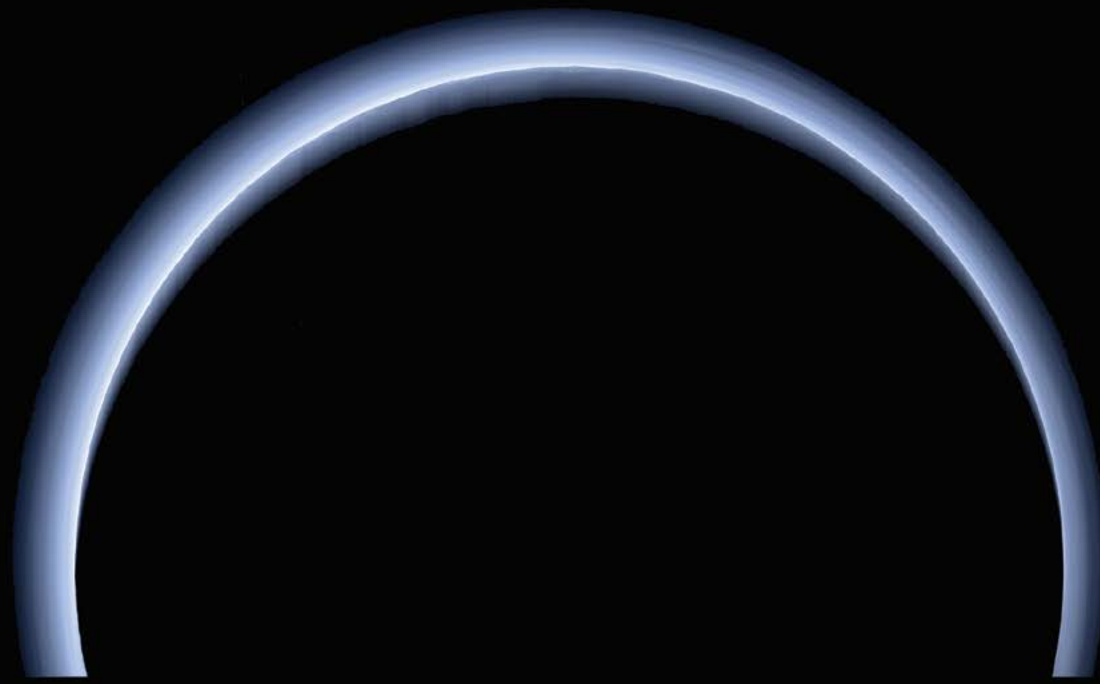
Dr. Kathleen Mandt shows the fail-safe door (outlined by rectangle), located below the regular aperture door (circled) on an engineering model of the LAMP instrument.

COURTESY NASA/GSFC/ARIZONA STATE UNIVERSITY PLUTO COURTESY NASA/JOHNS HOPKINS UNIVERSITY/APL/SwRI



# Blue Skies Over Pluto

Although NASA's New Horizons spacecraft bid Pluto farewell in July 2015, scientists are still mining the data from the historic flyby. SwRI's Dr. Alex Parker and Dr. Tod Lauer of the National Optical Astronomy Observatory painstakingly combined two types of image data to create this silhouette, which shows a halo of blue haze with 20 distinct layers reaching about 125 miles above the dwarf planet's surface.

Backlit by the Sun, the scientists compiled this hi-res color shot of Pluto from 120,000 miles (200,000 kilometers) away, three and a half hours after closest encounter. Shown in approximate true color, Parker and Lauer constructed the image from a mosaic of six black-and-white images from the Long Range Reconnaissance Imager, adding color data from the lower-res Ralph/Multispectral Visible Imaging Camera.

"Pluto's haze appears blue for similar reasons to the Earth's skies," Parker said. "Small particles in the atmosphere scatter light with short wavelengths more efficiently than light with long wavelengths, resulting in a blue appearance. In Earth's skies, it is the molecular oxygen and nitrogen that are responsible for this effect; in Pluto's, it is small particulates possibly made through the action of solar ultraviolet light on atmospheric methane."

As they settle down through the atmosphere, the haze particles separate into intricate, horizontal layers, some extending for hundreds of miles around large portions of the limb of Pluto. The haze layers extend to altitudes of over 120 miles (200 kilometers).

"If you look closely near the top of the image, you can also see the rugged landscape of Pluto in sharp relief against the hazes," Parker said. "You can also see the shadows cast by mountains onto the haze, and beams of sunlight passing through valleys illuminating the haze. These are reminiscent of features you would see in a spectacular earthly sunset."

New Horizons is now off to buzz past another alien world in the Kuiper Belt, due to encounter 2014 MU69 — a tiny, dim, frozen world discovered by an SwRI team in 2014 — on Jan. 1, 2019.

## BY THE NUMBERS
October 2016 – March 2017

151

presentations given in

13 states

and 9 COUNTRIES

58 articles published in

31 DIFFERENT PUBLICATIONS

24 patents awarded

**Southwest Research Institute** was named the 2016 Business of the Year by the San Antonio Business Journal. The paper cited "SwRI's varied industry-changing research and long record of success" as the impetus for the award.

**Southwest Research Institute** has received the 2017 Work-Life Seal of Distinction from WorldatWork, an international nonprofit human resources association. SwRI is one of 160 employers from 36 states, the District of Columbia, and Canada honored for its outstanding approach to employee engagement and commitment to the well-being of its workforce.

The **Juno Mission team** — led by Dr. Scott Bolton, associate vice president of the Space Science and Engineering Division — received the Nelson B. Jackson Award from the National Space Club and Foundation. The award, which recognizes significant contributions to the field of space, was presented at the 60th Annual Robert H. Goddard Memorial Dinner in Washington, D.C.

The **Canyon Lake Gorge Preservation Society** has recognized SwRI as a Lifetime Member. SwRI researchers have published more than a dozen journal articles about the site's geological structures and used the site to train hundreds of oil and gas personnel to recognize geology relevant to energy exploration.

## AWARDS

**Maria Araujo** and **Dr. Maher Dayeh** were named to the San Antonio Business Journal's "40 Under 40" list of rising stars in San Antonio. Araujo, a manager in the Intelligent Systems Division, leads a team of engineers and analysts developing flight software, smart grid energy systems, and sensor systems. She is currently developing smart technology to locate leaks in oil and gas pipelines. Dayeh, a senior research scientist in the Space Science and Engineering Division, serves as control account manager for flight software development for two missions to Jupiter's moons. He is credited with producing the first images of thunder.

**Dr. Steve Dellenback**, PMP, vice president of the Intelligent Systems Division, received the 2016 SAE International Delco Electronics Intelligent Transportation Systems Award at WCX17 in Detroit. Dellenback was recognized for his "exceptional work as a leader in the design, development, and deployment of Intelligent Transportation Systems."

**Walter D. Downing**, SwRI executive vice president and chief operating officer, has been elected chairman of BioMed SA, a nonprofit organization that promotes the local biomedical industry. Downing has been a member of the BioMed SA board since 2012.

**Dr. Ben Thacker**, director of SwRI's Materials Engineering Department, has been named a Fellow of the American Institute of Aeronautics and Astronautics (AIAA). Thacker was cited "for exceptional leadership and technical contributions in probabilistic analysis, uncertainty quantification and model validation."

**Dr. William Bottke**, director of the Space Studies Department, spoke about "Early Solar System Bombardment: Exploring the Echoes of Planetary Migration and Lost Ice Giants" as the Kavli Foundation Plenary Lecture at the 229th meeting of the American Astronomical Society (AAS) in Grapevine, Texas.

**Scott Hutzler,** a manager in the Fuels and Lubricants Research Division, received an "Award of Appreciation" from the ASTM International Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants at its annual meeting in Orlando, Fla.

## TRADE SHOWS

Offshore Technology Conference, Houston; May 1-4, 2017, Booth No. 2301

Xponential, Dallas; May 8-11, 2017
Booth No. 424

ISHM, Oklahoma City; May 16-18, 2017

InformEx & CPhI North America, Philadelphia; May 16-18, 2017, Booth No. 1341

Valve World Americas Expo & Conference, Houston; June 20-21, 2017, Booth No. 3

IFT Food Expo; Las Vegas, June 25-28, 2017
Booth No. 4939

ASME Turbo Expo, Charlotte, NC; June 26-30, 2017, Booth No. 512

Sensors Expo & Conference, San Jose, CA; June 27-29, 2017, Booth No. 1240

44th Annual Meeting & Exposition of the Controlled Release Society, Boston;
July 16-19, 2017

31st Annual AIAA/USU Small Satellite Conference, Logan, Utah; August 5-10, 2017
Booth No. 57-58

Specialty & Agro Chemicals America, Charleston, SC; September 6-8, 2017

IASH Symposium, Rome, Italy;
September 10-14, 2017

46th Turbomachinery Symposium & 33rd International Pump Users, Houston;
September 11-14, 2017, Booth No. 2726

American School of Gas Measurement Technology (ASGMT), Houston;
September 18-21, 2017

World Congress on Intelligent Transportation Systems, Montreal, Canada;
October 29 - November 2, 2017

ASNT Annual Meeting, Nashville, TN;
October 30 - November 2, 2017
Booth No. 1027

ASIP Conference, Jacksonville, FL;
November 27-30, 2017, Booth No. 17

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