SOUTHWEST RESEARCH INSTITUTE®

SUMMER 2023

TECHNOLOGY TODAY®

THE GREEN ISSUE

SwRI is installing this single-piece, high-speed turbine rotor in the Supercritical Transformational Electric Power (STEP) pilot plant on its grounds. Fabricated and assembled into its turbine case, the rotor is a key component of the system that will demonstrate and validate supercritical carbon dioxide (sCO_2) power plant performance at the 10 MWe scale. Replacing steam with sCO_2 as the working medium will increase the efficiency and modularity of thermal power systems. See related story on p. 14.

D026110

FROM ARPA-E TO PROJECT Z

This special issue of Technology Today recognizes that we find ourselves in a time that is both daunting and exhilarating. Just a few moments dedicated to watching or reading the news reveal the immense challenges we face in the areas of energy sustainability and decarbonization. Concerns about the future of our environment, ecosystems and human well-being are pervasive.

Nevertheless, within this crisis lies an extraordinary opportunity for research and development. SwRI is committed to “green” research, delving into renewable energy sources, water conservation, greenhouse gas detection and waste reduction. Our multidisciplinary resources empower SwRI scientists and engineers to innovate in various relevant fields. At the 2021 United Nations climate conference (COP 26), esteemed nature documentarian Sir David Attenborough remarked, “If working apart we are a force powerful enough to destabilize our planet, surely working together we are powerful enough to save it.”

SwRI has a long history in green research. Today, our work encompasses everything from early-stage technology development to extracting drinking water from the air after natural disasters to the creation of low-carbon fuels. With the federal government increasing its investments in greener technologies, SwRI is well positioned to leverage these programs and pioneer new areas of innovation.

While many of these innovations have global implications, SwRI has also brought solutions closer to home, benefiting the more than 2,700 employees residing in the greater San Antonio area. Our researchers have investigated the sources of various pollutants that degrade local air quality and impact the respiratory health of our families, friends and neighbors. This work has involved multiple helicopter flights over the San Antonio area, utilizing SwRI-developed technology to identify pollutant sources. We are also engaged in ongoing endeavors to improve urban heat island management, enhance plastics recycling and advance electric vehicle battery safety, all aimed at benefiting the city with potential to scale up for deployment in the state, across the country and even around the world. Additionally, our staff members are exploring ways to apply our green research experience to positively impact our campus through reduced water usage, energy savings and emissions reductions.

This issue of Technology Today highlights a range of ongoing initiatives at SwRI that aim to enhance global sustainability. Our work spans from exploring deep geothermal wells to electrifying large-scale vehicles used worldwide. While this issue offers only a glimpse into the multitude of projects undertaken by SwRI, it underscores our comprehensive and profound approach to solving some of the world’s most challenging problems.

Although the reality of today’s challenges can be alarming, the potential for research and development to address it is equally inspiring. Through innovation, technological breakthroughs and transformative changes in various research areas, we have the capacity to change the world, foster resilience and create a more sustainable future.

— Shane Siebenaler, *Director of SwRI Fluids Engineering Department who participates in an ad hoc SwRI working group on sustainable technologies*

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TECHNOLOGY TODAY

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IN THIS ISSUE

As our nation experiences record-setting heat waves and other extreme climate events, having the Summer 2023 issue of Technology Today focus on low-carbon energy and mobility solutions is timely. These solutions literally range from A to Z, as we conduct ARPA–E research into novel eco-mobility strategies and Project Z, which applies internal funding to explore using SwRI as a comprehensive testbed for net-zero emissions strategies.

The issue also features the big challenges — and potentially big impacts — associated with electrifying heavy equipment such as mining trucks, as well as possibilities for tapping geothermal energy to transition away from fossil fuels. SwRI also recently made a groundbreaking achievement, attaining supercritical energy operations for the first time in its 10-megawatt demonstration plant, laying the groundwork for power generation that is more efficient with a smaller footprint.

However, nearly every issue of Technology Today includes stories about how Southwest Research Institute is working to create clean, green solutions to today's vexing problems. For instance, the Summer 2022 issue included a feature about "A Chemical Solution to Plastic Pollution," addressing the 90% of plastics ending up in oceans and landfills due to recycling challenges.

The Spring 2022 cover story explored "Hydrogen and a Carbon-Neutral Future," particularly five opportunities SwRI is investigating. The article explored how to transition away from fossil fuels to a hydrogen economy, researching hydrogen generation and distribution, transportation and energy applications as well as safety issues associated with applying this clean, carbon-free combustion fuel.

The Summer 2021 issue included a listicle about "Six Power Plant- and Grid-Scale Storage Solutions," looking at a variety of technologies to help make the most of the energy resource mix, particularly renewables such as wind and solar power, which can fluctuate depending on the time of day and weather.

For most of its 75 years, SwRI has been a pioneer in energy, environmental and emissions research, critical experience and expertise needed to solve the challenges of the future. And this year, as this issue of Technology Today shows, is no different.

Sincerely,

Walter D. Downing

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

Advancing Eco-mobility

ARPA-E NEXTCAR program seeks 30% reduction in energy consumption

By Sankar Rengarajan, Michael Brown and Scott Hotz

While the transportation sector is the single largest source of greenhouse gases in the U.S., the fundamental efficiency of today's vehicles is quite high, offering significantly reduced emissions. Since model year 2004, CO_2 emissions have decreased by 25% and fuel economy has increased by 32%. These advances make it incredibly difficult to achieve significant progress using conventional vehicle efficiency improvements. Incrementally modifying components and control systems typically ekes out 1–2% improvements at costs often in the millions of dollars.

However, recent rapid advances in driver assistance technologies and vehicles with increased levels of connectivity and automation have created opportunities to improve the efficiency of future vehicle fleets in radically new ways. The initial ARPA–E's NEXTCAR Program had an ambitious target: To create enabling technology to reduce the energy consumption of a plug-in hybrid electric vehicle (PHEV) by an astounding 20% without changing the powertrain or compromising emissions, safety or drivability.

In 2017, a Southwest Research Institute-led team received a three-year contract from the Department of Energy to develop model-predictive control for energy-efficient maneuvering of connected and automated vehicles. The project's goal was to provide control algorithms leveraging vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) technologies to simultaneously optimize the route, speed profile and power flows of a hybrid vehicle. The project sought to define future powertrain performance requirements and enable more efficient control of the powertrain and vehicle dynamics.

DETAIL

The Department of Energy modeled the Advanced Research Projects Agency–Energy (ARPA–E) after the Department of Defense's Defense Advanced Research Projects Agency (DARPA). ARPA–E's NEXTCAR Program is short for "NEXT-Generation Energy Technologies for Connected and Automated On-Road Vehicles." ARPA–E funds emerging high-potential, high-impact energy technology projects to prepare for commercial investment.

ABOUT THE AUTHORS: From left, Sankar Rengarajan, manager of the Powertrain Engineering Division's Model-Based Control Section, specializes in dynamic systems and controls, particularly in energy efficiency and emission control applications. Michael Brown, an Institute engineer in SwRI's Intelligent Systems Division, has served various federal, state and commercial clients in projects ranging from advanced traffic management and traveler information systems to connected and automated vehicles and smart cities. Scott Hotz, director of the Powertrain Engineering Division's Control Systems Department, specializes in custom solutions through model-based control algorithms, embedded systems and electronics.

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Phase II of SwRI's ARPA–E NEXTCAR project seeks to increase energy savings to greater than 30% using Level 4 automation technologies, such as lidar and SwRI's patented Ranger localization technology.

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ECO-DRIVING

SwRI was particularly well positioned to conduct the program, with multidisciplinary expertise in vehicle powertrain development and connected and automated vehicle technologies. For most of SwRI's 75 years, automotive engineers have designed, developed and analyzed components, transmissions, engines and vehicles for efficiency and performance. Specialists also support research and modeling for fuel mixing, combustion, filtration and fluid flow analysis. As a pioneer in measuring vehicle exhaust emissions, the Institute continues to raise the bar with new methodologies of characterizing engine exhaust constituents.

SwRI also has over 25 years of experience developing and deploying advanced intelligent transportation and traffic management technologies to create safer, more coordinated and more efficient transportation networks. These smart technologies include a range of connected and automated vehicle applications that are now being applied to efficiency efforts.

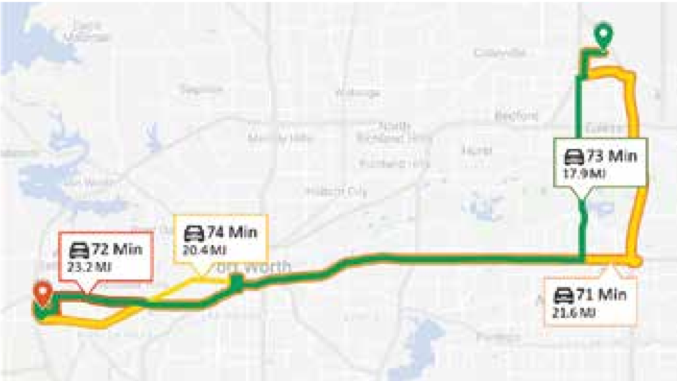
SwRI's NEXTCAR team developed and integrated components to assist in eco-driving — avoiding unnecessary stopping and minimizing acceleration that wastes energy — as well as instituting preferred routes and optimal vehicle speed profiles. Given this connected "look-ahead" preview of conditions, engineers also optimized powertrain operation in pursuit of a 20% improvement in energy economy.

Onboard sensing combined with data from V2V, V2I and V2X technologies provided the information needed to predict driving environments and develop new technologies and algorithms. Vehicle connectivity and automation were already improving vehicle safety and driver convenience. For this program, the team tapped into those existing data streams and put the information to use to improve vehicle efficiency. The team integrated these tools to develop next-generation vehicle dynamics and powertrain control software, designed to proactively use "look-ahead" information to anticipate vehicle power demand.

ECO-TOOLS

The new tools developed to meet these efficiency goals include eco-routing, eco-driving and power-split optimization.

SwRI refers to its eco-routing tool in development as "Google® Maps with energy." Using a mapping tool like Google Maps, drivers



SwRI-developed tools use roadway connectivity data to find the most eco-friendly route to a destination. While the average driver will save fuel by using these routes, heavy-duty truck fleets will realize the greatest energy savings.

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can set their destinations and see routes that may add a couple of minutes to their arrival but are more fuel-efficient. While the technology is appealing to the eco-minded consumer, for delivery and service fleets, this 5–10% savings in fuel consumption can add up to millions of dollars in savings each year while cutting carbon emissions.

Eco-driving uses information from neighboring vehicles to minimize braking and accelerations.

Hybrid-electric vehicles need an energy management system optimized to ensure good fuel economy while maintaining battery state-of-charge, controlling the power split between the engine and the electrical motor. Optimal power split scenarios depend on the driving cycle, initial state-of-charge and trip length. SwRI's power-split optimization tool uses knowledge of routes and speeds to optimize battery and engine operations to efficiently meet power demands.

SwRI engineers used internal funding to deploy the eco-driving technology in a mobile driver advisory application that runs on regular smart phones or tablets. The driver advisory app connects with traffic lights and roadway infrastructure to "see" up to half a kilometer ahead and alert drivers to drive more efficiently. For example, if the app senses a traffic light ahead, it will advise the driver to speed up or slow down by a few miles per hour to avoid stopping. For heavy-duty trucks, making a full stop at a red light and re-engaging the engine when the light turns green is a significant source of fuel consumption.

These app-based tools can be used in any on-road vehicle. Based on their success, the SwRI team collaborated with regulatory and commercial organizations, working to commercialize the new tools.

D025356_3152

SwRI developed an eco-mobility app that uses roadway connectivity data to advise drivers to speed up or slow down to avoid red lights. Significantly more energy is required to accelerate vehicles, particularly heavy-duty trucks, after making a full stop at lights.

DETAIL

Smart traffic lights improve intersection safety and efficiency, using data from sensors, cameras, GPS, vehicles, cell phones and other devices to detect traffic patterns and volume as well as pedestrians and bicyclists approaching an intersection.

D026088

Located in SwRI's Ann Arbor, Michigan facility, SwRI's connected and automated vehicle chassis dynamometer runs a vehicle in response to traffic data. A data acquisition system collects relevant operating data to determine the efficiency improvements.

DETAIL

A dynamometer or "dyno" is a laboratory test fixture that creates a load to duplicate various speed and torque requirements. The resulting data is used to calculate power.

D0261242

SwRI's connected and automated vehicle chassis dynamometer uses traffic simulation software to evaluate eco-mobility tools.

Separately, the U.S. Department of Energy funded a project to investigate the benefits of using connected and automated vehicle (CAV) technology with different types of vehicles, as well as evaluating the impact of smart infrastructure solutions like intelligent intersections as part of the Energy Efficient Mobility Systems initiative.

To support these developments, the team built a connected and automated vehicle chassis dynamometer to measure speed and torque to understand power. The dyno uses traffic simulation software to provide a controllable, repeatable environment to test the new technologies. The team calibrated the software using real-world data to simulate various cities, including San Antonio, Fort Worth, and Columbus, Ohio. The simulations proved critical for evaluating control algorithms and accurately quantifying energy consumption.

In 2021, SwRI received an R&D 100 award, recognizing its NEXTCAR work as one of the most significant innovations of the year by R&D Magazine.

ECO-II

Based on the success of Phase I, achieving more than 20% efficiency improvement, SwRI was awarded a three-year follow-on contract in 2021. This phase continues development of SwRI's cutting-edge connected and automated vehicle technologies to improve passenger vehicle efficiency and reduce carbon emissions, shooting for an increased 30% reduction in energy consumption. SwRI will integrate its technologies into a vehicle with Level 4 automation, which gives vehicles the ability to perform all driving operations on their own with optional human override.

In the second phase, SwRI is building on those technologies and expanding its predictive eco-routing, eco-driving and hybrid power control strategies. The eco-driving feature focused on longitudinal dynamics control and contributed about 10% of the energy savings. The algorithm helped the human driver make smarter decisions based on localized traffic knowledge through V2X connectivity and communication. The advanced perception and actuation precision of a Level 4 automated vehicle over a human driver allowed SwRI to expand the eco-driving framework to optimize for multilane dynamics and further reduce energy consumption.

The team discovered that the connected and advanced driving assistance systems that make cars safer and easier to drive can also make them much more efficient, using less power and saving drivers money at the pump. These technologies are a win-win for drivers and can lead to a cleaner transportation sector and rapid progress toward a carbon-free future.

D026105

The second phase of SwRI's NEXTCAR project builds on the success of eco-routing, eco-driving and power-split optimization, expanding to explore cooperative control, smart lane change/ merge and dedicated connected and automated vehicle (CAV) operations.

ECO-DEMONSTRATION

As Phase II progressed, SwRI focused on infrastructure and simulation studies and demonstrated the technology using the CAV chassis dynamometer and specialized test tracks. SwRI's technology suite, which is midway through its second development phase, has seen significant progress.

SwRI has made advancements in building a Level 4 autonomous vehicle, fusing widely adopted sensing technologies, such as lidar, with SwRI's patented Ranger localization technology. This technology maintains vehicle position within 2 centimeters, in contrast to GPS measurements, which can vary by several meters. The automation stack integrates with SwRI's drive-by-wire system, which uses electrical systems to replace mechanical braking and steering systems with minimal modifications to a vehicle.

DETAIL

Lidar, an acronym for "laser imaging, detection and ranging," determines distance, targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver.

Extensive testing on SwRI's virtual-traffic-enabled test track simulated real-world scenarios to evaluate technology performance. Engineers also tested vehicles traveling together in a synchronized formation or "platoon," validating computational fluid dynamics models for cooperative platoon formation. Through these tests, the team demonstrated how synchronized driving could optimize efficiency and how CAV technologies can help passenger vehicles operate more efficiently.

Currently, the SwRI team is seeking avenues to pilot the technology in real-world conditions and collaborating with fleet original equipment manufacturers and suppliers to help bring the technology to market. The "Eco-Mobility with Connected Powertrains" technology suite and the Phase II developments are available to license.

These technologies have the potential to revolutionize the transportation sector, reducing its carbon footprint through energy consumption and emissions reduction capabilities, while making roads safer and more efficient. By working together with industry, the SwRI team can make a significant contribution toward the development of sustainable transportation systems.

Questions about this story? Contact Brown at michael.brown@swri.org or (210) 522-3104, or Hotz at scott.hotz@swri.org or (210) 269-5252.

SwRI conducted extensive testing of its NEXTCAR applications on its virtual-traffic-enabled test track, simulating real-world scenarios to evaluate technology performance.

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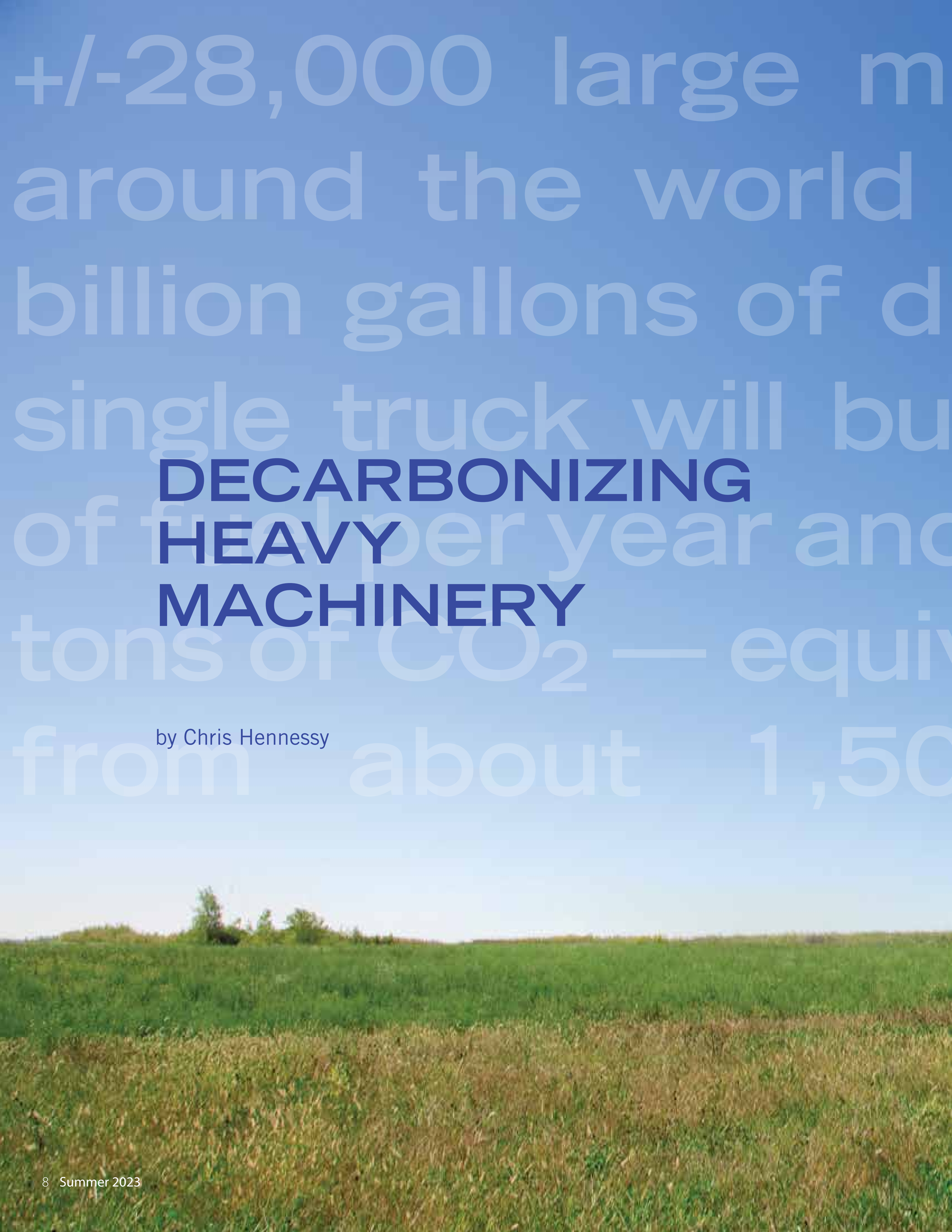


DECARBONIZING HEAVY MACHINERY

by Chris Hennessy


ine hauling trucks
consume over six
iesel every year. A
rn 250,000 gallons
d emit around 2,430
valent to emissions
00 Prius hybrids.

SwRI teams compared electrified cargo-handling equipment, such as this hybrid-electric gantry crane, to their diesel-hydraulic counterparts for CARB's near-zero freight initiative.

D026140

The transportation sector generates the largest share of green-house gas emissions in the United States, primarily from burning fossil fuels for cars, trucks, ships, trains and planes.

To combat this, the passenger vehicle industry is seeing explosive growth in electrified powertrains. Congressional incentives to build in North America are driving new manufacturing facilities and charging infrastructure.

Electric powertrains offer several operational advantages over traditional powertrains, but they also present several unique challenges, notably a steep sticker price and what's known as range anxiety — concern that an EV will run out of power before reaching its destination or a suitable charging point.

But what about heavy-duty vehicles? These large trucks and heavy equipment offer perhaps even greater carbon reduction opportunities while facing the same challenges in price and range, but at a larger scale.

Consider that about 28,000 large mine hauling trucks around the world consume over six billion gallons of diesel every year. Together, these mining trucks emit 68 million tons of carbon dioxide (CO_2) annually, roughly equaling the total greenhouse gas footprint of Finland or New Zealand. A single truck could burn 250,000 gallons of fuel per year and could not only produce more than 2,400 tons of CO_2 — compared to about 1,500 Prius hybrids — but also emit pollutants such as NOx and ultrafine particulates.

Market pressures are driving the heavy machinery industry, which includes rail and marine applications, toward net-zero emissions goals. Consumer product companies have set goals to reach zero emissions by 2050, which is cascading expectations to the entire supply chain, including the raw materials market. Regulatory and financial sectors are driving investor-led initiatives to characterize and support corporate actions to combat climate change, so investors know they are supporting greenhouse gas reductions. For example, the Securities and Exchange Commission has launched a task force to regulate the standardization of climate-related disclosures.

Southwest Research Institute has more than 40 years of experience developing clean emissions strategies for diesel engines, mainly pursuing technology to allow vehicles to meet regulatory goals. Today, market forces are driving new initiatives, and regulatory entities have enlisted SwRI to evaluate the availability and readiness of technology to meet those demands.

SwRI used dataloggers to monitor this electric side pick cargo handler. The project collected almost a million rows of data each day for analysis to help a commercial client optimize its electrification plans for freight equipment.

D026106

DETAIL

Data loggers are electronic devices that automatically monitor and record operational parameters over time, allowing conditions to be measured, documented, analyzed and validated. Sensors detect information, which is stored on a computer for analysis.

CARGO HANDLERS

SwRI worked on the California Air Resources Board Zero and Near-Zero Emission Freight Facility program at BNSF San Bernadino Intermodal Railyard. Over six months, the team studied the electrification of drayage trucks, forklifts, gantry cranes and locomotives, evaluating them side-by-side with their diesel engine counterpart, to determine how effectively they moved freight.

SwRI used data loggers to monitor a battery-electric locomotive, a hybrid crane, an electric side pick cargo handler and an electric Class 8 drayage truck, as well as their conventional diesel-powered counterparts. Data collected included energy consumption, refueling/recharging times, peak electricity rates and missions for the diesel-powered equipment. At the project's peak, 10 dataloggers generated almost one million rows of data each day. SwRI's data analytics software then distilled relevant information to help a commercial client optimize their electrification plans for cargo-handling equipment in California.

Recharge time is also a critical operational constraint for cargo handling equipment because most of these systems operate 24/7. Having to take systems offline and move to charging stations affects freight efficiency.

MINING ELECTRIFICATION

The challenge is the same for electrifying equipment for mining operations, on a much larger scale. Mining trucks and locomotives are propelled by electric

Mine hauling trucks are enormous, measuring up to 65 feet long and weighing about 500 tons, some 260 times heavier than a passenger car.

D026082

traction motors. SwRI is studying the effectiveness of replacing the diesel engine coupled to a generator to provide electricity via batteries. The mining industry is increasing its investment in high-efficiency energy conversion and electrification, realizing more efficient operations burn less fuel and produce fewer emissions. Companies are analyzing different value propositions and what types of electrification make sense, creating a net benefit to the operations.

The usage, lifecycle and safety requirements of mining trucks are very different from passenger cars based on size alone. The scale of these vehicles to the typical EV creates very different operational demands. The largest dump trucks are over 65 feet long and can haul 450 tons of materials in a load at a fuel efficiency of 5.5 gallons of diesel per mile. They weigh 500 tons, some 260 times heavier than a passenger car.

The failure mode of a piece of equipment that costs more than $5 million is also quite different than the failure profile of a passenger car, which focuses on passenger safety over preserving the capital equipment investment.

ENABLING TECHNOLOGIES

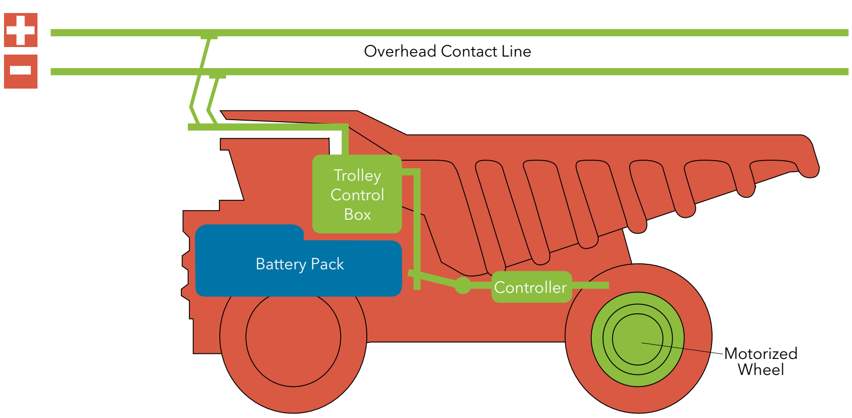
To recoup the significant capital costs for mining equipment, operations must run 24 hours a day. SwRI is studying the various business models addressing how to cost-effectively electrify these monster trucks. For instance, downtime for recharging results in a 70% efficiency penalty. However, swapping out batteries results in a value proposition better than its diesel engine counterpart.

Future solutions under evaluation include the integration of "trolley" lines. When delivering raw ore to a locomotive or a ship, mining vehicles traverse a regular route, offering the possibility of charging batteries dynamically as they haul materials. Installing electric charging lines into the infrastructure allows an enterprise to increase these value propositions by continuously operating 24/7 through dynamic charging, eliminating downtime and range anxiety.

BATTERY TESTING

Engineers consider critical situations on a massive scale, including unique usage, lifecycle and safety requirements. Electric batteries for heavy-duty machinery must meet rigorous demands and extreme safety requirements to enable sustainable operations. Key operational and lifecycle parameters include 15 times the power and 20 times the energy requirement of passenger car applications. Mining trucks encounter comparatively much greater mechanical abuse, shock and vibration than a typical passenger vehicle experiences during a drive to work.

Researchers analyzed electrical abuse associated with large power demands and the thermal profile created while delivering megawatts of power over many hours. When heat builds, thermal stresses can lead to battery failures. SwRI is using internal



To electrify giant mining machinery, SwRI considered adding trolley lines to selected segments of the delivery route to charge onboard battery packs while trucks are in service, allowing the haulers to operate 24/7.

D026125

D023631

Fire specialists expose fully charged electric vehicle batteries to gasoline pool fires.

CHEDE
CLEAN HYBRID ELECTRIC DIESEL ENGINES
A Consortium of SwRI

For more than 28 years, SwRI has led the industry's longest running diesel research consortium, the Clean Hybrid Electric Diesel Engine (CHEDE-8). The joint industry program pursues the world's most efficient powertrain solutions to meet the needs of the industry 10-plus years into the future. The current program includes a focus on hybrid heavy-duty diesel engines and developing technologies to exceed future fuel economy and emissions regulations through electrified powertrains. Off-road and vocational applications offer significant opportunities to maximize the use of high-power density engines with highly efficient motor and battery systems.

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Comprehensive test facilities allow all battery mechanical, electrical, thermal and performance testing to be conducted in-house at a single location.

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SwRI battery test facilities include altitude chambers.

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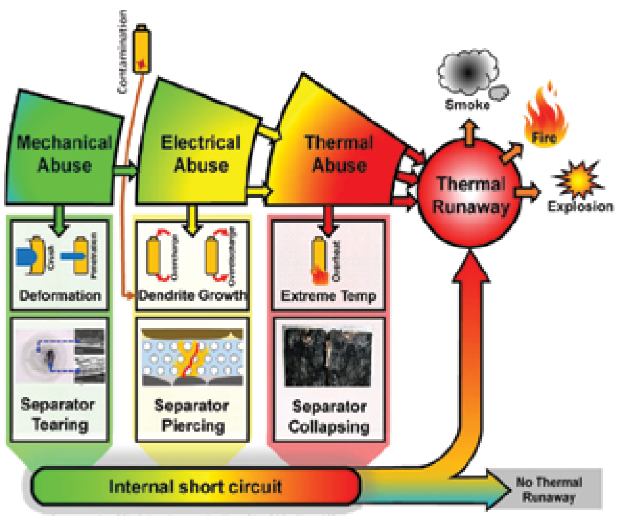


SwRI has developed test setups to evaluate and characterize mechanical, electrical and thermal abuse for battery technology.

D017976_3073

Shaker tables allow SwRI to assess the exceptional vibration that batteries for large mining vehicles would experience.

D021749_6318

SwRI developed equipment to crush test whole battery packs (pictured) as well as fixtures to crush test individual cells.

research funding to understand these critical failure modes, developing techniques to simulate and physically test thermal, structural and crash failures.

SwRI has invested a tremendous amount of capital in its battery test laboratory. The facility can simulate multiple environments, altitudes, and shake and vibration scenarios. To address battery safety, engineers have designed tests to evaluate different materials between the cells, evaluating both the structural and energy propagation effects through the pack, as well as how heat propagates between cells. If a battery cell fails, it's important to develop techniques to limit the impact on the rest of the vehicle.

In SwRI's fire technology facilities, a complete vehicle battery pack can be immersed in flames to identify its point of failure. Structural deformation, such as could occur in a crash, can be simulated at crush test facilities for individual cells and full packs. SwRI ballistics experts evaluate battery response to projectiles impinging the pack and how to mitigate damage in these scenarios. Electromagnetic interference and compatibility are evaluated in SwRI anechoic chambers.

SwRI's multidisciplinary expertise brings fresh perspectives and a range of capabilities to develop innovative EV solutions. The Institute remains committed to helping the heavy equipment industry find creative, cost-effective techniques to reduce fuel usage, while generating fewer exhaust emissions.

Questions about this story? Contact Hennessy at chris.hennessy@swri.org or (210) 522-3079.

ABOUT THE AUTHOR: Chris Hennessy directs the Powertrain Design and Development Department. He has over 25 years of experience in research, advanced concepts, development, validation and certification of powertrain systems for the light- and heavy-duty markets.

D026005_9934

STEP DEMO PILOT PLANT ACHIEVES SUPERCRITICAL CO_2 CONDITIONS

A $155 million, 10-megawatt supercritical carbon dioxide (sCO_2) test facility at SwRI in San Antonio, developed in collaboration with GTI Energy and GE Research and sponsored by the U.S. Department of Energy (DOE), has successfully achieved its first operation with sCO_2 at supercritical fluid conditions in its compressor section. This accomplishment represents significant progress toward readying the Supercritical Transformational Electric Power (STEP) Demo pilot plant for system-level testing.

"This exciting milestone represents a significant advancement for a truly transformational project," said Dr. Tim Allison, director of SwRI's Department of Machinery. "STEP Demo is laying the groundwork for power generation that is more efficient, with a smaller footprint."

Unlike conventional power plants that use water as the thermal medium, STEP is designed to use high-temperature sCO_2 to increase efficiency by as much as 10% due to its favorable thermodynamic properties. Carbon dioxide is nontoxic and nonflammable and, when held above a critical temperature and pressure, can act like a gas while having a density near that of a liquid.

The efficiency of sCO_2 as a working fluid allows for STEP turbomachinery to be approximately one-tenth the size of conventional power plant components, providing the opportunity to shrink the environmental footprint and construction cost of new facilities. For example, a desk-sized sCO_2 turbine can power up to 10,000 homes. The technology is also compatible with concentrated solar power and industrial waste heat.

"The sCO_2 power cycle is a breakthrough clean, compact and high-efficiency power generation technology that can deliver significant environmental performance," notes Bhima Sastri, director of the DOE Office of Fossil Energy and Carbon Management Energy Asset Transformation Program. "We look forward to continued operation of the current test to demonstrate control and operability of this power cycle while validating system performance over long periods of time."

The STEP Demo pilot plant is one of the largest demonstration facilities in the world for sCO_2 technology, designed to dramatically improve the efficiency, economics, operational flexibility, space requirements and environmental performance of this new technology. The team is installing the sCO_2 turbine for testing later this year.

SwRI is an industry leader in the development of sCO_2 power cycles. Staff members have conducted numerous related DOE projects advancing the efficiency, reliability and commercial readiness of sCO_2 power cycle turbomachinery, heat exchangers, cycles and systems.

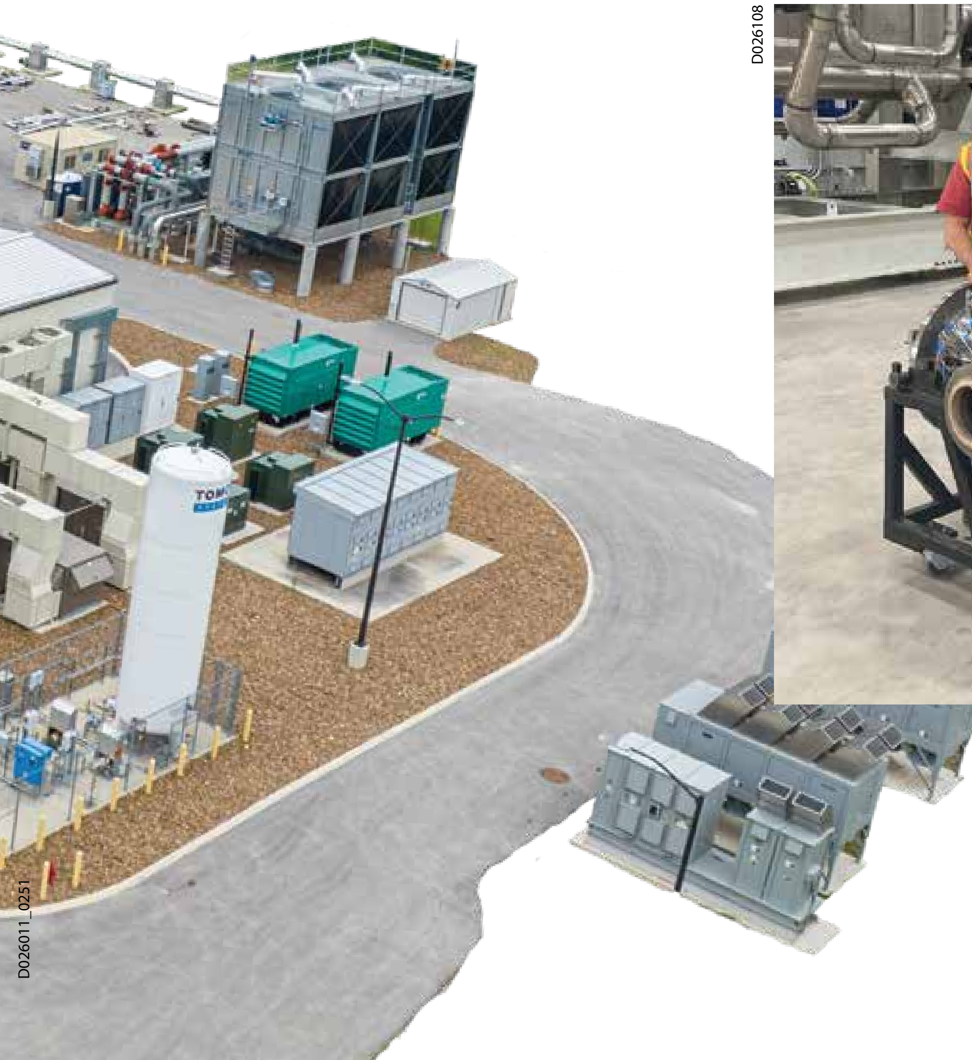
"Our team brings extensive experience with sCO_2 technology and the key building blocks to make the STEP Demo project a success and a landmark demonstration," Allison said.

D025779_3193

SwRI designed and manufactured this unique sCO_2 turbine for installation into the STEP demonstration pilot plant. Testing will begin later this year.

D026108

SwRI's John Klaerner, left, lead turbine engineer, and Dr. Jeff Moore, right, principal investigator of the STEP Demo project, are pictured with the recently assembled sCO_2 turbine for the10 MWe demonstration plant under construction at SwRI.



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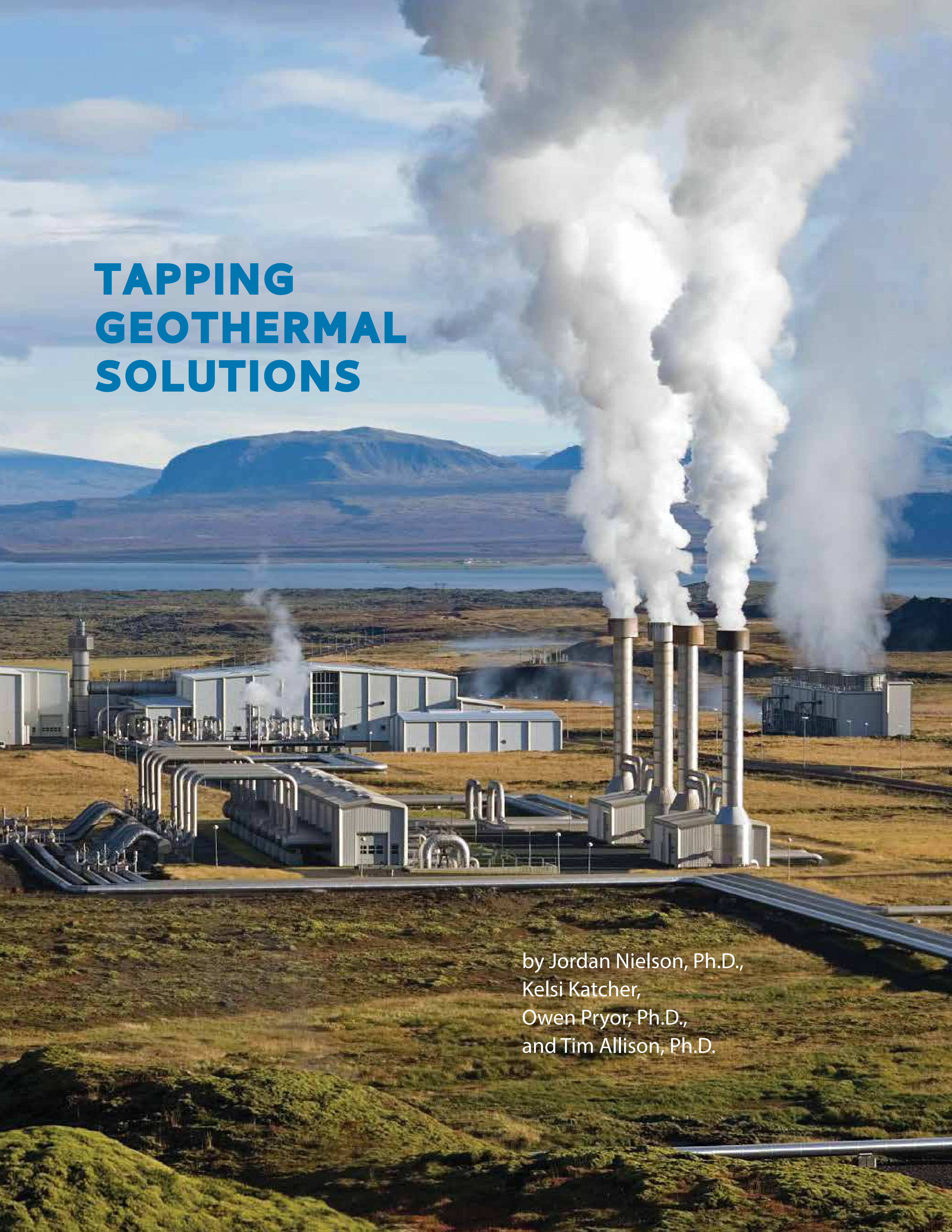
TAPPING GEOTHERMAL SOLUTIONS



by Jordan Nielson, Ph.D.,
Kelsi Katcher,
Owen Pryor, Ph.D.,
and Tim Allison, Ph.D.

Electric power generates the second largest share of greenhouse gas emissions and includes emissions from electricity production used by end use sectors, such as industry. Nearly 80% of electricity in the U.S. comes from burning fossil fuels, mostly coal and natural gas.

Geothermal energy as a zero-carbon, sustainable and renewable energy source remains largely untapped. This environmentally friendly resource has the potential to meet heating, cooling and electricity demands for the future, but there are challenges to overcome to fully exploit this natural resource. Geothermal energy taps existing heat beneath the Earth's surface to produce energy.

Underground reservoirs of hot water or air are accessed by wells, ranging from a few feet to several miles deep, bringing steam and very hot water to the surface to generate energy or for direct use in heating and cooling systems. Geothermal energy is renewable, produced as naturally occurring radioactive elements decay, heating the Earth's interior. Geothermal power plants produce electricity, running 24 hours per day, seven days per week, regardless of weather conditions, and they consume less water than conventional electric power plants. Harnessing geothermal power from domestic resources requires only a compact powerplant, which typically emits no greenhouse gases and generates a fraction of the lifecycle emissions associated with solar panels and natural gas.

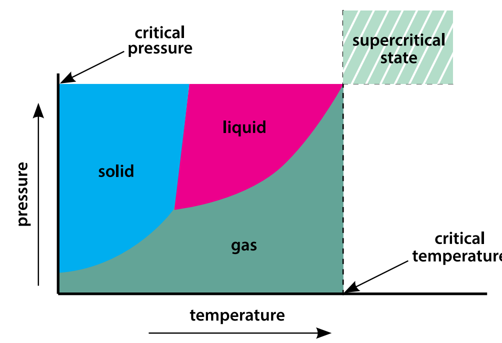
Geothermal energy is a viable zero-carbon power source that could provide highly reliable baseload electricity on the path toward a decarbonized energy economy. A recent collaborative study analyzed the geothermal potential in Texas, concluding total geothermal resources are roughly a million times the state's annual electricity generation. If the state drilled geothermal wells at its existing pace for oil and gas production wells, geothermal energy production could match the state's total use of fossil fuel energy in just four years.[1] Geothermal power shows promise for many locations beyond Texas as well. Recent advances in engineered, deep and closed-loop geothermal technologies have created opportunities for surface power generation to operate at higher temperatures with higher efficiencies. Southwest Research Institute is conducting research to develop and validate technologies for commercial deployment, including recent and ongoing efforts to develop supercritical carbon dioxide (sCO_2) technology for geothermal energy.

SUPERCRITICAL CARBON DIOXIDE

Supercritical CO_2 is a fluid state of carbon dioxide, held at or above its critical temperature and critical pressure. Carbon dioxide has a critical temperature of 88 F (31.1 C), which is a relatively moderate temperature. At conditions near its critical pressure of 7.39 Megapascals (1,072 psi), CO_2 experiences strong density changes with only a few degrees of temperature

DETAIL

A lifecycle perspective accounts for all greenhouse gas emissions connected to a good or service, from production through service life and disposal.



The supercritical temperature of a substance is the temperature where gases cannot become liquid, regardless of the applied pressure. (See related story on p. 14)

D026139

SwRI is investigating geothermal energy as an underutilized zero-carbon sustainable energy solution in Texas. Pictured at left is the Nesjavellir Geothermal Power Plant in Þingvellir, Iceland.

ABOUT THE AUTHORS: The late Dr. Jordan Nielson was a group leader in SwRI's Rotating Machinery Section, providing design expertise, engineering support and project management oversight for sCO_2 power generation systems, particularly in geothermal applications. Kelsi Katcher is a senior research engineer specializing in machinery and component design and testing activities, including high-pressure, high-temperature sCO_2 power cycle applications. Research Engineer Dr. Owen Pryor designs and analyzes machinery and power cycles, developing energy storage, turbomachinery, combustion dynamics, alternative fuels and supercritical carbon dioxide technology. Dr. Tim Allison leads SwRI's Machinery Department, designing, analyzing and troubleshooting advanced turbomachinery in a range of energy production applications.

[1] Beard, J.C. and Jones, B.A., "The Future of Geothermal in Texas: Contemporary Prospects and Perspectives," Cynthia and George Mitchell Foundation, 2023.

change. These fluid properties can be exploited to create a closed-loop thermosiphon, circulating sCO_2 through a turbine generator with only thermal inputs. This passive heat-exchange-driven process does not require a pump or compressor, minimizing parasitic loads and increasing power cycle efficiency.

With internal research funding, SwRI validated transient and steady-state models for an sCO_2 thermosiphon through a laboratory setup. The project applied these validated models to develop turbine designs, system sizing and technoeconomic models for various power generation applications, including data center and geothermal applications. The analysis found geothermal installations with large elevation changes (at least 2,300 meters) to be the most promising application of an sCO_2 thermosiphon for power generation with a potential thermal conversion efficiency over 17%.

OPTIMIZATION

A follow-on project used the model and datasets to analyze a commercial thermosiphon-based geothermal system developed by a commercial client. The model provided expected pressures, temperatures and flow rates for a 12 MWe sCO_2 turbine at the surface. SwRI then used the data to investigate the powerplant capital costs for a geothermal system, including the turbine and required cooling equipment. The analysis showed that a radial turbine is well suited for sCO_2 inlet conditions from 80-150 C. The analysis also showed that cooling the process fluid before reinjection in the geothermal well is the largest challenge for the techno economics of the power cycle, representing much larger costs than the sCO_2 turbine. However, the cost of cooling is comparable to present-day geothermal power cycles while greatly reducing the cost of the power generation equipment.

sCO_2 GEOTHERMAL APPLICATIONS

SwRI has developed a 3 MWe sCO_2 turbine design for a commercial client to evaluate its geothermal system. The high-speed radial turbine is designed for a 347 F (175 C) inlet temperature and drives a generator through an approximately 10:1 speed-reducing gearbox. After the full-scale laboratory test, the turbine will be delivered to a field site for full system testing.

DECARBONIZING TEXAS OILFIELDS

With internal funding, SwRI is collaborating with The University of Texas at Austin to identify favorable conditions for harnessing geothermal power in the Wilcox-Eagle Ford-Austin Chalk petroleum production region. The team will quantify the downhole conditions available in the petroleum play, and SwRI will build models to explore different power cycle options and examine the techno economics and technical feasibility of these power cycles for the application.

GEMS WORKSHOP

SwRI will host a new Geothermal Energy Machinery and System (GEMS) Workshop this fall to provide an opportunity for experts in industry, academia and government to meet and discuss the technology development needs for advanced geothermal surface plants. As a joint industry-government-academia workshop, the GEMS open information and networking session aims to advance geothermal power plant technology, including direct (steam) flash, indirect organic Rankine, sCO_2 and other power cycle machinery and systems needed to meet demands for advanced geothermal surface power technology. The workshop will bring researchers, industry partners and end users together to discuss state-of-the-art

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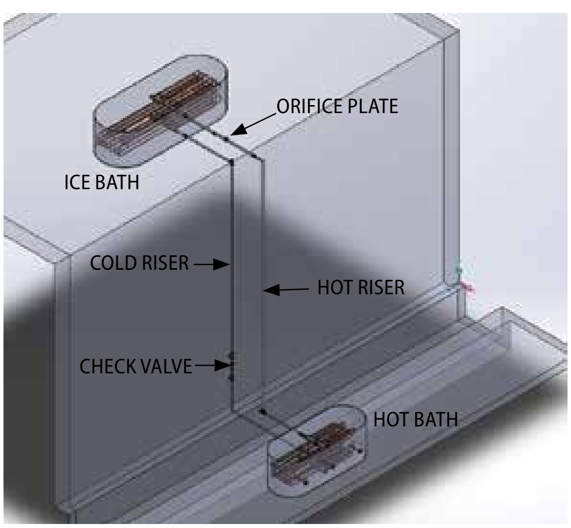
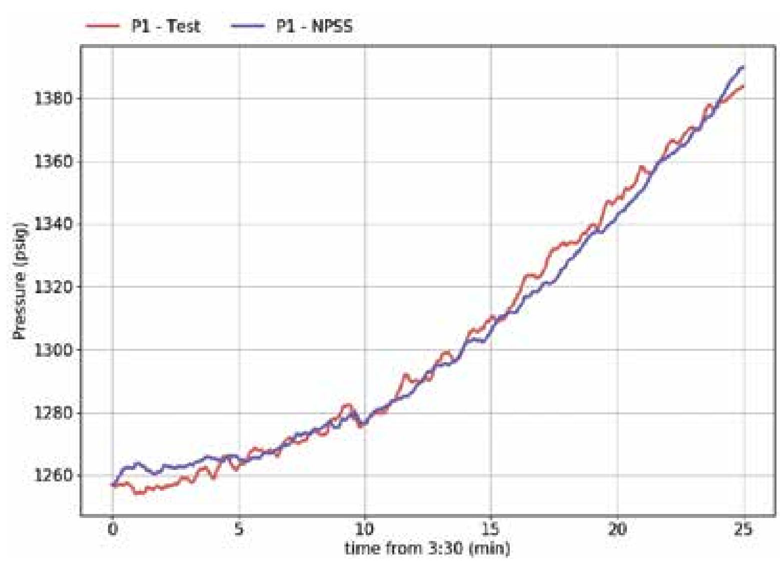
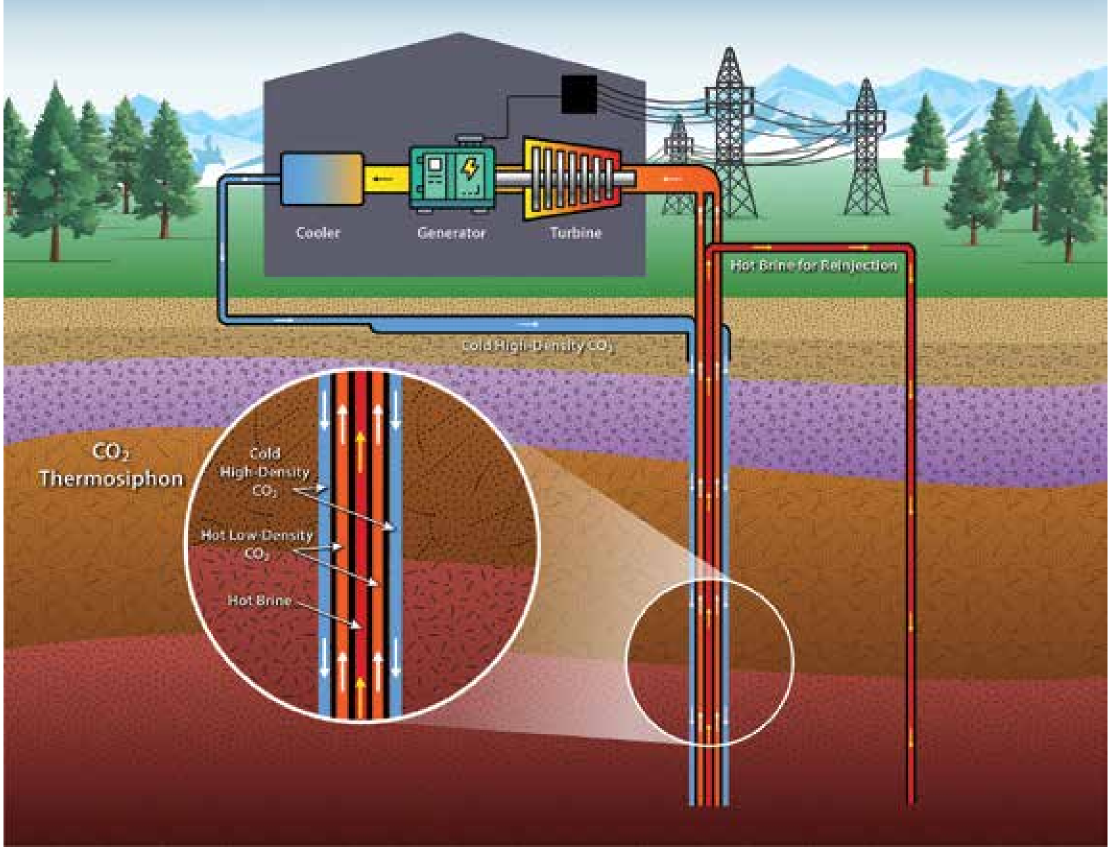




D026136

SwRI developed a lab-scale sCO_2 natural convection test loop (left) to validate simulated pressure transients (right).



D026093

This schematic of a geothermal thermosiphon illustrates its CO_2 injection leg, CO_2 production leg, surface equipment and brine reinjection leg configuration.

DETAIL

Technoeconomic modeling analyzes the economic performance of an industrial process, product or service, estimating capital and operating costs as well as potential revenue.

technology and application requirements. Participants will identify technology gaps to develop guidance to identify, coordinate and direct future pre-competitive research and development activities to advance geothermal power technologies.

As extreme weather events like heat waves as well as cold weather anomalies like Winter Storm Uri increase in frequency with a changing climate, geothermal energy could improve energy reliability and resilience, providing comfort and peace of mind for consumers. SwRI is investigating a range of new technologies to make the most of this underutilized secure, clean and ubiquitous resource.

Questions about this story? Contact Allison at tim.allison@swri.org or (210) 522-3561.

D025965_7721

SwRI engineers developed a 3 MWe sCO_2 turbine for geothermal applications and integrated the machinery into a production rig.

D026097

This article is dedicated to Dr. Jordan Nielson, who passed away unexpectedly in April 2023. Nielson led many of SwRI's efforts developing geothermal power system technologies and was known for his strong work ethic and team leadership.

Innovative, Efficient Hydrogen Compressor Supports FCEV Refueling Stations

SwRI developed a new hydrogen compressor designed to improve the efficiency and reliability of technology used to refill fuel cell electric vehicles (FCEVs). The linear motor reciprocating compressor (LMRC) is hermetically sealed and includes a linear motor driven design.

"LMRC was built and designed to compress hydrogen for refueling vehicles with hydrogen fuel cells," said SwRI Principal Engineer Eugene Broerman, the project's lead investigator. "To refuel hydrogen vehicles, the gas must be compressed to high pressures first. So, we set out to design a more efficient, leak-proof compressor."

A key challenge for hydrogen compression is hydrogen's small particle size, which increases the potential for leaks as the gas flows through equipment.

"Because hydrogen particles are so small, there are inherent material compatibility issues when designing a compressor," Broerman said. "The small particles can sneak in and alter materials and equipment performance. For instance, we had some early issues with the hydrogen particles causing magnets to fail, so we had to coat the magnets more effectively to prevent that."

The novel LMRC features an airtight compressor, hermetically sealed using a combination of SwRI-developed solutions. Coatings protect magnets from hydrogen incursion and embrittlement, while improved valve designs minimize leaks. It also utilizes a ceramic piston to minimize heat expansion and lower stress on its seal.

"Typical compressors have a piston and crank mechanism that requires them to make the same motion every time, with every revolution of the motor that's driving it," Broerman said. "SwRI's LMRC is linearly actuated, so we can change the linear motion profile to optimize the compression process."

To avoid contaminating the hydrogen gas, most hydrogen compressors are oil-free mechanisms. Most reciprocating compressors have motors that repeatedly make the same motion and require lubrication for maintenance. Mounted for vertical motion, LMRC's linear motor employs a unique dynamic seal design and moves the piston in a user-defined pattern. As a result, the compressor's seals and bearings experience less friction, negating the need for traditional lubrication. The leak-proof compressor can be adapted for other applications, such as hazardous gas or flare gas recovery.

Originally funded by the U.S. Department of Energy and cost-shared by ACI Services, LMRC has since been supported by internal research funding at SwRI. The LMRC was successfully run for the first time in 2020 and completed continuous operation at design conditions in 2022. Going forward, Broerman plans to modify different aspects of LMRC's design to increase efficiency and speeds to boost flow rates and apply the technology to other compression applications requiring hermetic sealing.

"These types of projects are critical to advancing compression technology as the hydrogen economy continues to grow," Broerman said. SwRI has a multidisciplinary team dedicated to hydrogen energy research initiatives to deploy decarbonization technologies across a broad spectrum of industries.

D026098

Transnational Sustainable Manufacturing Program

D026075

SwRI and Tecnológico de Monterrey (Tec de Monterrey) are jointly funding three research and development initiatives to advance sustainable manufacturing and technology in the United States and Mexico. The trio of projects are the first selected and supported through the Sustainable Manufacturing Program, a transnational research and development collaboration established between SwRI and Tec de Monterrey — a private, nonprofit, independent university based in Monterrey, Mexico — in August 2022. The program provides grant opportunities funded by both organizations.

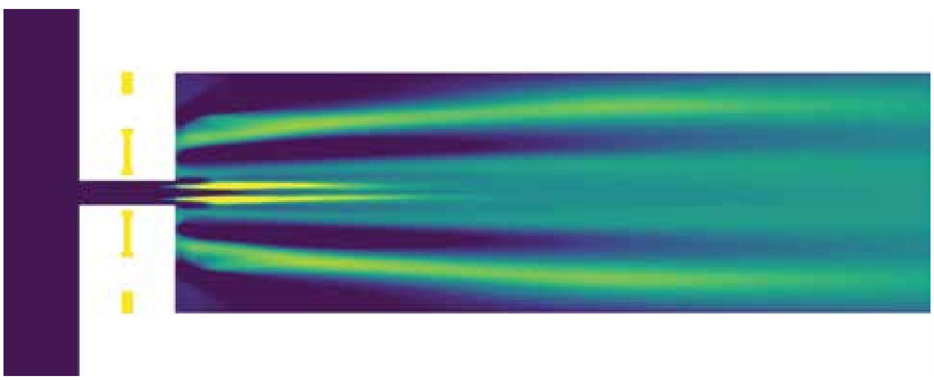
"We look forward to the progress that develops from this collaboration and the long-term impact of this research on industry and the planet," said SwRI President and CEO Adam L. Hamilton, P.E.

Sustainable manufacturing practices conserve energy and natural resources, using technology and materials that protect the environment while supporting technical advancements. Each project includes researchers from both organizations.

SwRI's Eloy Flores III and Dr. Michael MacNaughton are collaborating with Tec's Dr. Alejandro Montesinos-Castellanos and Dr. Ladislao Sandoval Rangel on a carbon capture and utilization project to reduce carbon dioxide emissions, creating biochar using unique pyrolysis processing techniques. The team is evaluating the capture and storage properties of the charcoal-like substance (seen above), which can also be recycled for other uses, such as fertilizing soil.

SwRI's Alice Y. Yau and Tec's Dr. Cecilia Daniela Treviño-Quintanilla are investigating how to recycle and reuse industrial rubbers and plastics, which often end up in landfills or oceans. Researchers will break down the materials to create environmentally friendly raw materials that could potentially support production of foams, adhesives, coatings and other industrial and biomedical materials.

SwRI's Matthew Kirby and David Riha along with Tec's Dr. Alex Elías-Zúñiga are developing a recyclable carbon-fiber-reinforced polymer composite using an innovative forging process that is more energy-efficient than traditional techniques. Lightweight composites used for high-strength applications are typically hard to recycle.



D026074

SwRI is exploring the use of "green" hydrogen fuel for gas turbines used to generate power. The designs include a nozzle that rapidly mixes and injects air (dark blue in the image) and fuel (yellow in the image) into the combustor to prevent flashback, a common hazard in hydrogen-fueled power generation applications.

SAFER, MORE EFFECTIVE HYDROGEN INJECTOR FOR GAS TURBINES

SwRI engineers are designing innovative "green" hydrogen combustion systems for gas turbines used in power generation. The designs prevent flashback, a common concern in hydrogen-fueled combustion systems, which can damage fuel nozzles.

Hydrogen fuel has numerous benefits — notably, it produces no carbon emissions during the combustion process. However, it's highly reactive, which makes it more difficult to control than natural gas or the liquid fuel typically used in gas turbines.

"With pure hydrogen fuel, traditional low-emissions designs are highly susceptible to a damaging phenomenon known as flashback," said Griffin Beck, manager of SwRI's Propulsion and Energy Machinery Section. "This occurs when the flame in the combustor flashes back into the nozzle, which can damage the equipment."

To remedy this, SwRI is exploring novel ways to mix air and hydrogen within the nozzle while avoiding flashback. The designs generated as part of the project support the development of a 100% hydrogen-fueled combustion system for an industrial gas turbine while also targeting very low nitrogen oxide (NOx) emissions.

"While hydrogen does not create carbon dioxide emissions, it does create NOx," Beck said. "However, when air and hydrogen are mixed efficiently in the nozzle, NOx emissions are significantly lower."

SwRI used computational and analytical tools to design a unique nozzle that rapidly mixes air and hydrogen through small, perpendicular pathways. The design then forces the mixture out of the nozzle and into the combustor at flow rates that prevent flashback.

PROJECT Z

Advancing Net-Zero Power Emissions

by Joshua Schmitt

To achieve the 1.5 C and 2 C global warming goals adopted in the 2015 Paris Agreement, the United States recently announced targets for a 100% carbon-pollution-free electricity sector by 2035, 50–52% reduction in economy-wide emissions by 2030 and net-zero emissions economy-wide by 2050. Achieving these targets will require rapid validation and scale-up of decarbonizing technologies, including carbon capture from fossil-fueled power plants as well as long-duration energy storage to dramatically increase renewable power integration.

Southwest Research Institute conducts more than 4,000 research and development projects every year in more than 2 million square feet of offices, laboratories and special facilities at its San Antonio campus. This research consumes electricity on the mega-watt (MW) scale. In 2023, staff initiated an internal research program known as Project Z, for zero carbon dioxide emissions, to investigate SwRI as a potential pilot application for implementing net-zero emissions strategies to power its research programs.

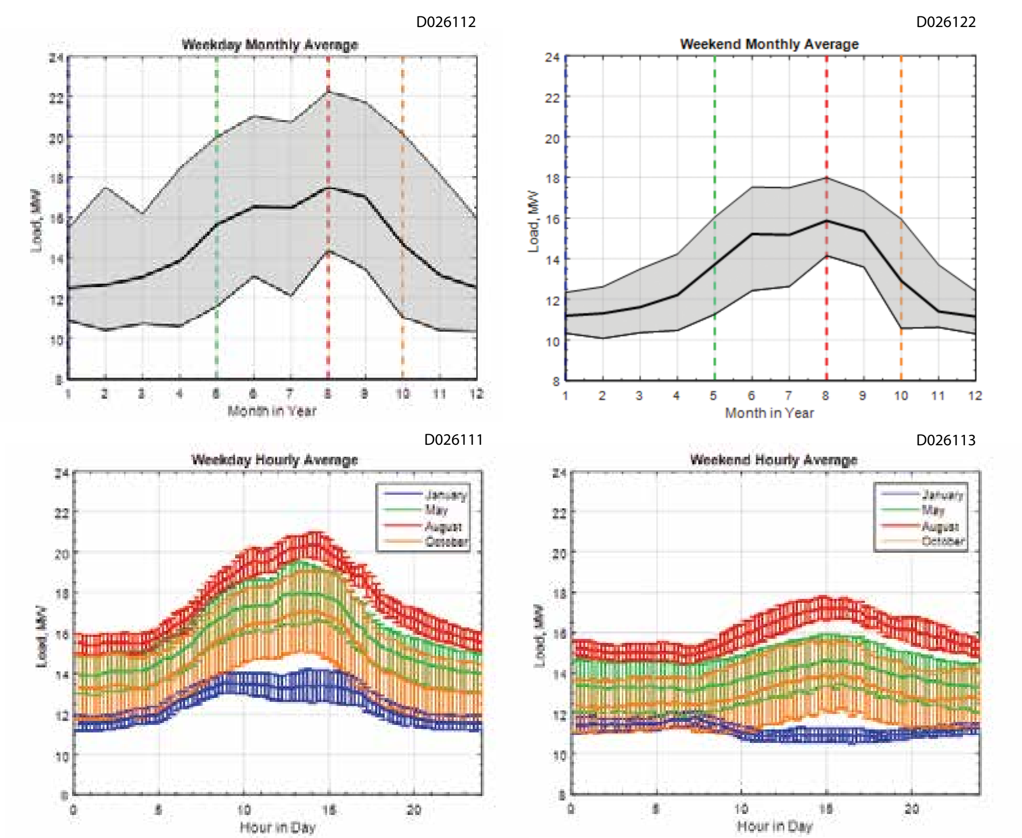
PROJECT Z APPROACH

The project team is analyzing first-of-a-kind net-zero research pilot plant configurations, envisioned as a hybrid microgrid system composed of integrated fossil fuel plus carbon capture and renewable plus energy storage power generation systems. The team is examining the pathway to developing and demonstrating clean energy technologies onsite, which mimic the renewable/storage/fossil fuel dynamics and integration expected to power the future. The project engineers are evaluating systems to ensure reliability for SwRI campus needs. They estimate costs and reduction in carbon emissions to identify future system configurations that reduce environmental impact without increasing the cost of electricity.

SwRI is developing these analysis methodologies into a powerful analysis tool as part of the internally funded research

DETAIL

One megawatt equals one million watts or 1,000 kilowatts, roughly enough electricity for the instantaneous demand of 750 homes at once.



SwRI looked at monthly trends in its electric load over the year for weekday and weekend usage. The solid line shows the average, and the envelope indicates monthly minimums and maximums. The bottom row shows diurnal trends in select months with error bars indicating a standard deviation in the load variation at that time of day. The trends are also broken down by weekday and weekend.

D025535

SwRI hosts a solar farm on its grounds to assist the local utility company in studies of decarbonization technologies.

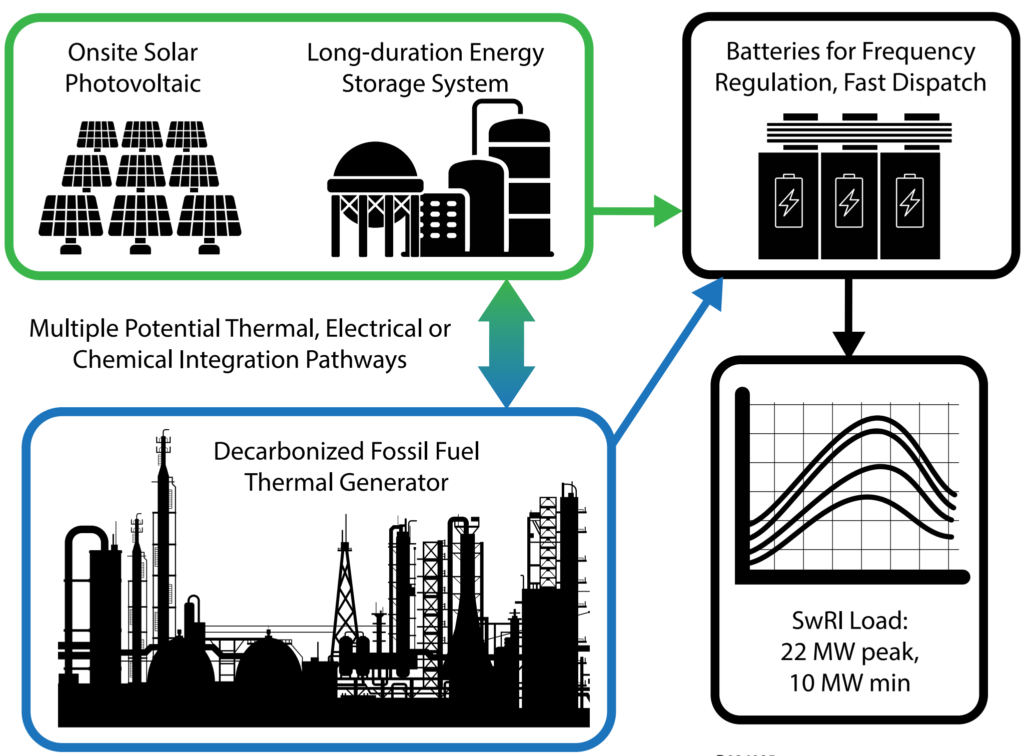
An electric substation supplying power to the Institute offers capabilities to study how to reduce energy and emissions.

and development program. This flexible, configurable tool maps energy resources to demands by analyzing multiple facility operations, sizing and storage dispatch strategies, outputting useful design metrics including fuel and materials consumption, construction costs, operating costs, and lifetime cost and emissions. Using this tool, the industry can compare a diverse set of renewable technologies against the baseline, providing information needed to select the best low- or zero-carbon solution for meeting energy demands.

As part of the analysis, a research roadmap will define opportunities for future clean energy test capabilities at SwRI. Research pilot plants are essential for technology scale-up, expanding supply chains and advancing operational / control strategies. They also provide long-duration testing and performance validation, build commercial confidence and provide a platform for component and technology development at a relevant scale. Ultimately, the Project Z pilot is envisioned as a behind-the-meter power generation facility at SwRI, deployed in phases, initially establishing a large-scale solar photovoltaic installation followed by a short-duration battery storage solution. The final phase will combine long-duration storage with decarbonized natural gas power generation.

PROJECT Z BENEFITS

The current project is analyzing and evaluating the zero-net emissions energy technologies that can reliably power SwRI's



D026085

SwRI's Project Z pilot concept studied decarbonization strategies using conventional and renewable resources, integrating clean fossil fuel technology, long-term energy storage and batteries for frequency regulation and fast dispatch.

DETAIL

Frequency regulation balances electricity supply and demand at all times, particularly over time frames from seconds to minutes. Fast dispatch sources of electrical power can be rapidly accessed or turned on to meet demand.

D026068

SwRI has conducted a range of energy storage demonstration projects, including building and commissioning this first-of-a-kind pumped thermal energy storage pilot facility on its grounds. Developing long-duration, large-scale storage capabilities — such as this facility developed in collaboration with Malta Inc. — will help balance energy volatility and reliability issues associated with integrating renewable sources into the energy mix.

IMAGE COURTESY MALTA INC.

campus. It's laying the groundwork for deploying renewable and zero-carbon energy onsite, studying potential cost savings and emissions reductions while exploring the dynamics of grid independence.

The team anticipates that Project Z will fuel future research opportunities by providing an industry-accessible research platform for pilot-scale testing and evaluation of new clean energy technologies. The project could establish a blueprint for decarbonizing industrial facilities that can benefit from onsite power generation, energy storage or carbon capture systems. In addition, the pilot can advance behind-the-meter or off-grid energy resiliency for critical and distributed generation applications.

The SwRI campus offers a unique testing ground for this type of research. In addition to having sufficient natural gas/solar resources and previous pilot plant design and construction experience, SwRI has established expertise in energy system research and development, a proven industry collaboration network and an existing behind-the-meter electrical infrastructure that can utilize produced electricity for economical long-duration testing.

PROJECT Z FUTURE

Project Z is an ongoing internal research and development project with expected completion by September 2023. The project will quantify the trade-offs among various net-zero technologies, guiding future decisions on technology implementations on campus at the MW scale. As a first step, the project team is also working with SwRI Facilities to complete an engineering study evaluating various locations to add solar panels on the grounds.

The team is also developing a flexible and detailed analytical tool that will allow decision-makers to compare a wide set of zero-emission technologies. At SwRI, this includes solar energy generation, battery storage, long-duration energy storage and fossil-fuel generation with carbon capture. This tool and analysis expertise can be extended to future government and industry collaborators, evaluating wind resources, electric load profiles, industrial heat loads and hydrogen production, storage and use.

The project will also identify new challenges in the future of net-zero energy emissions infrastructure. SwRI's Project Z offers a unique opportunity to understand and test net-zero emissions technology that could, one day, power our way of life.

Questions about this story? Contact Schmitt at joshua.schmitt@swri.org or (210) 522-6777.

D025834_5636

SwRI has installed a large-capacity liquid hydrogen tank to expand its advanced hydrogen energy research initiatives. The tank's capabilities support multidisciplinary research to leverage opportunities and address obstacles related to hydrogen energy research and development.

D025994_9772

ABOUT THE AUTHOR: Senior Research Engineer Joshua Schmitt specializes in designing energy systems, turbomachinery, heat exchangers and energy storage technology. He applies this expertise to oxy-combustion, carbon capture, hydrogen storage, gas turbines, electrified thermal storage, solar power generation and supercritical carbon dioxide (sCO_2) systems and components.

COST-EFFECTIVE PATHWAYS FOR MALARIA MEDICINE

D026071

SwRI collaborated with UTSA to synthesize highly potent derivatives of the antimalarial drug artemisinin, which could lead to a more cost-effective treatment for the deadly disease.

SwRI collaborated with The University of Texas at San Antonio (UTSA) to develop a new chemical technology to make the highly potent antimalarial drug artemisinin, which could lead to more cost-effective treatments. Recently featured on the cover of the scientific journal Organic Letters, the work was supported by the Bill and Melinda Gates Foundation as well as by a Connecting through Research Partnerships (Connect) grant, a joint SwRI-UTSA effort to enhance scientific collaboration between the two institutions.

In 2021, 247 million cases of malaria led to 619,000 deaths worldwide. The most effective malaria treatments use the drug artemisinin, which is derived from the sweet wormwood plant, Artemisia annua. However, the process of isolating artemisinin from the plant is time-consuming, and crop yields are susceptible to weather patterns, insect infestations and other factors. Despite scientific advancements in treatment methods, the cost of artemisinin still burdens the countries most affected by malaria.

"We were able to develop a novel way of synthesizing artemisinin that mimics how it's made in nature," said SwRI Senior Research Scientist Dr. Shawn Blumberg. "Our method mimics the biosynthetic pathway of how artemisinin is made in the plant where it originates. We studied the intermediate compounds along that pathway and then used chemistry to create those same intermediates and recreate the pathway."

In 2020, Blumberg and UTSA Professor Dr. Doug Frantz received a $125,000 grant from the Connect program to build on work supported by the Bill and Melinda Gates Foundation to create a more cost-effective way to synthesize artemisinin.

"Nothing in public scientific literature suggested this would work," Frantz said. "This was challenging chemistry that we were trying to pull off, but we let science tell us where to go. It enabled us to design a process of taking a common intermediate in the biosynthetic pathway for artemisinin and converting it all the way to artemisinic acid, which is the direct precursor to artemisinin."

With drought, wildfire and insects making it difficult to depend on sweet wormwood yields, Blumberg and Frantz hope drug companies can use this new method to produce a more potent and cost-effective malaria treatment, especially for the impoverished countries often most affected by the disease.

"The supply of artemisinin remains somewhat erratic, which causes price instabilities, and countries dealing with this endemic need a stable, cost-effective solution," Blumberg said. "While the new process we've created might not completely supplant current methods, it can complement other approaches and help to stabilize the world's supply of artemisinin."

IMAGE COURTESY UTSA

The most effective malaria treatments use the drug artemisinin, which is derived from the sweet wormwood plant, Artemisia annua.

ECLIPSE DOWN UNDER

Through the Citizen Continental-America Telescopic Eclipse (Citizen CATE) 2024 project, SwRI scientists led a team to image the Sun's outer atmosphere, the corona, during a short solar eclipse on the opposite side of the Earth. Using four platforms in the northwest corner of Australia, the team successfully observed the million-degree solar corona at the April 20 eclipse viewed from the town of Exmouth on the North West Cape peninsula. The Australian eclipse serves as both a unique scientific opportunity and a training exercise for the program's leadership in preparation for the 2024 U.S. eclipse.

The CATE 2024 team traveled nearly 10,000 miles for one minute of totality to observe the Sun's corona from the unique perspective offered by total solar eclipses. These phenomena allow scientists to view the complex and dynamic outer atmosphere in ways that aren't possible or practical by any other means. SwRI is leading the Citizen CATE 2024 experiment, a broad scientific outreach initiative that will make a continuous 60-minute high-resolution movie during the April 8, 2024, solar eclipse over the United States. CATE 2024 will use a network of 35 teams of citizen scientists representing the local communities within the eclipse shadow path.

"Even though the Australian eclipse was very short, our team of community scientists performed flawlessly and captured fabulous images of the structure of the elusive solar corona," said Dr. Amir Caspi, a principal scientist at SwRI in Boulder, Colorado, and leader of the Citizen CATE 2024 project. "This eclipse provided the perfect opportunity to test our equipment and procedures, and to train our community leaders for the next eclipse in 2024."

The SwRI-led Citizen CATE 2024 project is funded by grants from the National Science Foundation and NASA. Beyond its scientific goals, the project aims to engage many unique and diverse communities along the eclipse path as an integral part of a major scientific research effort.

The current project builds on the experience of the first Citizen CATE experiment, expanding the scientific objectives by measuring polarized light and engaging with teams across the new eclipse path. Dr. Sarah Kovac, a 2017 CATE participant and now a postdoctoral researcher at SwRI, serves as project manager for the 2024 expedition.

"Participating in CATE as a young undergraduate inspired me to pursue a career in heliophysics," Kovac said. "Seven years and one Ph.D. later, I get to be on the professional side of planning an eclipse expedition, and it's beyond exciting to share this passion with the next generation of young scientists."

The project will begin to recruit teams from eclipse path communities in this fall. Interested parties can find more information and a contact form on the project's website, https://eclipse.boulder.swri.edu.

IMAGE COURTESY SWRI/CITIZEN CATE 2024/DAN SEATON

Through the Citizen CATE 2024 project, SwRI's Dan Seaton produced this false color, polarized image of the solar corona during the 2023 total solar eclipse viewed from Exmouth, Western Australia.

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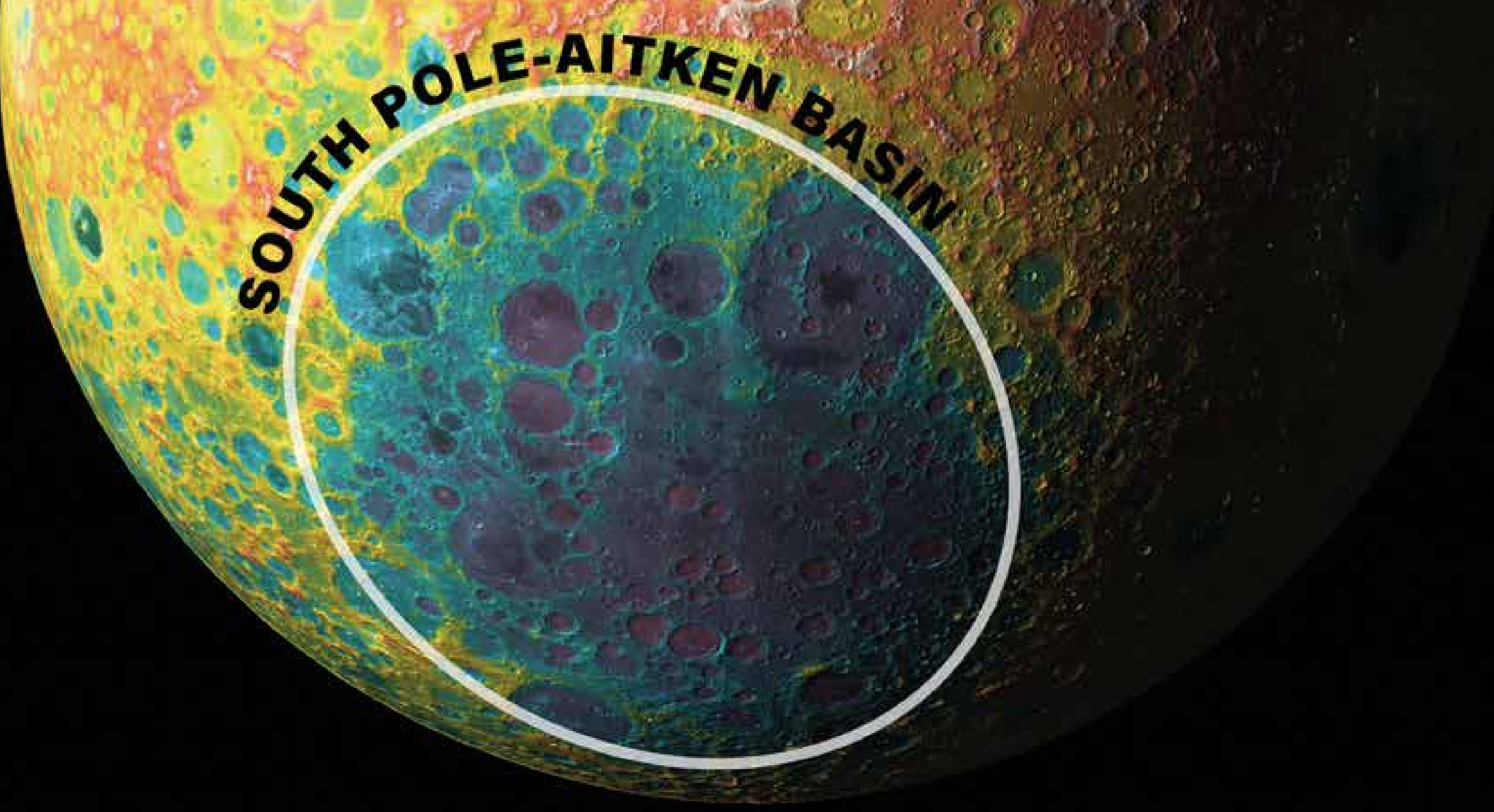

IMAGE COURTESY NASA/GODDARD

D026070

SwRI TO LEAD NASA/SSERVI CENTER FOR LUNAR ORIGIN AND EVOLUTION

Southwest Research Institute has entered into a five-year, $7.5-million cooperative agreement with NASA to lead the Center for Lunar Origin and Evolution (CLOE). The Solar System Exploration Research Virtual Institute (SSERVI) center will support enabling science for human exploration of the Moon as well as the Endurance-A mission concept, a far side lunar rover mission prioritized by the 2022 Planetary Science and Astrobiology Decadal Survey report.

"The Moon is unmatched in its potential to provide fundamental advances in our understanding of the origin and early evolution of the solar system," said SwRI's Dr. William Bottke, CLOE principal investigator. "Human exploration of the Moon revolutionized lunar science in the past and promises to do so again in the near future."

Apollo samples from the lunar nearside provided the foundation for current knowledge of the Moon's composition, crust and bombardment up to 4 billion years ago. But the earliest history of the Moon in its first 500 million years remains less well understood. NASA's Artemis Program will send humans back to the Moon starting in the mid-2020s with landings in the south polar region. Exploration of the more ancient lunar far side will reveal the preserved record of the earliest bombardment of the Moon, including the oldest and largest impact basin. The ancient 1,500-mile-wide South Pole-Aiken (SPA) basin extends from near the South Pole to cover much of the far side's southern hemisphere.

The far side of the Moon is the hemisphere that always faces away from Earth because of the Moon's synchronous rotation. Compared to the near side, the far side terrain is rugged, with a multitude of impact craters and relatively few of the large, dark basaltic features characteristic of the nearside.

"Exploring the Moon has tremendous potential for supporting transformative science," said CLOE Deputy Principal Investigator Dr. Robin Canup, vice president of SwRI's Solar System Science and Exploration Division. "Models indicate that the Moon formed via a titanic collision with the Earth at the end of our planet's formation. Clues needed to unravel the nature of this event are still on the Moon and can help us better characterize terrestrial planet formation."

CLOE will focus on models of terrestrial planet formation and early lunar bombardment, the conditions of Earth-Moon origin, and how exploration of the SPA basin can allow us to better understand solar system formation and early evolution. Because the impact that formed SPA was so large, it almost certainly excavated material from the Moon's deep interior. Collecting samples of these materials would significantly expand knowledge of the Moon's bulk composition and subsurface volatile content — key data needed to reveal the conditions of the Earth-Moon origin and the thermochemical evolution of a young rocky world.

"The time is ideal for SSERVI — a program designed to work at the interface of NASA's robotic scientific and human exploration programs — to play a central role in supporting and maximizing the scientific return from planned lunar exploration," Bottke said. "The envisioned Endurance-A robotic rover would traverse SPA and collect carefully selected samples to be delivered to Artemis astronauts for return to Earth, producing an Apollo-class sample set from the far side of the Moon."

SIMULATING OFF-ROAD ENVIRONMENTS TO TEST CONNECTED, AUTOMATED VEHICLES

SwRI has created a 3D simulation tool to test automated vehicles in virtual off-road environments modeled after real-world conditions. The research expands SwRI's investment in software-in-the-loop solutions to test connected and automated vehicles (CAVs) in scenarios ranging from congested roadways to off-road terrain.

A simulated 3D environment supports evaluations of large numbers of scenarios that would be cost-prohibitive to test in the real world. The technology meets U.S. Department of Defense demands for modeling and simulation tools to help advance the development of automated ground vehicles (AGVs).

SwRI used internal funding to develop a "pipeline" of technology with custom algorithms, off-the-shelf software, open-source tools, and publicly available map data. The project developed a "Simulation Scene Adjustment Tool" with a 3D video-game-style interface to test virtual ground vehicles on off-road terrain. The simulator also creates a digital twin, a virtual representation of an automated vehicle that looks and behaves like its counterpart in the real world.

"Simulation with the digital twin is crucial for AGV testing and development," said Joe Auchter, who led the research for SwRI's Intelligent Systems Division. "Our Simulation Scene Adjustment Tool allows a user to push AGVs to their limits and explore 'what-if' scenarios in a variety of simulated environments more rapidly, safely and cost-effectively than real-world testing allows."

SwRI's simulator consists of a graphics engine, dynamics engine, vehicle modeling tools, vehicle terrain interaction models and plug-ins to communicate with an autonomy software stack. It builds scenes with geographic information system (GIS) data such as digital elevation models (DEMs) from aerial scans conducted by the San Antonio River Authority and other government agencies.

"We developed algorithms to generate synthetic environments from user-configurable GIS data such as DEMs," Auchter said. "This allows us to build simulated test environments that share relevant characteristics with real geo-specific locations where vehicles will eventually operate."

SwRI's computer models simulate computer vision and sensing outputs for lidar, radar, cameras, GPS and other subsystems that provide data for AGV navigation and path planning systems. A dynamics engine simulates forces caused by gravity and motion as the vehicle model moves through the 3D environment. Simulated vehicles can be programmed with weight, speed, horsepower, center of gravity and other realistic characteristics. A graphics engine simulates trees, grass, terrain, objects and visual effects such as sky and clouds.

SwRI has made safety and security a priority in the development of autonomous vehicles and automated driving systems as the technology reaches advanced levels of readiness for civilian and military use.

"If you look at field testing of automated vehicles, there are simply not enough miles or novel situations that you can throw at a vehicle to encounter all the edge cases for sensors and software," said Jerry Towler, assistant director of SwRI's Robotics Department. "Modeling and simulation help test AGVs and Advanced Driver Assistance Systems to enhance safety and ensure capability before and alongside deployment into real-world testing environments."

D026076

SwRI's Simulation Scene Adjustment Tool evaluates automated vehicles in 3D simulations of off-road environments. The image shows 3D scenes featuring different ground cover, simulating grass, foliage or rocks to virtually test military automated ground vehicles (AGVs).

D026081

SwRI demonstrates AGVs traversing real-world terrain after virtual testing using its Simulation Scene Adjustment Tool.

NASA Center Focusing on Additive Manufacturing

SwRI is contributing to a new NASA institute to improve understanding and enable rapid certification of metal parts created using advanced additive manufacturing (AM) techniques. The Institute for Model-based Qualification & Certification of Additive Manufacturing (IMQCAM) will work to improve computer models of additively manufactured metal parts and expand their utility in spaceflight applications.

Additive manufacturing uses 3D printing or rapid prototyping to build an item by layering plastic, metal and other materials using a custom computer-generated design. Because AM creates sturdy components with intricate design qualities, it appeals to a wide range of users, including the aerospace, medical and manufacturing industries.

IMQCAM is one of two new Space Technology Research Institutes (STRIs) created by NASA to develop technology in critical engineering and climate research arenas. NASA began creating STRIs to strengthen its ties to the academic community through sustained investment in the development of research and technology crucial to NASA's future.

Over the course of five years, this STRI will develop detailed computer models, or digital twins, for additively manufactured parts that have been validated against experimental data and subjected to rigorous uncertainty quantification protocols. The models will evaluate the fatigue response of spaceflight materials currently used for 3D printing, as well as introducing and qualifying new materials.

SwRI will aid in technology transfer of university-developed models for practical industrial use. This process will include integration with the SwRI-created DARWIN® (Design Assessment of Reliability with INspection) fracture mechanics and reliability assessment software, which supports damage-tolerant design and analysis of metallic structural components. The new IMQCAM is led by Carnegie Mellon and Johns Hopkins universities.

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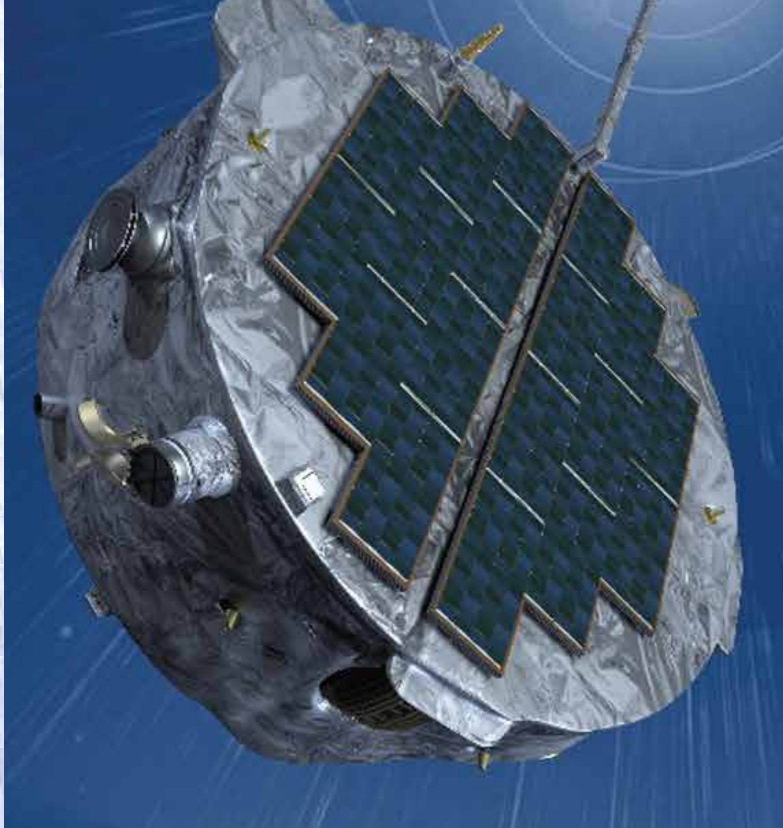


IMAGE COURTESY COURTESY NASA/JOHNS HOPKINS APL/PRINCETON UNIVERSITY D026067

IMAP on Track for 2025 Launch

NASA's Interstellar Mapping and Acceleration Probe (IMAP) mission has completed its Mission Critical Design Review and is on track to meet its scheduled 2025 launch. IMAP will study the interaction between the solar wind and the interstellar medium as well as the fundamental processes of particle acceleration in space. In addition to managing the payload office, SwRI is providing IMAP's Compact Dual Ion Composition Experiment (CoDICE) instrument and supporting other instrument teams.

"IMAP will help us gain a greater understanding of how our heliosphere interacts with the interstellar medium, providing a better understanding of our place in the galaxy," said Susan Pope, director of SwRI's Department of Space Instrumentation and IMAP's payload manager.

IMAP will help researchers better understand the boundary of the heliosphere, a sort of magnetic bubble surrounding and protecting our solar system, where the constant flow of particles from the Sun, called the solar wind, collides with material from the rest of the galaxy. This bubble limits the amount of harmful cosmic radiation entering the heliosphere. IMAP instruments will collect and analyze particles that make it through.

The CoDICE instrument, initially developed with SwRI internal funding, combines the capabilities of multiple instruments into one patented sensor. CoDICE will measure the distribution and composition of interstellar pickup ions, particles that make it through the "heliospheric" filter. It will also characterize solar wind ions as well as the mass and composition of highly energized solar particles associated with flares and coronal mass ejections.

SwRI is a key member of the teams for other payload instruments, responsible for the detector on IMAP-Hi and the conversion subsystem on IMAP-Lo. SwRI is also building high-voltage power supplies for the Solar Wind Electron (SWE) and the Global Solar Wind Structure (GLOWS) instruments and providing digital electronics for four IMAP instruments.

SwRI PURSUES NEXT-GENERATION NOAA CORONAGRAPH

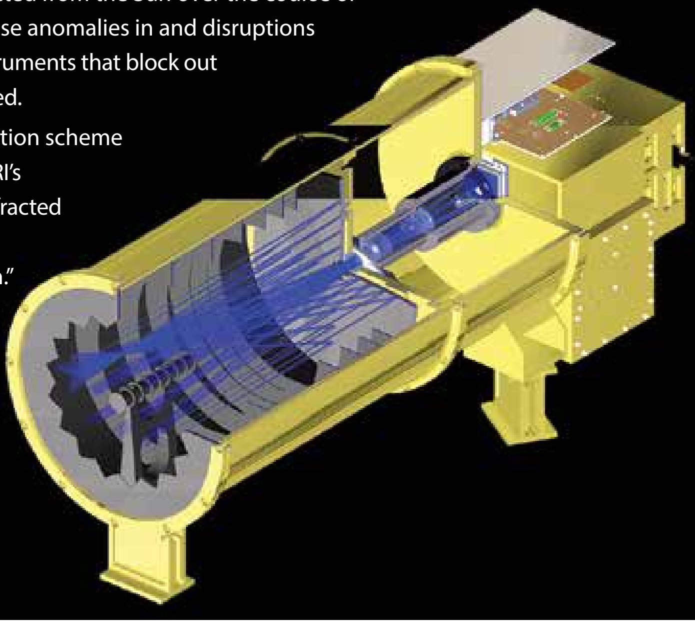
NASA has selected SwRI for a Phase A study to develop the Space Weather Solar Coronagraph (SwSCOR) on behalf of the National Oceanic and Atmospheric Administration (NOAA). NOAA's Space Weather Next Program is charged with providing critical data for its space weather prediction center. SwRI is one of five organizations developing a definition-phase study to produce the next-generation NOAA L1 Series COR instrument to detect and characterize Earth-directed coronal mass ejections (CMEs).

CMEs are huge bursts of coronal plasma threaded with intense magnetic fields ejected from the Sun over the course of several hours. CMEs arriving at Earth can generate geomagnetic storms, which can cause anomalies in and disruptions to modern conveniences such as electric grids and GPS systems. Coronagraphs are instruments that block out light emitted by the Sun's surface so that its outer atmosphere, or corona, can be observed.

"SwSCOR is a short, externally occulted coronagraph with a novel 1.5-stage occultation scheme that enables darker, wider-field imaging than a single multi-disk occulter alone," said SwRI's Dr. Craig DeForest, who is leading the study. "Its design redirects the major source of diffracted stray light formed by the occulter itself. This design enables imaging closer to and/or farther from the Sun than comparably sized instruments with conventional occultation."

Stray light is the largest challenge of coronagraph design. Coronal structures a few degrees away from the Sun are a billion times fainter than the Sun itself. Current multi-disk occulters cut stray light by many orders of magnitude. Adding more disks yields more occultation but tightens machining and assembly tolerances.

"SwRI is investigating several novel occulter designs," DeForest said. "Preliminary laboratory experiments with our latest prototype indicate a more than 10-fold improvement over similar-geometry multi-disk designs in use today, while improving manufacturability and alignment tolerances."



D026078

SwRI RESEARCHES FASTER SPACEFLIGHT TECHNOLOGY

SwRI is evaluating the next generation of fast and reliable microprocessors for embedded spaceflight systems, seeking technology that performs more complex tasks using less power.

"Conventional spaceflight technology is larger, heavier and more power-hungry than today's microprocessors, which translates to bigger spacecraft, larger solar arrays and more batteries with complex thermal control — all of which can be very expensive to launch," said Patrick Saenz, a computer scientist in SwRI's Intelligent Systems Division. "Our latest research is exploring much faster computers with a smaller footprint."

Using laboratory tests, engineers determined that newer microprocessors built with "instruction set architectures" could outperform conventional spaceflight technology under certain configurations. The research opens the door to embedding space systems with the same microprocessors used in cell phones and other Earth-based electronics.

The team first evaluated open-source reduced instruction set computers (RISC-V or "risk five"). Among other findings, researchers determined that some space-ready circuits, known as Field Programmable Gate Arrays (FPGAs), were incompatible with faster RISC-V soft-core processors. Other FPGAs, however, successfully operated with RISC-V and even outperformed conventional processors. Then SwRI evaluated the performance and power consumption of an Advanced RISC Machines (ARM) processor. The ARM processor outperformed a legacy processor with more than five times the processing power, using a fraction of the energy.

"The dynamic power management features offered by the ARM processor can provide finer tuning of power utilization throughout a mission's lifetime," said Kayla Henderson, an SwRI embedded systems software engineer.

RISC-V and ARM technology can also improve software development, reuse and interoperability for space missions.

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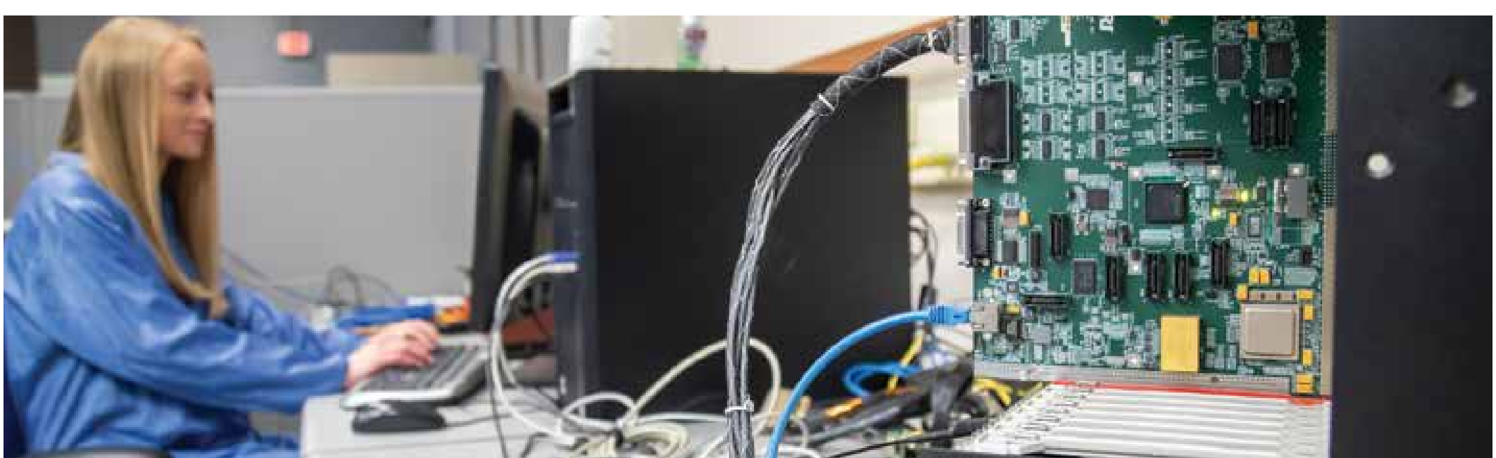

UPCOMING

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

NASGRO Virtual Training Course begins Aug. 1, 2023.

Industrial Gas Turbine Combustion on Aug. 2, 2023. Free webinar.

Manufacturing Supervisor Certification Program. SwRI's Texas Manufacturing Assistance Center (TMAC) is offering the in-person training program on various dates and multiple locations starting Aug. 15, 2023.

Operations and Supply Chain Management course, Sept. 11, 2023. Virtual TMAC training.

Penetration Mechanics Short Course, September 11, 2023. In-person training.

Improve Your Business Processes by Value Stream Mapping, Sept. 14, 2023. In-person TMAC training.

Lean Manufacturing Certification Program, starting Oct. 4, 2023. TMAC-SAMA weekly training sessions.

Gas Turbine & Compressor Short Course, starting Nov. 6, 2023. In-person four-day training.

Introduction to Inventory Management, Nov. 8, 2023. In-person TMAC training.

TRADESHOWS:

Life Cycle Industry Days & Wright Dialogue with Industry, Dayton, Ohio, July 31, 2023, Booth No. 410.

Small Satellite Conference, Logan, Utah, August 5, 2023, Booth No. 50.

American Society of Biomechanics Annual Conference, Knoxville, Tennessee, August 8, 2023.

Ground Vehicle Systems Engineering & Technology Symposium, Detroit, August 15, 2023, Booth Nos. 227 & 229.

National Strength and Conditioning Association Tactical Annual Training, Las Vegas, August 22, 2023.

IEEE AUTOTESTCON, National Harbor, Maryland, August 28, 2023, Booth No. 119.

IMAGE (DEG/AAPG) International Meeting for Applied Geosciences & Energy, Houston, August 28, 2023, Booth No. 306.

Texas Groundwater Summit, San Antonio, August 29, 2023.

Florida Automated Vehicles Summit, Tampa, Florida, September 6, 2023.

Air Vehicles Technology Symposium, Dayton, Ohio, September 12, 2023, Booth No. 8.

Defense and Security Equipment International, London, September 12, 2023, Booth No. H8-325.

D026087

Dr. Thomas E. Briggs, an Institute engineer in the Powertrain Engineering Division, has received the Forest R. McFarland Award by SAE International, an organization that works to advance mobility, knowledge and solutions for humanity's benefit. Established in 1979, the award honors the late Forest R. McFarland, a long-time SAE International member, for his many contributions to the organization. The award recognizes outstanding contributions by volunteers who further the goals of SAE International events in planning, development and dissemination of technical information.

D026104

Dr. Peter Lee of SwRI's Tribology Research and Evaluations Section has been named a Fellow of the Society of Tribologists and Lubrication Engineers (STLE). An STLE fellowship recognizes society members with significant contributions over 20 years of active practice in tribology. These contributions must meet a standard considered by STLE above and beyond those typically expected of a scientist or engineer. Tribology is the study of lubrication, friction and wear, and STLE Fellows are considered authorities in the field. As of 2022, only 187 individuals have been granted this recognition.

D026086

Dr. Natalie Smith has received a 2023 American Society of Mechanical Engineers (ASME) Dedicated Service Award, recognizing more than 10 years of dedicated voluntary service to ASME marked by outstanding performance, demonstrated and effective leadership, prolonged and committed service, devotion, enthusiasm and faithfulness. In 2022, the ASME bestowed the Dilip R. Ballal Early Career Award on Smith, and she won the Best Paper Award at the 2015 ASME Turbomachinery Exposition in the Structures and Dynamics Committee. She is serving as the Conference Chair for Turbo Expo 2023.

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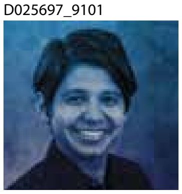

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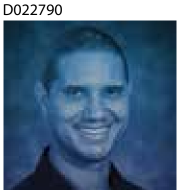

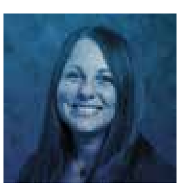

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Four SwRI space scientists were recently honored by having an asteroid named after each of them. The asteroid known as 2000 FE26 was named (28620) Anicia for SwRI's **Dr. Anicia Arredondo-Guerrero** in recognition of her spectroscopic observations of asteroids and asteroid families, stellar occultation observations of Trans-Neptunian Objects and lunar hydration studies. The asteroid known as 1998 VA46 was named (30232) Deienno for **Dr. Rogerio Deienno** in recognition of his studies on the early dynamical evolution of the solar system and the effects of planetary migration on small bodies populations. The asteroid known as 2000 GV153 was named (40241) Stephanie-jarmak for **Dr. Stephanie G. Jarmak** in recognition of her spectroscopic observations of asteroids and the study of regolith adhesion and planetesimal formation through laboratory and CubeSat microgravity experiments. The asteroid known as 2000 WW184 was named (34665) Akbarwhizin for **Dr. Akbar D. Whizin** in recognition of his microgravity and laboratory experiments to study planetary formation and the effects of high- and low-velocity collisions on planetesimal aggregation and asteroid evolution.

TECHNOLOGY
TODAY

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

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