

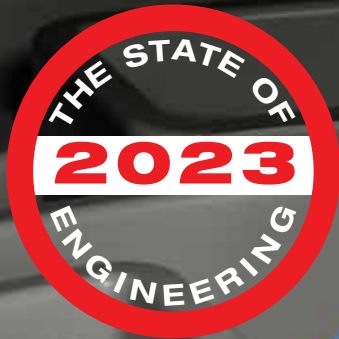
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ENGINEERING

No. 01

145

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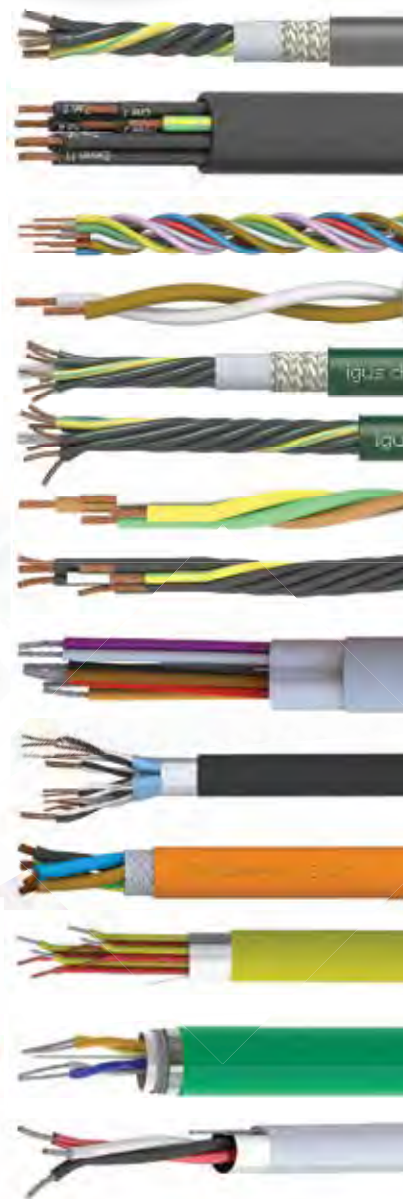
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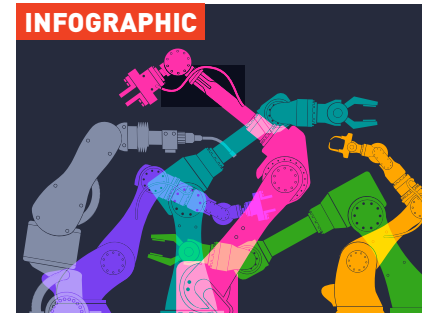
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STOP MEETING LIKE THIS

NO ONE LIKES UNNECESSARY MEETINGS, yet most managers acknowledge it's difficult to reduce them. While such meetings hold the potential to get important work accomplished, wasteful meetings chop up the day and make it harder for employees to refocus when they get back to their desks. Senior managers in a range of industries report that unnecessary meetings can actually interfere with bringing their teams closer together. In this ASME Career Center story, we spoke to managers who shared five ways they've cut down on the number of unnecessary meetings at their businesses.

MEMBERS-ONLY CAREER CONTENT: CAREERCENTER.ASME.ORG

INFOGRAPHIC



RISE IN INDUSTRIAL ROBOT SALES

SINCE THE SPRING OF 2020, the pandemic has impacted every facet of the global economy, disrupting supply chains and raising prices on goods. But as our infographic explains, new data from the International Federation of Robotics shows bright prospects for industrial robot sales.

QUIZ



LOOK AT HYDROELECTRICITY

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EPISODE 85: Carbon Capture Is Poised for Fast Growth

Battelle's Neeraj Gupta talks about the state of carbon capture and sequestration, a key climate action technology.



EPISODE 84: Space Stations After ISS

Matt Ondler, chief technology officer and director of spacecraft development at Axiom Space, discusses the challenges in developing a commercial space station.



EPISODE 83: Small Firm Digitally Transforms

Doug Gudenburr of DMI Companies talks about his firm's adoption of digital engineering technology and the impact it's had on the bottom line.



EPISODE 82: Offshore Wind Power in New York

Georges Sassine, vice president for large-scale renewables at the New York State Energy Research and Development Authority, discusses the state's plans for harnessing offshore wind power.



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DECEMBER/JANUARY



ON THE COVER

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STATE OF ENGINEERING 2023: WORKING TOGETHER

As manufacturing roles converge, industry and academia must learn to collaborate.

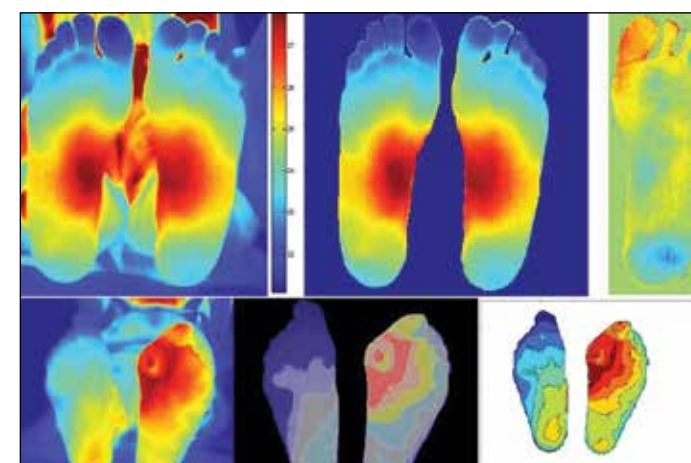
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Made in the PV shade.



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Jeffrey Winters
Editor in Chief

THE VOICE OF ENGINEERS

Milestone anniversaries are always a time for both looking back and looking ahead. In this issue, the volume number, a sort of odometer for the magazine, turns over to 145, which isn't exactly a round number but is worth noting. Volume 150 will be the next truly major anniversary, but who knows whether we'll be celebrating that occasion in 2027—or avoiding lemurpox while hiding from a robot insurrection? So, let's take stock of the magazine while we can.

When I started at *ME* 20 years ago (an actual round number), the magazine was set up quite differently than it had been in previous decades. In 2002, the magazine was close in style to a trade publication, with primarily staff-written industry round-ups or reports on engineering projects. The advantage to that approach is that staff writers with particular beats can develop sources in industry and may uncover new developments before they break into the headlines.

The newness of the approach was also a limitation: Each month, we started with a blank slate, so every issue was assigned, reported, written, and edited in the space of two weeks to allow for graphic production and readying the magazine for the printer. There wasn't a lot of room in that schedule for reflection.

Nor was there a space for something that had been a feature in the decades prior: The voice and point of view of engineers, technologists, and policymakers.

One pleasure of this job is looking though archival issues of the magazine (something that was easier in the pre-pandemic era, when bound copies were in a closet 20 feet from my desk). Go through issues of *Mechanical Engineering* from the 1930s or the 1960s, and you'll see articles authored by leaders of industrial corporations or heads of federal agencies. While the magazine of the early 2000s was oriented around industry news, in decades past, *ME* had a deep concern with technology trends and the intersection of engineering and society.

Over my time here, I have pushed for more articles authored by engineers and policymakers. No matter how well reported an article may be—and I believe the articles produced by our staff and freelance writers are fantastic—there is something satisfying about reading the thoughts of those dealing with a challenge up close. When the name on the front says *Mechanical Engineering*, the content shouldn't only be about engineers, but to the extent possible, by them.

The cover story in this issue is written by Simon Leigh, a one-time engineering professor who is now the senior manager for global education strategy at Autodesk. He discusses the results of a survey that Autodesk conducted with ASME on the future of manufacturing and how engineering education should transform in the face of the workforce demands of Industry 4.0.

One of the results Leigh found that was most surprising to me was broad support from academics for a shift to a more skills-oriented engineering education paradigm. The ivory tower concept, where universities are isolated from practical concerns, is being replaced by a collaborative approach where academia and industry converge to provide opportunities for students to learn useful skills.

Elsewhere, Assistant Secretary for the Office of Nuclear Energy Kathryn Huff discusses efforts by the Biden Administration to promote advanced nuclear power technologies. Two recent ASME Federal Government Fellows, Michael Woodmansee and Jaclyn Brennan, tell the stories of their work on Capitol Hill, where they each assisted in preparing landmark engineering-oriented legislation for passage. And there's more, including the thoughts of ASME members on the letters page.

As we begin Volume 145, I am proud of the magazine and the showcase it provides for the voices and accomplishments of mechanical engineers. We've set a high mark. Let's see if future issues can meet it—in five years or 145 years. **ME**

FEEDBACK

What do you want to see more of in the magazine? Email me.
wintersj@asme.org



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APRIL/MAY 2022

Reader Minner argues that national manufacturing solutions are not enough.

« One reader argues for regional manufacturing solutions, while another calls for backing up renewables with fossil fuels.



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LOCAL FOCUS

To the Editor: I found myself nodding in agreement with much of what Steven R. Schmid and Shreyes N. Melkote wrote in their article, "Manufacturing and the Great Resignation" (April/May 2022). The points made regarding the false narrative of an epic decline of the U.S. manufacturing industry, the common view of educators and parents of manufacturing as a career to be avoided by their students and children, and the cumulative impact of these long-held views resulting in a massive workforce shortfall for manufacturers across the country all hit the mark.

I was, however, struck by the sorely lacking discussion on potential solutions. Manufacturing USA is a fantastic network of technology focused institutes; however, like all societal challenges, the manufacturing workforce dilemma will take a "team" effort to address.

When viewed in aggregate, the manufacturing workforce challenge may seem to be a national issue, but it is actually the collective result of challenges across industries and individual manufacturers across the country. In addition to national "top-down" efforts, the solution (or solutions) must also incorporate local and regional efforts directly supporting manufacturers on their specific needs.

That is what the NIST Manufacturing Extension Partnership (MEP) network has been doing for nearly 35 years, and combined with countless local and regional economic development agencies, education and training institutions, foundations, and related community groups, they form

a backbone of support for manufacturers across the country. Fortunately, shortly after the inception of the Manufacturing USA in 2014, teaming across these organizations (in particular, between Manufacturing USA and MEP) became a key focus. Manufacturing USA focuses on developing technologies and workforce solutions, then the MEP Network helps ensure these results reach the small and medium manufacturers that make up over 98 percent of U.S. manufacturers.

It is key that all these organizations continue to receive the focus and funding required by the massive challenge we are facing.

Matthew Minner, Pittsburgh, Pa.

BACK IT UP

To the Editor: The need for renewable power backup, as discussed in John Kosowatz's excellent article, "Watts in Store" (February/March 2022), is underscored by the fact that at one point in the 2021 Texas blackout disaster, wind power plants on the state grid generated at only 1.6 percent of their nameplate capacity. Grids with conventional plants need 20 percent reserve capacity to reliably serve peak load, but this experience proves that wind turbines need vastly more (and non-renewable) backup for the same security level, and not just for a few hours (a fact that seems not to be considered by those touting the supposedly low cost of renewable resources).

The cost and complexity of providing this support seems insurmountable until

one realizes that it's already there. We don't need to invent or build anything, just relegate existing generation plants, including coal plants, to backup status where and to the degree that renewables are added. We learned in Texas that the weaknesses of renewables can't be fully addressed by power sources such as natural gas supply systems with their own vulnerabilities. A hefty amount of capacity with onsite fuel storage is required.

This solution doesn't provide good political sound bites, but any engineer will instantly recognize the advantage of not wantonly destroying generations of infrastructure investment.

There are two problems. Firstly, grid operators must drop their fixation on market solutions and simply pay backup plants for the service they provide. No generation plant owner will go in the hole by numerous millions of dollars per year in the hope of generating at \$9,000/MWh for a day or two per decade.

The second problem is much tougher. Having a primary power generation fleet and an equal-sized backup fleet will be much more expensive than the present arrangement, and energy is a substantial component of the price of nearly everything we produce. Nations that remain fossil-fueled will then be in a position to capture almost all the manufacturing jobs they've not yet taken, with no net improvement in worldwide CO₂ output. There must be a global solution or no solution, and all signs presently point to the latter outcome.

Don Lock, Bethlehem, Pa.

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EVs TAKE FLIGHT

Two-seat personal VTOL aircraft set to take to the skies.



With delivery currently set for 2024, the Skyfly Axe is a two-seat vertical takeoff and landing aircraft with an all-electric range of 100 miles.

Photo: Skyfly

London-based startup Skyfly is currently taking pre-orders for its Axe, a two-seat personal electric vertical takeoff and landing aircraft (eVTOL). Delivery is slated for 2024.

The Axe, which looks a bit like an overgrown quadcopter, is the fruit of an earlier delivery drone startup, said Michael Thompson, Skyfly founder and CEO.

"My experience started when my background flying helicopters and working with unmanned drones merged," Thompson said. "I was going to pursue a career as a commercial pilot, but everything was going the way of drones. I started a company called The Drone Company, which still runs to this day, and is a service provider, deploying autonomous tech for surveying, inspection and the like.

"From that, I developed the love of

distributed propulsion," he continued. "I initially looked into delivery drones, but saw the market was crowded and complex. The design we came up with just so happened to be good for manned aircraft. Certification-wise, drone delivery created a lot of issues, and I wanted to create something that fell in line with existing light-aircraft regs."

It is these regulations that Thompson and team hoped to stay within based on weight, size, and capabilities, because the Axe is a fixed-wing aircraft.

"The whole approach that we're going for is traditional aircraft design, not trying to reinvent the wheel," Thompson said. "This is a four-wing design—essentially a quadcopter—but it flies as a canard-configured fixed-wing aircraft. You get the best of both worlds."

With a 48-kWh battery pack on board, the eVTOL weighs 944 pounds. It can

carry a load of 379 pounds, and has a maximum takeoff weight of 1,232 pounds, 1,543 pounds of thrust, and can travel up to 100 miles in flight on battery power. It also has a hybrid variant that combines a smaller battery pack with a range-extending generator if you need to travel farther—200 miles is possible in that configuration.

The team spent three years working on the Axe and went through five iterations and designs, Thompson explained, with the end goals being maintaining affordability, keeping it lightweight, using what's already available, and prioritizing safety. The Axe has a 9:1 glide ratio with mechanical linkage to control surfaces. That enables the Axe to not be reliant on electric control systems in the event the redundancy of its eight engines were to be compromised.

A fully electric version has batteries

in the front and the rear bulkheads. "We needed only to work out what fuel levels we need to give us the performance we want, but still being fully electric," Thompson said.

Similar to a consumer drone, the Axe rises vertically on four 4.9-foot diameter propellers and tilts forward to gain horizontal speed like a helicopter. It can reach high speeds of 100 mph and measures 16.4 feet long.

For redundancy while hovering, the aircraft has two 35-kW motors, giving each propeller 70 kW. While the three-wheeled aircraft can takeoff and land vertically, it can also takeoff like a conventional airplane from a runway as short as 164 feet. The aircraft can climb at a rate of 2,300 foot per minute.

"Again, this is how we can hit the price point," Thompson said. "We can get all the components off the shelf. Don't have a lot of overhead; Using motors that exist already; Flight control systems have already been proven. We know they work. We aren't reinventing anything that works, which saves a lot of cost.

"We've got it so right with our two-seater," he said. "And you can do a lot of maintenance yourself. Don't have to open anything to do your A Check—just visually inspect it. It's a whole new world and an owner-operator heaven."

As to where Skyfly sees itself going in the future, the sky truly is the limit, Thompson said.

"We want to prove we're safe and it's not dangerous to fly the Axe," he said. "Once we have a cohort of happy customers, we may go into a five-seat commercially certified aircraft. That is one of the end goals, especially for our investors."

For now, Skyfly is preparing for production and delivery of its pre-orders in 2024, with a base price of approximately \$175,000.

For those with the money and the inclination, reservations can be arranged at www.Skyflytech.com. **ME**

MICHAEL BEACHUM is an independent writer in Dallas, Texas.

RECYCLING E-WASTE CLOSER TO HOME

Recovering rare-earth metals from used electronics is an expensive but necessary endeavor. Recycling used electronics keeps hazardous metals out of the environment, of course. But one part of the recycling dynamic tops even that: separating the special metals from the e-waste stream, while doing so economically and without creating pollution.

For at least one researcher, that means creating a recycling process that can be done in communities—to "recycle locally," as it were—and add income and jobs at the local level.

All this turns out to be a big endeavor.

The rare-earth metals recovered in recycling are needed to make new electronics, like phones and laptops. The metals—they are the lanthanides on the periodic table—aren't really rare, but mining and separating them in a tedious process, said Vishnu Sundaresan, a mechanical engineer who manages the Recycling at Point of Disposal (RPOD) program funded by the U.S. Department of Defense.

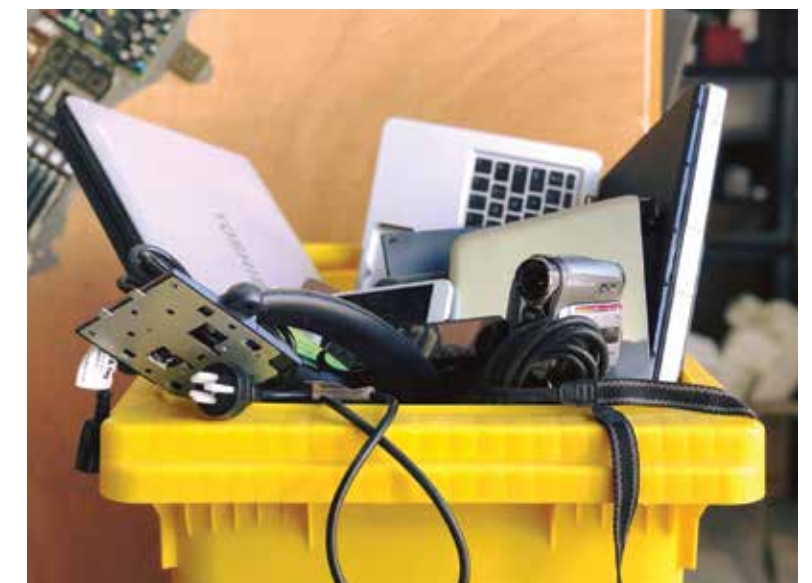
It makes economic and environmental sense to reuse the metals gleaned from outdated devices. But that doesn't mean electronics recycling is inexpensive.

Far from it, Sundaresan said.

The critical elements are a small part of the e-waste stream, about 0.1 percent to 5 percent, and Sundaresan said the current method used to separate them is inefficient, expensive, and causes pollution.

Today, recovery is mainly done through smelting, separating the materials through melting. The process calls for extremely high tempera-

continued on p. 15»



Electronics contain rare-earth minerals that can be recycled for reuse. Current recycling processes are expensive and cause pollution.



HOW PRODUCTION-READY IS ADDITIVE MANUFACTURING?

To find out, go **beyond the success stories** and look at whether AM can meet your expectations.

With success stories ranging from eyeglass frames to aircraft parts, additive manufacturing has been shown to be production capable. Leveraging what AM does differently produces tales with outstanding results and intriguing outcomes.

When weighing how well AM could work with your business, it is important to ask, are the stories that make the news exceptions? Or are they representative of a broader swath of industry? In other words, what is additive manufacturing's production-readiness level?

Speaking in a qualitative sense rather than quantitatively through measures such as technology readiness level or TRL, the degree to which additive manufacturing is production-ready depends on requirements and expectations.

“IF YOU PLAY BY THE OLD RULES, GAME OVER. IF YOU REWRITE THE RULES WHILE STILL DELIVERING PRODUCTS THAT WORK, THE DOOR TO PRODUCTION READINESS OPENS.”

It is often said that insanity is doing the same thing and expecting a different result. When it comes to expectations of additive manufacturing, it is not exactly rational to demand the same things that you have come to expect from traditional processes. Additive manufacturing is different, and with the differences come unique challenges.

If you gauge additive manufacturing based on the same operation and performance criteria for molding, machining, or casting, the differences become outliers on the manufacturing scorecard. The outcome is that production-readiness levels fall, possibly removing the additive approach as a manufacturing option.

So, the key to achieving production readiness is to adjust the requirements and alter expectations.

Obviously, some mandatory requirements must be met to deploy AM for production work. There are some projects for which these measures may make the production-readiness level unsatisfactory. If so, keep using your established production method.

However, many production characteristics may be unquestioned legacies from prior work when manufacturing with conventional methods. On the surface, they may appear to be absolute requirements; when investigated, they could prove to be more flexible than initially believed. It is these measures that can make or break additive manufacturing's production readiness. If you play by the old rules,

game over. If you rewrite the rules while still delivering products that work, the door to production readiness opens.

Rising a level above part specs, such as tolerance and surface finish, there are several potential deficiencies when it comes to production work. For engineers and managers who want to use additive manufacturing, these capabilities may require adjustment to expectations. Two criteria that can doom the production opportunity are throughput and part cost. When measured against high-volume processes like injection molding, additive manufacturing is very likely to fall short.

Some recent conversations I've had with contract manufacturers revealed

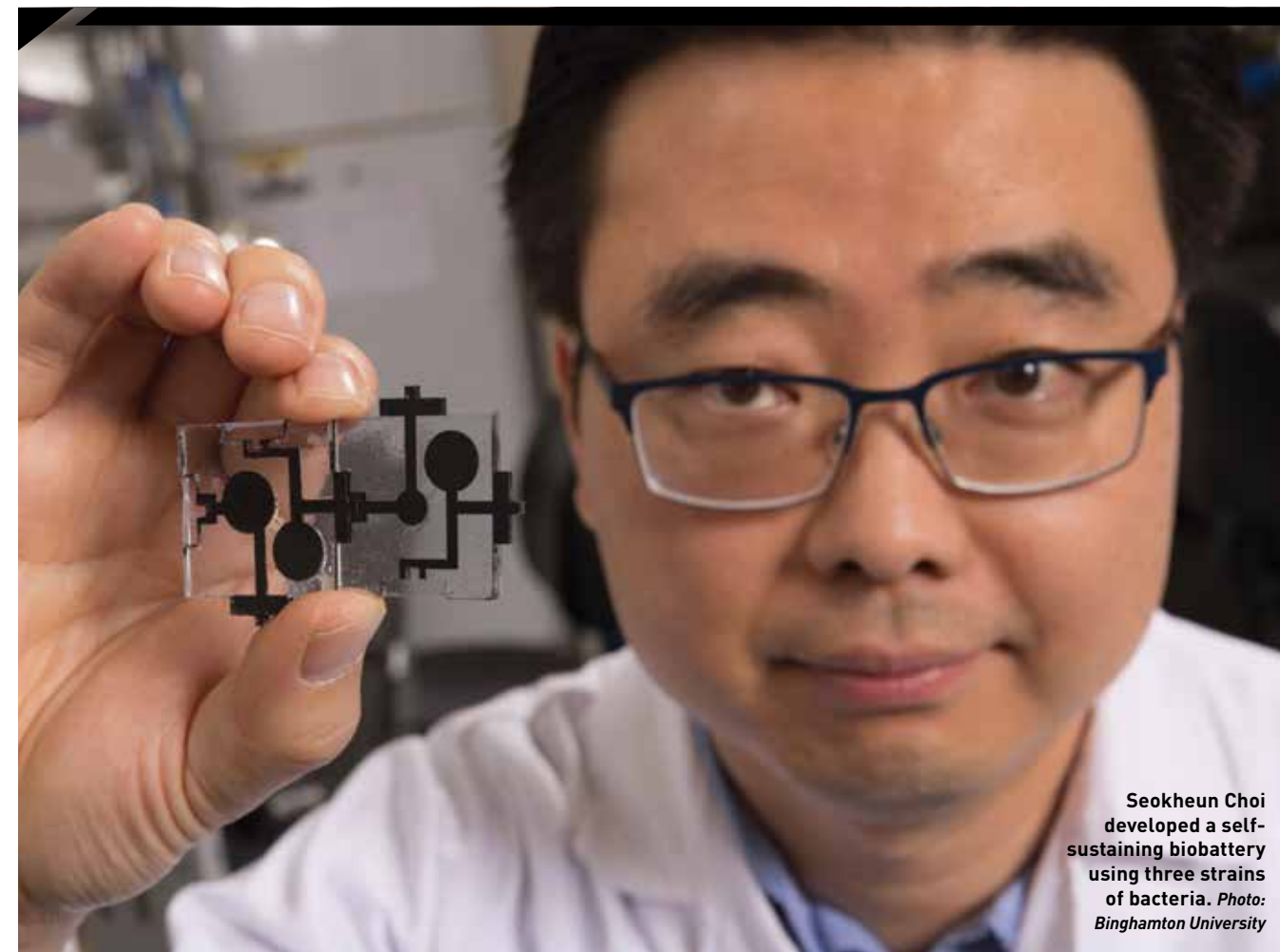
additional shortcomings when evaluated through the lens of established manufacturing operations. These include machine reliability, machine repeatability, mechanical property consistency, automation, and integration, which boil down to achieving high yield and high efficiency on the production floor.

The final two shortcomings that I will mention are in the category of control, which manufacturers covet. To varying degrees, those that develop additive manufacturing machines have limited users' control over the printing parameters and barred the ability to repair a broken machine. This we-know-best approach contradicts the routine operating procedures for all other manufacturing processes.

With all of these deficiencies, can additive manufacturing be production ready? For those who have invested time and energy into adaptation to counter additive manufacturing shortcomings, the answer is "Yes." But for those companies that expect an out-of-the-box experience to be just like that of conventional manufacturing will find the answer to be a resounding "No."

You can make additive manufacturing production-ready for suitable projects. That is what the companies behind the success stories have done. They invested the time to understand, characterize, and counter the factors that impede production readiness. They have adopted a rational approach to implementing AM for production work. **ME**

TODD GRIMM is president of T.A. Grimm & Associates, an additive manufacturing consulting and communications company, and a 30-year industry veteran.



Seokheun Choi developed a self-sustaining biobattery using three strains of bacteria. Photo: Binghamton University

SELF-SUSTAINING BIOBATTERY KEEPS THE JUICE FLOWING

The inhospitable poles, the open seas, fault lines, sun-scarred deserts, and war zones are just a few places where tiny sensors might monitor their environment, wirelessly reporting their findings back to civilization. To do so with any reliability requires some type of long-term battery to power those sensors.

"These electronics will be in very remote locations, so it's really hard to replace the batteries," said Seokheun "Sean" Choi, a professor of electrical and computer engineering at Binghamton University.

Solar cells take up a large amount of space, are expensive, and don't work when it's cloudy. Other energy harvesting techniques are similarly

dependent on their environment and offer even spottier power.

To solve the problem, Choi has created a self-sustaining battery for micro-devices in harsh and remote environments, and it runs on bacteria.

BY CONNECTING 24 BATTERIES, CHOI WAS ABLE TO PRODUCE ENOUGH ELECTRICITY TO SEND A SIGNAL TO A CELL PHONE.

Choi is not the first researcher to derive a little power from bacteria. But previous efforts, including his own, relied on a single heterotrophic strain. That means that once it's consumed all its food, it won't produce more power until it's been fed again.

To become self-sustaining meant keeping his power-producing bacteria from going hungry. Choi turned to another bacteria, *synechocystis*, which has the ability to photosynthesize. Its waste is food for the power-generating bacteria. Choi also used a third bacteria that breaks down waste from *synechocystis*, converting it to a chemical that improves the power density of the power-producing bacteria.

"The organic material produced by the photosynthetic bacteria will be used by the two bacteria below," said Choi. "That way it will be self-sustainable."

But bacteria cannot live on food alone. They also need the right temperature and humidity. Choi does not see that

continued on p.17»



RESOURCE CONSTRAINTS AND RENEWABLE ENERGY

Despite what you might have read, a reliance on rare-earth minerals won't derail the energy transition.

The economic upheaval unleashed by the coronavirus pandemic has focused a lot of minds on logistics, supply chains, and resource limits. Consumer reaction to empty shelves in big box stores drove some of this, but there is also a debate about the viability of an energy transition—the shift from unabated fossil fuels to cleaner options—that is reliant, in part, on critical rare-earth minerals.

Limits are real. We don't live on an infinite-sized planet. But when I read the phrase *critical rare-earth minerals*, I am reminded of the Voltaire quip about the Holy Roman Empire: It was "in no way holy, nor Roman, nor an empire."

It is true we will need much larger volumes of certain materials to build the magnets and other power electronics devices for a heavily electrified and

copper, graphite, silicon, and more.

These minerals are extracted through conventional earth-removal mining methods and sometimes deplorable labor practices. Lithium and cobalt are especially getting attention either because of the significant volumes needed for the growing battery market or moral hazard of depending on materials from unsafe or unethical mines.

Geopolitics has also put these minerals under the microscope. The risk is that countries such as China, which processes or refines more than half of the world's lithium, cobalt, and rare earths, or Bolivia, which has massive lithium reserves—would cut off supplies to gain economic or military leverage.

These concerns are all worthy of attention and remain a blemish on the world's nascent clean energy sector. Thank-

“FROM A SECURITY PERSPECTIVE, THE TRANSITION SHIFTS AND LESSENS GEOPOLITICAL RISKS.”

clean energy economy. According to the International Energy Agency, an electric vehicle needs about five times as many kilograms of minerals than a conventional car with an internal combustion engine. And solar panels and wind farms need minerals with a total mass three to six times higher per megawatt of generating capacity than natural gas or coal-fired power plants.

However, not all these materials are rare-earth minerals, which inhabit the lanthanide cul-de-sac of the periodic table. While many of the materials gaining scrutiny have exotic or scary names—molybdenum, arsenic, and manganese—others are both familiar and common:

fully, innovators and manufacturers are already working on replacing or minimizing the most contentious materials. For instance, techniques such as the direct extraction from brines or eventually even seabed production are growing quickly or attracting significant investment. The hope is that critical materials could be produced in many places. Further, designers are continually reducing or replacing the lithium and cobalt requirements for batteries. Progress is swift, but demand is growing quickly, so the problem doesn't just disappear.

Suppliers of incumbent energy sources such as coal, oil, and natural gas have used the focus on rare-earth and other

critical minerals to make it seem as if the energy transition is creating more problems than they are solving. In reality, the tradeoff is a net positive. The transition from fossil fuels to renewables may worsen the problems related to critical minerals exposure, but it nearly eliminates the problems related to emissions.

Conventional energy options also have risks from critical materials and mining. They depend on many of the same materials, just a smaller volume. Plus, companies mine or drill to extract fossil fuels, raising concerns about poor labor conditions and pollution.

From a security perspective, the transition shifts and lessens geopolitical risks. Countries with the reserves or processing capacity might cut off the flow of copper or lithium (which is bad and would temporarily slow deployment of new installations); they can't turn off the wind or sun. Users of these cleaner options would be insulated from immediate disruption by bad-acting, heavy-handed petrostates who can turn off the flow of energy. The oil embargos of the 1970s and the weaponization of gas supplies by Russia this year are stark examples of the threat.

The dependence on critical minerals is a substantial improvement in energy security because the disruption only affects the short-lived construction phase of an energy project, not the operational phase, which lasts decades.

In the end, moving to cleaner options might not produce the best of all possible worlds, but despite the increased requirement for key minerals, it is a big step in the right direction. **ME**

MICHAEL E. WEBBER is the Josey Centennial Professor of Energy Resources at the University of Texas in Austin.

continued from p.11»

RECYCLING E-WASTE

tures and bringing the metals to those extremes is where most of the expense comes in, he said.

RPOD is backing initiatives—one of them at Iowa State University in Ames—intended to recover e-waste metals at a fraction of the current cost and without generating toxic gases or liquids. The RPOD program itself is intended to look at how feasible it is to extract up to seven low-volume fraction elements “that would otherwise be lost as process waste in contemporary recovery techniques,” Sundaresan said.

This is where Martin Thuo comes in. Thuo is an associate professor of materials science and engineering at Iowa State, and in June he and his team learned they'd received RPOD funding for their recovery process, which was

inspired by stalactites and stalagmites growing in caves. Instead of smelting the metals, they de-alloyed them producing what Thuo calls a classic “ship in the bottle” effect.

De-alloying metals is a way to separate metals and purify them. The process works through controlled applications of oxygen and relatively low temperatures, bringing the most reactive components to the surface in stalagmite-like spikes.

The least-reactive components remain in a purified, liquid core surrounded by brittle metal-oxide spikes. In that way, the metals are separated.

“The structure formed when the metal is molten is analogous to filled cave structures such as stalactites or stalagmites,” Thuo said.

Stalactites and stalagmites form with water, while the researchers use oxidation to create these structures.

The oxidation technology works at temperatures of 500 °F to 700 °F, which is far below the temperatures needed for smelting e-waste, Thuo said.

Thuo has a vision for his e-waste recovery process, even though work on it is just beginning. He wants the process to be done in towns and cities rather than being outsourced to larger companies. In other words, he wants the profits to stay local.

The equipment would be relatively easy to install and the process doesn't require a large footprint, Thuo said.

The days of environmentally safe, relatively inexpensive recycling of e-waste aren't yet here, but when they arrive Thuo wants the to benefit local economies, rather than distant ones. **ME**

JEAN THILMANY is an engineering writer based in Saint Paul, Minn.

ROBOTIC END-EFFECTORS

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INVESTING IN AMERICA'S NUCLEAR FUTURE

Recent legislation **allocates money toward** replacing fossil-fueled power plants with **advanced nuclear reactors**.

Terry Pratchett once wrote, “Most magic merely consists of knowing one extra fact.” In 1912, when scientists began reporting that carbon emissions from burning coal would impact our climate, the specter of climate change became reality. But atomic power was unquestionably still magic.

In the 1930s, humanity discovered the one extra fact that brought the magic of nuclear fission into reality. Experiments by chemists Otto Hahn and Fritz Strassman, along with the explanatory theory from physicists Lise Meitner and Otto Robert Frisch, revealed the possibility of unleashing vast amounts of power from atom splitting. As world war approached, unprecedented spending by the U.S., a rapidly mobilized workforce, and profound ingenuity enabled us to harness that magic for both war and peace.

As soon as we harnessed nuclear fission, the U.S. built reactors, not just experimental, research, and naval reactors, but also commercial power plants. Between 1970 and 1990, U.S. workers put over 95 GWe of commercial nuclear energy capacity on the grid, slightly more than what remains on it today.

Nuclear energy remains the largest source of carbon-free electricity in the U.S. The goals set by the Biden-Harris Administration for a 50 percent reduction in carbon emissions by 2030, a 100 percent clean-power grid by 2035, and a net-zero economy by 2050 will require a buildout of every clean energy technology available, including nuclear power. When two new Westinghouse AP1000 reactors come online in Georgia (at Vogtle Units 3 and 4) in the coming year, they'll add nearly 2.5 GWe of clean power to the grid.

But that's not nearly enough. Recent

analyses by federal agencies and the International Energy Agency indicate our national carbon mitigation targets can only be achieved by keeping as many existing reactors online as possible and potentially doubling U.S. nuclear power capacity by 2050.

The Biden-Harris Administration is meeting this challenge via the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA).

The BIL includes \$6 billion for the Civil Nuclear Credit Program for credits to keep existing nuclear reactors from prematurely retiring due to economic factors. The BIL also provides \$2.5 billion for the Advanced Reactor Demonstration Program to develop, license, construct, and deploy two advanced reactors by 2028: X-energy's Xe-100 small modular high-temperature reactor in Washington state and TerraPower's Sodium sodium-cooled fast reactor at a retiring coal plant in Wyoming.

Meanwhile, the IRA includes clean energy production tax credits rewarding existing and new nuclear reactors for the emissions they avoid as well as the high-paying jobs they support. IRA also appropriates \$700 million for a domestic supply chain of High-Assay Low-Enriched Uranium (HALEU). This fuel, with a ratio of ²³⁵U between 5 percent and 20 percent, enables higher power densities, supports longer core lifetimes, and is needed for most advanced nuclear reactor designs. Establishing a HALEU supply will help improve U.S. energy security by providing a trustworthy fuel supply chain for advanced reactor deployment.

Today's advanced reactor designs seek economies of scale through modular fabrication and assembly. Many can adjust

their power output to match demand and pair with renewables to provide 24/7 emissions-free electricity. These reactors hold massive potential for decarbonization, not only for a reliable electric sector, but also for clean hydrogen production, desalination, and process heating for the industrial and manufacturing sectors.

DOE's Office of Nuclear Energy supports RDD&D—research, development, demonstration, and deployment—for many advanced small modular reactor and microreactor concepts through our annual appropriations. Chief among these is the Carbon Free Power Project, in which we've partnered with Utah-based energy services provider UAMPS on a first demonstration and commercial deployment of NuScale's VOYGR-6. That sixpack of small, modular, light-water reactors will be built in Idaho Falls and connected to the grid by 2029.

Our planet's clean energy transition must transform terawatts, requiring hundreds of gigawatts of nuclear energy to complement the hundreds of gigawatts of renewable and storage capacity we must also deploy. We must also stop emitting carbon dioxide, which requires retiring fossil generation. Advanced reactors are well-suited to replace these fossil assets without leaving communities and skilled craftspeople behind. If we can replace most of our coal plants with nuclear energy, we may yet meet this moment. But it will require a great deal of engineering, and perhaps a bit of magic. **ME**

KATHRYN HUFF is Assistant Secretary for the Office of Nuclear Energy. She is a member of the American Nuclear Society and past chair of ANS's Nuclear Nonproliferation and Policy Division and Fuel Cycle and Waste Management Division.

continued from p.13»

SELF-SUSTAINING BIOBATTERY KEEPS THE JUICE FLOWING

as a problem. “The beauty of miniaturized systems is that you can add more functional electronics,” he said. “For example, you can add a micro-sized heater. Using a closed-looped system, we can provide an appropriate temperature for the bacteria.”

A single 3-cm-by-3-cm biobattery produces between 10 and 100 microwatts. That might sound tiny, but it's a giant leap from Choi's first photosynthetic fuel cells, which eked out picowatts.

The new bacteria sandwich can also be linked, in series or in parallel, to increase the output. By connecting 24 batteries, Choi was able to produce enough electricity to send a signal to a cell phone.

Choi is experimenting with various ways of increasing the power density, including the addition of nano particles to improve electron transfer efficiency and different materials to improve the microbe/anode interface. One thing he's not considering is engineering a better bacteria.

“I wanted to use naturally existing bacteria,” he said. “We have no idea how genetically engineered bacterial cells affect our environment. It could be negative or positive. We have no idea.”

So far, the battery has survived, producing energy for 22 days, a great jump from previous bacteria-driven batteries that lasted only a few hours. Using micro-heaters and other improvements he's working on, Choi hopes to extend the duration to months and even years. He also plans on eventually making a biobattery package that can float for sensing applications in oceans and waterways, and to make it self-healing for greater self-sustainability.

“This is a first step,” he said. “We have a long way to go.” **ME**

MICHAEL ABRAMS is a technology writer based in Westfield, N.J.

LAB TO PRINT HOUSES FROM WASTE

The Advanced Structures and Composites Center at the University of Maine in Orono is putting its polymer 3D printer (the world's largest) to good use—quite literally. Researchers there plan to build good, cheap, fast, and economical housing from wood that would otherwise go to waste.

Unlike most printed construction projects, which use concrete, the center's project capitalizes on some of Maine's natural resources, specifically wood fibers and wood residuals such as scrap lumber, sawdust, construction debris. They hope to sidestep the increased costs of traditional construction materials caused by supply chain disruptions.

The center, in partnership with researchers at the U.S. Department of Energy's Oak Ridge National Labs in Tennessee, has created a way to convert the wood materials into a fine, powdery sawdust (what it refers to as “wood flour”) that's then bound by biopolymers made from corn or other plants before the mixture is formed into pellets, melted, and extruded into a desired shape.

The initiative is just one of many innovations coming out the new digital research laboratory specializing in large-scale, bio-based additive manufacturing that uses artificial intelligence and arrays of huge 3D printers. It is projected to be a \$90-million facility that many anticipate will be no different than, say, a next-generation car manufacturing line, building sections of homes, or modules, before delivering them to sites where they are then assembled.

According to Habib Dagher, founding executive director of the composites center, the hope is the lifespan of the homes it creates will rival and even surpass the quality, durability, and reliability of conventional housing.

Printing modular housing may also address another dilemma facing the construction industry: a shrinking workforce due to retirements outpacing younger workers entering the industry. In fact, it's challenging to find drywall installers, electricians, and plumbers since many young people entering the workforce prefer working with computers or other less-physical tasks.

The hope is the new construction paradigm will greatly reduce construction costs by essentially adding value to low-grade wood residuals that are cheaper than lumber. By using its emerging robotic and artificial intelligence technology to automate construction, it's predicted a traditional stick-built home can be constructed faster and less expensively, but equally as sound.

Mark Wiesendanger, development director at MaineHousing, the state housing authority, said all indications suggest the material looks to be both weather- and insect-proof, and because the material is natural, it's environmentally friendly and doesn't off-gas like plastic products.

The center, in collaboration with MaineHousing, is currently building a prototype—a single housing unit, which they hope will be ready for outdoor testing by the end of the year, according to reports. It anticipates that the facility could “print” a 600-square-foot house in as little as three days, including the walls, roofing, and floors. The technology could someday also be used to create apartment buildings, the researchers said. **ME**

MICHAEL BEACHUM is an independent writer in Dallas, Texas.



A new composite of wood and biopolymers can be extruded into components for cheap and durable new homes. Photo: University of Maine



STRIVING TO BUILD WORKFORCE 4.0

ASME's philanthropic programs aim to develop engineering education, career support, and innovative ideas.

Two irrefutable facts confront today's engineering community.

The first is the pervasive shortage of technical talent prepared to meet the workforce demands of Industry 4.0. The second is the imperative to build both environmental and social sustainability into every engineered solution.

Fortunately, there is a clear path forward on both fronts.

ASME's philanthropic programs are sharply focused on meeting the related challenges of advancing a more equitable and inclusive Workforce 4.0 to build a more sustainable future. Simply put, we will never solve the world's great problems without harnessing the broadest array of talent drawn from the full spectrum of humanity. That means not only

message that engineering is a rewarding, exciting, and welcoming profession. Our robust college scholarships program helps put an engineering education within reach of those for whom tuition may be a formidable barrier. And programs like E-Fest and E-Fest Careers allow engineering students to network with employers and demonstrate their technical and collaborative skills.

The next strategy is *Careers that Matter*. ASME's philanthropic programs include two that help bridge the gap between education and employment, especially for those who are underrepresented in technical fields. ASME's Community College Education Pathways initiative provides resources to students and faculty at two-year institutions to better

ASME's programs promoting sustainability fall under the third strategy, *Ideas that Innovate*. Participants in Engineering for Change, or E4C, and ISHOW, along with its recent spin off, Idea Lab, address the United Nations Sustainable Development Goals (SDGs). E4C Fellowships advance both environmental and social sustainability through six-month, technology-driven impact projects around the world. The E4C online platform is a one million-member innovation community focused on solving the UN SDGs.

Social entrepreneurs look to ISHOW, ASME's thrice-annual hardware accelerator, to receive design guidance and seed capital to further develop their solutions from prototype to marketplace. Modeled on ISHOW, the recently launched Idea Lab engages entrepreneurs at the earliest stage of the hardware development process.

Education. Career support. Innovative ideas. These are the three strategic pillars of ASME's philanthropic programs. Based on rigorous tracking and performance data, these initiatives are making a positive difference. Our mission now is to scale them to amplify their global impact.

Fueling that mission is the ASME Foundation's Campaign for Next Generation Engineers, a five-year, \$50-million fundraising effort whose supporters share our belief that a sustainable world is possible, and it will be tomorrow's more diverse, better prepared engineers who will build it. **ME**

STEPHANIE VIOLA is executive director of the ASME Foundation and managing director of ASME Philanthropy. Find out more about ASME's philanthropic programs at www.asmefoundation.org.

“WE WILL NEVER SOLVE THE WORLD'S GREAT PROBLEMS WITHOUT HARNESSING THE BROADEST ARRAY OF TALENT DRAWN FROM THE FULL SPECTRUM OF HUMANITY.”

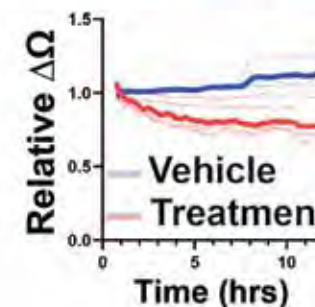
empowering and enabling more women and people of color to become sustainability innovators, but also creating new opportunities for those with two-year degrees and other certifications to enter the technical workforce.

Because it is positioned at the intersection of industry, academia, government, and the nonprofit sector, ASME is uniquely able to convene all these stakeholders in a coordinated effort to help make the engineering profession more equitable and the planet more sustainable. We've adopted three key strategies to effect this ambitious transformation.

The first strategy is *Education that Inspires*. This begins with reaching students in the early grades with the

align the curriculum with the needs of local employers, and provide internship, apprenticeship, and employment opportunities to students. A related program concentrates resources at historically Black colleges and universities.

Just this fall, ASME launched FutureME, a comprehensive online career development platform that is the first of its kind in the engineering community, enabling students and early-career engineers to, among other tools, map potential career paths and identify the training and certifications required to pursue them. Eventually the platform will include an employment networking resource to match employers with those seeking technical jobs.



PERFECT FIT

Elastic sensor measures changing tumor size to one-hundredth of a millimeter.

When treating cancer, one of the most basic tasks physicians do is measure the size of the tumor. Has it grown or has it shrunk, and by how much? To do so, doctors order expensive but accurate imaging tests, or in some cases measure tumors by hand using calipers.

That could change soon with a new elastic sensor that measures tumor growth or shrinkage in real time.

The device is made of thin elastomeric material overlaid with a very thin layer of gold. "The sensor itself was born of the idea of using cracked gold in flexible and stretchable electronics," said Alex Abramson, now an associate professor of chemical and biomolecular engineering at Georgia Tech. "Cracked gold works really well, allowing for conductivity at about 5 percent to 15 percent when stretching."

As a post-doc, Abramson was part of a team at Stanford University's lab operated by Zhenan Bao, that set to work on the project, developing the device in a little over two years. Abramson said, to his knowledge, it is the first sensor used in cancer research to measure tumor progression.

"That's what's really exciting," he said. "It may very well have been used in other applications. But when you get up to much higher levels of stretching and strain, it exponentially increases its resistance, and so we are operating in this area where the exponential increase in resistance is occurring to allow us to get that really fine level of strain resolution."

The device is called FAST, for Flexible Autonomous Sensor measuring Tumors. It is detailed in a paper published earlier this year in *Science Advances*.

It has been tested and used on mice partly because tumors can be grown on or directly under the skin, allowing easy

ASSESSING CANCER-FIGHTING DRUGS

LAB Bao Research Group, Stanford University; Zhenan Bao, leader.

OBJECTIVE Utilize principles from chemistry, physics, and material sciences to develop flexible and stretchable materials, electronics, and energy devices inspired by human skin.

DEVELOPMENT Create an elastic sensor that fits on mice tumors to measure growth or shrinkage in real time, assessing the efficacy of unproven cancer-fighting drugs.

application, said Abramson. Its near-term use promises to be in assessing the efficacy of cancer drugs.

Thousand of new cancer drugs are tested every year on mice with subcutaneous tumors. But the process in assessing their effectiveness is slow because present technologies for measuring tumor regression from drug treatment take weeks to provide an answer. It is difficult and labor intensive work, especially if tumors must be measured by hand with calipers. Radiological methods cannot deliver continuous data needed for real-time monitoring.

Researchers said there are three major advances to the technology. It provides continuous monitoring because the sensor is applied physically to the mouse; its flexibility covers the entire tumor and can better measure shape changes; and it is autonomous and noninvasive.

The sensor wirelessly connects to a small electronic backpack that parses data and sends to smartphone. Future drugs can be easily tracked and quickly assessed for their potential.

Abramson said the device is easy to fabricate, using about \$60 worth of off-the-shelf materials. "Our publication shows how anybody in any type of research lab could fabricate this device," he said. "The hope is that people will adopt this around the world, and it won't be just us working on it." **ME**

JOHN KOSOWATZ is senior editor.



Q&A PHIL BAYLY

LEARNING HOW PEOPLE GET CONCUSSIONS, or traumatic brain injury, is an important first step in treating or even preventing them. Philip Bayly, the Lee Hunter Distinguished Professor of Mechanical Engineering and chair of the Department of Mechanical Engineering and Materials Science at Washington University in Saint Louis, is one of the foremost researchers in the study of how external shocks manifest themselves in the brain. He gave a talk on the subject at the 2022 ASME International Mechanical Engineering Congress and Exposition.

ME: How did you start studying traumatic brain injury?

Philip Bayly: A group of physicians at Washington University School of Medicine asked us, what are the forces and accelerations on the human head when playing sports? We quickly went on to ask: What's happening inside your head? How is the brain deforming? What stresses and strains are in there?

If you think about it, it's natural that mechanical engineers would tackle those questions for acceleration stress.

ME: And what does happen?

PB: Your skull and brain move together—then the skull stops, and the brain keeps on moving because of its inertia and interacts with the skull. The brain is going to deform as a result. There are membranes, blood vessels, and collagenous structures that connect the skull to the brain and serve to transmit

energy from the skull to the brain. The process is very mechanical.

ME: What's something unexpected you've learned about that connection?

PB: We learned that the brain has natural frequencies it likes to move at. So, imagine plucking a piano string or guitar string, the string wants to oscillate at a given frequency. Turns out the brain does, too. So, the expression that a person got his bell rung? It's not directly applicable in the same sense—the brain is much more heavily damped, and you're not going to hear the sound—but your brain is going to want to respond to a certain frequency. That's potentially important, because those are frequencies that the brain might be vulnerable to.

ME: When I played high school football 40 years ago, getting our bell rung was treated like a joke. Why did it take so long to treat traumatic brain injuries seriously?

PB: Partly it's an injury you can't see, and in some ways it's subtle to detect even in its effects. So it's an invisible injury. You can go back on the field and function, and you can even resume some normal activities. But it's still an injury and if you go back out and play, you can get more easily hurt again because there's a cumulative effect over time.

The culture of sports was a factor, too. When I played ice hockey, there were some injuries that you were expected to play through. People would say, tough it out. It turns out for brain injuries, you really shouldn't.

ME: Your research is being funded in part by the military. When did they start becoming interested in the effects of concussions?

PB: In the early 2000s, military personnel going to Iraq and Afghanistan were encountering IEDs (improvised explosive devices). Protection was getting better—they had body armor, they had armored vehicles—so these military personnel were surviving the blast. But they were coming home with the effects of blast on their brain.

ME: What can be done to reduce the effects of traumatic brain injury, at least in sports?

PB: I went to undergrad at Dartmouth College, and the football coach at Dartmouth, Buddy Teevens, has no contact, no tackling in practices. He teaches his players to tackle using tackling dummies, and they have far fewer documented concussions. So, the idea of having a controlling and limiting the amount of unnecessary head impacts is a good one.

But in my opinion, for an NFL quarterback to play at full speed, preventing that player from having a concussion is probably impossible. They are tackling each other, and heads are going to hit the turf. It's not because they're intending to injure someone, but because that's how the game is played. **ME**

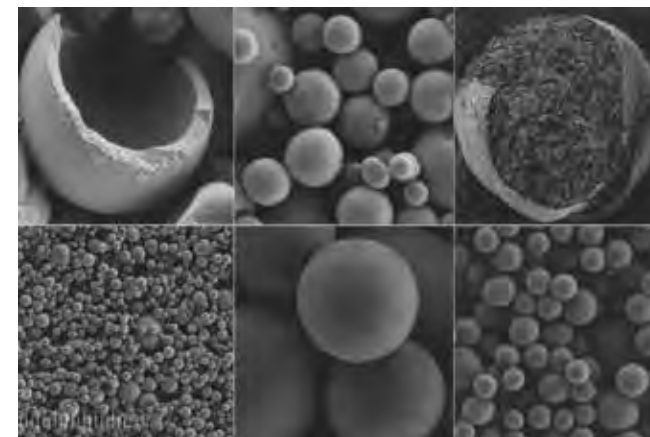
JEFFREY WINTERS is editor in chief.

REPLACING PLASTIC WITH NATURAL SILK

The world's plastic problem isn't restricted to the macro-sized trash floating about our oceans and stocking our landfills. Plastic microbeads, used in paints, agriculture, and cosmetics, are just as serious an environmental threat and are increasingly found in animals all over the world. In an effort to combat the problem, the U.S. has banned the use of microbeads in cosmetics and the European Union has moved to outlaw them completely by 2025.

But the purpose of microbeads—the delayed delivery of what they hold inside—makes them near essential to industry. Herbicides have to be released slowly over time, so they don't kill the plants they are trying to protect. Cosmetics release vitamins when applied to their target area. With plastic, pores in the beads and mechanical breakdown control the timing of payload delivery. But the plastic itself, of course, doesn't break down.

Now researchers at MIT have created a substitute microbead made of a material that is far more biodegradable than plastic: silk.

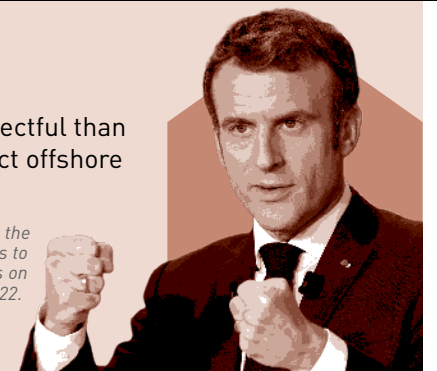


Plastic microbeads are an environmental nuisance. Beads made from silk could replace plastic for most applications.

Images: Muchun Liu, MIT

"Other countries that are no less respectful than we are of wildlife managed to construct offshore wind farms in five or six years."

French president Emmanuel Macron, while touring the site of an offshore wind project that took 11 years to complete. He was quoted by the Financial Times on September 25, 2022.



"We are using silk because it has a natural polymorphism," said Muchun Liu, a postdoctoral associate at the university and lead author of the paper "Microencapsulation of High-Content Actives Using Biodegradable Silk Materials," which appeared in the journal *Small* in July 2022. "When the silk is in the silkworm, it's in liquid form. When it spins out, it automatically transforms into this crystallized insoluble form."

That form can be returned to its malleable state through a simple and sustainable process. Liu and her team proved it by first cutting and boiling silk cocoons in water and sodium carbonate to remove their keratin layer, then they used lithium bromide to dissolve the silk. "It's all physical," said Liu, "We're not chemically modifying the polymer, just breaking the hydrogen bonds." Later, when it's time to reshape the silk, the hydrogen bonds are reintroduced.

The resultant product is not just good for the planet, it's also good for our bodies. "You can eat silk," said Benedetto Marelli, a professor of civil and

environmental engineering at MIT and co-author of the study. And it's not just the process that's sustainable. Each silk cocoon produces a single thread of silk, so if there's any deformation, or if the thread is not long enough, silk producers discard it. "But we're not interested in the

fiber," said Marelli. "So, we can tap into the waste of the silk industry."

Should their technique catch on so much that they end up using more silk than the silk industry currently creates as waste, producing more silk might still prove sustainable. "As long as the agriculture around planting mulberry trees is done in a sustainable way, then using more silk means having more trees in the environment," Marelli said.

The bond-broken silk is nearly as versatile as the plastic it's meant to replace. The polymer chains can be organized so that the material can be tuned to work with existing encapsulation machinery. It can also be made as hydrophilic or hydrophobic as an application calls for. "Different folding provides different properties," said Marelli. "Think about this protein as a very long noodle. When you release a noodle on a table it's going to be randomly distributed. If you carefully position the noodle, it can get a more ordered structure."

Marelli and Liu tested their silk beads with an herbicide. It performed as well as, if not better than, the plastic beads have been doing the job on farms.

"The hope is that other researchers will jump into this work," Marelli said. "The whole society has benefited so much from plastic, but in the last century the focus was the health of people—now we need to start focusing on the health of the planet. This is where everyone needs to come together—consumers, policy makers, academia—to find a way to replace some of these plastic components with biodegradable ones." **ME**

MICHAEL ABRAMS is a science and technology writer based in Westfield, N.J.



Doctoral student Marie Georgarakis demonstrates the Myoshirt. Photo: ETH Zurich

WEARABLE MUSCLES WORK WITH USERS TO RESTORE MOBILITY

Robotic “exoskeleton” technology has greatly advanced in recent years, restoring mobility and functionality to those who have lost it. But these technologies are expensive and typically only used in rehabilitation settings, so they are not practical for everyday use. Alternatively, a group of researchers at ETH Zurich in Switzerland are developing “wearable muscles” inside of a vest-like garment, called the Myoshirt, to fill this gap in the industry.

“The key change was to design these robots so that they don’t behave as an external skeleton with a structure around the human body, but more of a low-profile design where the robot is thought of as an external layer of muscles,” said Michele Xiloyannis, who is part of the postdoctoral team at ETH’s Sensory-Motor Systems Lab.

The team’s vision for the Myoshirt is for

it to be low maintenance, quiet, and sleek enough to be worn underneath clothing, making it an ideal solution for those with restricted mobility who might want to be more discreet.

The Myoshirt was designed based on human anatomy. By assisting the shoulder, the overall functionality of the arm is improved. In the case of stroke patients, for example, by removing the force of gravity on the shoulder, the hand has improved strength and range of motion. Considering this, the team created a closed loop system powered by a single actuator and control unit.

Two anchor points at the shoulder and upper arm are linked together with artificial “tendons” that are crafted out of Dyneema fiber, the same material used for climbing and parachuting. The tendons are guided through Bowden cables, which connect to the actuator

in an external box. When the user lifts their lower arm they activate the system, which then applies indirect force to assist them in completing their movement.

The team recognized the importance of a system that could work with the user in predictable ways. The user wouldn’t want an arm to go up when they’re trying to lower it, so force sensors in the tendon measure speed, velocity, and orientation to detect what movements the user is trying to accomplish, and a gravity assistance model determines how much force to apply. The user can also adjust the force based on their preferences.

“This means that the Myoshirt moves in synchrony with you,” Xiloyannis said. “So you start the movement and the robot follows while removing a percentage of gravitational forces. This is something that we chose specifically because people with neurological and neuromuscular

disabilities have problems elevating their arm against gravity. So gravity is the main obstacle for them, and this device makes them feel weightless so they can do daily activities.”

The team had a number of challenges to work through in developing Myoshirt, particularly with creating a system that could adapt to the specifications of the user. Depending on the fit of the device and the user’s own anatomy, the device behaved differently. Xiloyannis said they researched this for years, using modeling and identification techniques to find these nonlinearities in the system. They ultimately found that by closing an inner control loop on the velocity in the motor axis they were able to counteract the nonlinearities.

“What ultimately fascinates me about this technology is its overall simplicity,” Xiloyannis said. “As engineers, we like to solve complex problems with complex solutions. We don’t always follow the simplest path. And this experience has taught me ‘the simpler, the better.’”

The team is now tasked with streamlining the design. They’d like it to weigh less than five pounds. They also need to make it comfortable so it can be worn for hours, and they want to reduce power consumption and increase its efficiency.

In a controlled study, the team worked with 12 individuals, two of whom had mobility restrictions, and found that all were able to raise their arms or lift objects for much longer than without the Myoshirt. Endurance increased by an average of 36 percent and many of the participants reported the system to be intuitive and easy to use. Xiloyannis said the team was encouraged with the results and their goal is to make this technology a part of everyday life for those with mobility restrictions.

“As engineers we forget that there are also social implications to the way we design these devices,” he said. “Ultimately, what these devices should do is make people more independent and increase their quality of life.” **ME**

CASSANDRA MARTINDELL is a science and technology writer from Columbus, Ohio.

REMOTE CONTROL FOR EXCAVATORS

A nonprofit research institute that has been developing robotic devices for decades has created a prototype robotic excavator to perform some of the typical, if not mostly repetitive, tasks one might expect from such a piece of equipment with just the wave of an arm, the move of a joystick, or through automation.

Reuben Brewer, senior robotics engineer at SRI International in Menlo Park, Calif., said researchers at SRI basically took a diesel-powered hydraulic excavator and created a “robotification kit” to turn it into a robot.

“We don’t touch the hydraulics at all,” he said. “We’ve got computers and sensors that you bolt on to it that, essentially, connects to the internet, and we use electric motors to move all of the levers and pedals like a human does.”

When asked what the motivation was for developing the kit, Brewer explained SRI is always looking for ways to improve people’s lives.

“Construction jobs are a perfect fit where robotics can make workers’ daily grind better by addressing the traditional three Ds of dirty, dangerous, and dull,” he said. “As a starting machine to get people excited about what’s possible, we chose the childhood-dream favorite of the excavator. It turns out that operating an excavator can be pretty uncomfortable and hazardous.

“We thought it’d be awesome to be able to do the same work from the comfort and safety of an air-conditioned, clean space somewhere else on the site, across town, or even in a different city or state,” Brewer said.

The most obvious benefits include everything from safety and comfort to efficiency and autonomy as some of the tech powering the equipment provides complete omniscience, like 360 point cloud for a more immersive experience and to eliminate blind spots. Atop the excavator’s canopy is a light beacon for automatic human detection that immediately stops operation if triggered, as well as stereo cameras. The dust- and waterproof sensors feed a 360-degree view to the operation and safety systems.

The hardware, which also includes sensors, runs off the excavator’s battery and recharges itself as the excavator runs.

Theoretically, operators could be more productive and even work on several different jobsites at once. When asked about the obvious concerns of “robots replacing humans,” Brewer said he sees the robotic equipment as a way to attract a new generation of workers. An operator can be up and digging in 20 minutes since the controls are so much more intuitive and don’t require as much muscle memory. **ME**

MICHAEL BEACHUM is an independent writer in Dallas, Texas.



SRI's robotification kit allows construction equipment to be virtually operated.

Photo: SRI/Reuben Brewer

HOW METROLOGY TOOLS MEASURE UP

Engineer and quality control guru H. James Harrington once said, “If you can’t measure something, you can’t understand it.” Fortunately, the metrology tools now available for engineers can provide a variety of ways to measure objects’ sizes and shapes and, in the process, enable better decision making for part quality, inspection, process controls, and reverse engineering. Manufacturers facing the need for tight tolerances at increasingly smaller scales require higher-precision equipment. For example, some features can be as small as a few thousandths of an inch with positional tolerances of one-thousandth of an inch. Quick and accurate

online inspection is increasingly essential for fine-tuning production and getting products to market faster. Continual growth in computing power and programming has made many advances in inspection technology possible. Because speed is increasingly urgent for manufacturers, especially with supply chain delays, product inspection needs to be fast, accurate, and nondestructive. Some of the top tools that metrology engineers utilize to measure product dimensions and manufacturing processes have been identified below. **ME**

MARK CRAWFORD is a science and technology writer in Corrales, N.M.



BLUE-LIGHT 3D SCANNER

Need to measure something without touching it? Blue-light 3D scanners provide optical, non-contact measurements that capture full-field scans of a volumetric area collecting millions of points per scan. The scanners use the principle of triangulation, projecting a fringe pattern of light across a part’s surface. Cameras then record apparent changes in the pattern as it scans across the surface, and the system uses the distortion seen at different angles to determine 3D coordinate measurements. The resulting 3D images detail complex geometric features of the part and any surface defects. Scans can capture up to 100 frames per second with high precision. *Photo: Zeiss*

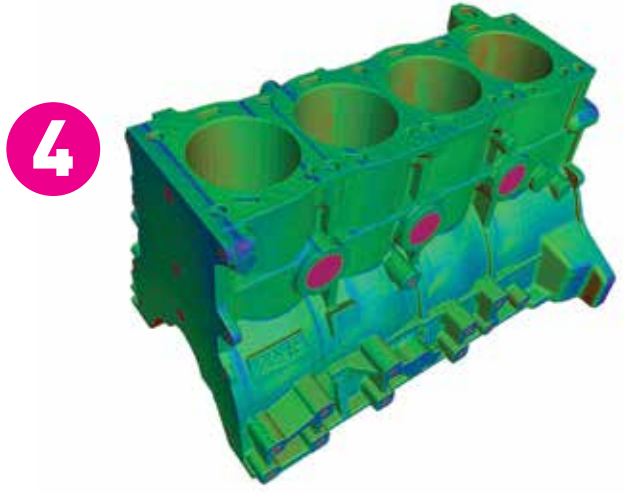
ADAPTIVE MACHINING
Adaptive or “hybrid” machining equipment integrates measurement technology with machining tools on the same machine. Using laser sensors, measurements for a component can be collected in real time as the component is being machined. That means toolpaths can be corrected down to the individual X-Y-Z coordinate points to compensate for any variations in the surface geometry from part to part. That is intended to ensure extremely high consistency and accuracy after each part is machined. Accuracy can be carried over to large parts; one system boasts less than 0.001 inch tolerance even on parts up to three feet long. *Photo: Siemens*



LASER SCANNERS
Typically mounted on a tripod, laser scanners are used when large objects and areas need to be measured. The scanner projects a laser dot or a laser line onto a moving mirror that reflects it across surfaces that can be dozens or in some cases hundreds of feet away, capturing data in real-time. The systems can pull in millions of reference points within a few seconds and laser scanners mounted on robotic arms can measure finer detail than coordinate-measuring machines, sometimes down to one-hundredth of an inch or less. Laser scanners have also been adapted for use in mobile applications such as LIDAR. *Photo: Leica*



CT SCANNING
X-ray computed tomography (CT) equipment takes multiple images of a product from a variety of angles and then employs software and a technician to convert the images into a voxel-based 3D model of the object. The technology can inspect parts inside and out and compare the CT-generated 3D measurement to the CAD model, providing the unique ability to detect internal flaws that cannot be seen using a surface scan. It is also a rapid process; scan times of a few tenths of seconds per part are possible. CT scans can achieve accuracy to the millionth of an inch (0.000001 inches), much greater than other technologies. *Photo: Zeiss*



COORDINATE-MEASURING MACHINES
A longstanding metrology tool, coordinate-measuring machines (CMM) feature a high-precision probe that touches the surface of a part to collect critical-dimension data. Software then analyzes that information to see if the product complies with the original CAD dimensions. Originally, the probe was a small, physical object that was controlled by an operator, but today CMMs can use optical probes and are often on the end of a computer-controlled robotic arm. Although CMMs are highly accurate, they do require parts be physically removed from the production line to be measured off line, which slows down production. *Photo: Faro*

WOMEN IN ENGINEERING

LILLIAN M. GILBRETH, PRESIDENT, GILBRETH INC., MONTCLAIR, N.J.

A pioneer in industrial psychology applies an engineering lens to the question of why women become engineers.

Is there work in the engineering field required to be done, and can adequately trained women do this work satisfactorily? Records going back prior to the First World War and expanding during that war prove that women did all types of engineering work they were allowed to attempt and, in many cases, with far less training than had been thought necessary. This is a much more complicated statement than it may seem, for it involves problems of securing opportunities, securing training, and securing adequate evaluation. Both the exigencies and the motivation of war are apt to be so much greater than those of peace that it is very difficult to utilize war experience in times of peace.

We must add to this the fact that postwar situations, economically and socially, are apt to be such that women return from work outside the home to the home, both because they give up the outside jobs to men and because their home and family duties become, in some cases at least, more demanding. We have, however, a wealth of illustration concerning women who remained in the engineering field and have continuously achieved more or less outstanding success according to the nature of the job and their own capacities. This material had not been sufficiently analyzed and evaluated to open operating jobs in the engineering field to women in this country, before this present war and the defense needs which preceded it began.

There is no doubt that at the present moment women engineers are not only accepted, but increasingly demanded, on operating jobs. Even those most optimistic about the results have been amazed at the rapidity with which women with engineering training have been placed. The number of openings available increase with great rapidity and adjustments to jobs have been made readily and have facilitated operating efficiency.

Turn now to the question: "Is it necessary that women go into engineering?" One may say tentatively, at least, in peacetime and during depressions, "No"; during expansions, "Probably"; in war, "Yes."

Does this mean that the problem is that women go into engineering "to replace men?" If so, we have a far more difficult problem than if we state the need as "to do work needing to be done, which has been done by men in such a way as they can best do it." The first problem implies making over women; the second problem implies making over jobs. The first of these would mean less responsibility to make changes placed upon the operating group, but a terrific responsibility put upon the personnel group. The second problem would mean divided responsibilities between both groups.

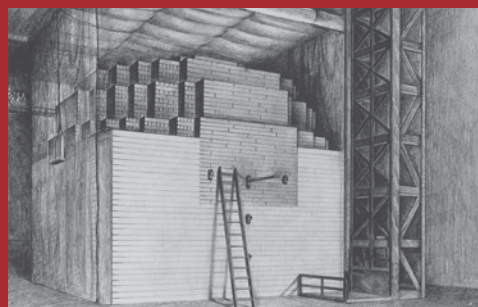


LOOKING BACK

Women were succeeding in roles traditionally held by men when this article was first published in December 1942.

CHICAGO PILE-1

The month that Gilbreth's article about women in the war effort was published, a team of physicists and engineers had a secret success that would change history. On a blustery Chicago afternoon, physicist Enrico Fermi and 48 scientists from the University of Chicago Metallurgical Laboratory, or Met Lab, gathered on the squash court under the west stands at Stagg Field staring at a stack of forty thousand graphite blocks containing uranium and uranium oxide held together in a 24-foot wooden frame. This ungainly assembly was known simply as the "Pile." The group had performed dozens of experiments on the Pile, but this time the Pile achieved the first engineered, controlled, self-sustaining chain reaction for 30 minutes. Chicago Pile-1 had gone critical, and today it is considered the world's first nuclear reactor. This success, combined with other groups across the United States and Canada as part of the Manhattan Project, helped lay the foundation for harnessing nuclear power, and of course, the atomic bomb.



The Chicago Pile-1 reactor, which was built in a converted squash court at the University of Chicago, had almost no safety features. Photo: U.S. Department of Energy

At the present time what is needed on the personnel side is a friendly cooperative attitude toward women who are engineers and those who desire to become engineers. On the operating side, what is needed is a careful study of jobs in order to place women where they can do their best work, and in order to make adjustments where these seem justified. **ME**

THIS ROBOT LEARNS BY WATCHING



Right now, only serious robots are really helpful to humans: the kind that need hours of programming and perform repetitive tasks on the assembly line. We have yet to create domestic robots to make coffee or take out the garbage. The reason is simple: they're just too hard to teach.

Now, a group of researchers at Carnegie Mellon University in Pittsburgh have created an algorithm that lets robots learn by just watching. After only a single human-performed demonstration of, say, pulling out a drawer, a robot equipped with the algorithm will make an attempt at reproducing the action. If it fails, it learns from its mistakes, repeatedly trying till it gets it right.

What's more, it can perform imitative operations in real kitchens and offices, not just in the lab.

"When it comes to getting robots to do different tasks, we're always focused on quasi-static, simple, tabletop setups in very controlled settings," said Shikhar Bahl, a doctoral student spearheading the research at the university's Robotics Institute. "I'm interested in building algorithms for robots to interact in different types of environments and different types of homes—in the wild, basically."

Robotists hoping to create autonomous machines that can work in the

Researchers at Carnegie Mellon have created an algorithm that lets robots learn by just watching. Photo: Emily Dieckman

real world, with all its complexities and irregularities, are often stymied by a chicken and egg problem: to get a robot to operate autonomously, you need a lot of data, but to collect a lot of data, a robot needs a certain amount of autonomy. Bahl sidestepped the issue by looking at another way of learning. "We were inspired by how children learn," he said. "They watch everything around them."

Similarly, Bahl's robot sees the state of a room before human manipulation and compares it to what it sees after human manipulation. No other goal is input in any other way. It then imitates the human behavior to achieve the end result.

The robot is programmed to pay careful attention to the hands and arms of the person showing it what to do before trying the same movements with its own appendages. If after mimicking what it saw the result is not same, it tries again until it achieves the intended goal.

"There's very little chance it will be successful after just observing," said Bahl. "Once it knows approximately what the human is doing it builds an exploration scheme around it. We want the robot to autonomously get better and better at the task."

The method, called In-the-Wild Human Imitating Robot Learning or WHIRL, has allowed a co-bot to first watch and then learn how to open doors and drawers and close them halfway, fold shirts, clean whiteboards, and turn on faucets.

At the moment, a WHIRL-controlled robot has some limitations. For one thing, it can't judge by sight alone whether an object might be too heavy for its gripper. It also is not skilled enough to imitate meticulous, detailed, or pains-taking tasks like knitting or whisking an egg. Those limits reflect the current abilities of computer vision systems. As they get better, so will WHIRL.

Bahl is also working to advance WHIRL so that it learns not just from live demonstrations, but by searching YouTube videos as well. It could then have a near-infinite abilities.

Such an adept imitator might have a use in manufacturing. "Maybe not on an assembly line, where you need very organized and very controlled programming," says Bahl. "But maybe where people are hand designing different aspects of a product."

Google's Everyday Robotics is also an attempt to create a personal robotic aid for everyday tasks. Their model, though, is language based, where the task matches one it has in its database, like cleaning up a spill.

"These ideas could be nicely merged," said Bahl. "You could have a high-level language model that tells the robot what to do, and it searches on YouTube to learn low-level skills."

Bahl also hopes to create a way for humans to correct a robot if it's not doing things right. He wants to add other inputs like touch, language, and audio. And he wants WHIRL to learn for the long term.

"If I do something in one kitchen, can I do it in another kitchen?" he wonders. "We want it to be able to operate in any different scene." **ME**

MICHAEL ABRAMS is a science and technology writer in Westfield, N.J.

BY THE NUMBERS: WHAT COUNTS AS STEM EDUCATION?

Are U.S. universities minting enough engineering graduates? Compared to other countries, we could be doing more.



This fall, engineering students arrived on campus for a return to more-or-less normal college experience after two years disrupted by the COVID-19 pandemic. The disruption has allowed some space for re-examining what American universities should be doing, including whether they should be more focused on producing graduates with strong technology training.

Earlier in 2022, the National Science Foundation produced a report, *Higher Education in Science and Engineering*, which looked at key indicators for all graduates in science and engineering fields. In addition to engineering, the broad science fields they considered were computer science, agricultural science, social and behavioral science, and a catch-all “physical and biological sciences and mathematics and statistics.” Drawing on data from 2018, some 41 percent of the 1,987,274 non-post-graduate degrees awarded by U.S. universities were in one of these science and engineering fields.

That number tells you very little in isolation. For one thing, these science and engineering fields are drawn in an incredibly broad manner. To facilitate international comparisons, the NSF

report relies on classification scheme developed by the United Nations Educational, Scientific and Cultural Organization and, for instance, includes under the category of “social and behavioral sciences” not only psychology and sociology, but economics, library science, and journalism.

From a technological competitiveness point of view, then, the more interesting fraction of graduates is those receiving “engineering” degrees (which is also broad, but at least only includes fields involved with manufacturing and construction as well as pure engineering). Is awarding 148,000 such degrees a lot—or too little?

The NSF report includes data on degrees awarded by a large number of nations. It makes sense that populous countries such as India and China would produce a lot of college graduates as well as plenty with STEM degrees, no matter how one defines them. In terms of percentages of all students receiving their first degrees, science and engineering accounts for as many as 47 percent of graduates in Russia and only 25 percent in Brazil, but most major countries are similar to the U.S.

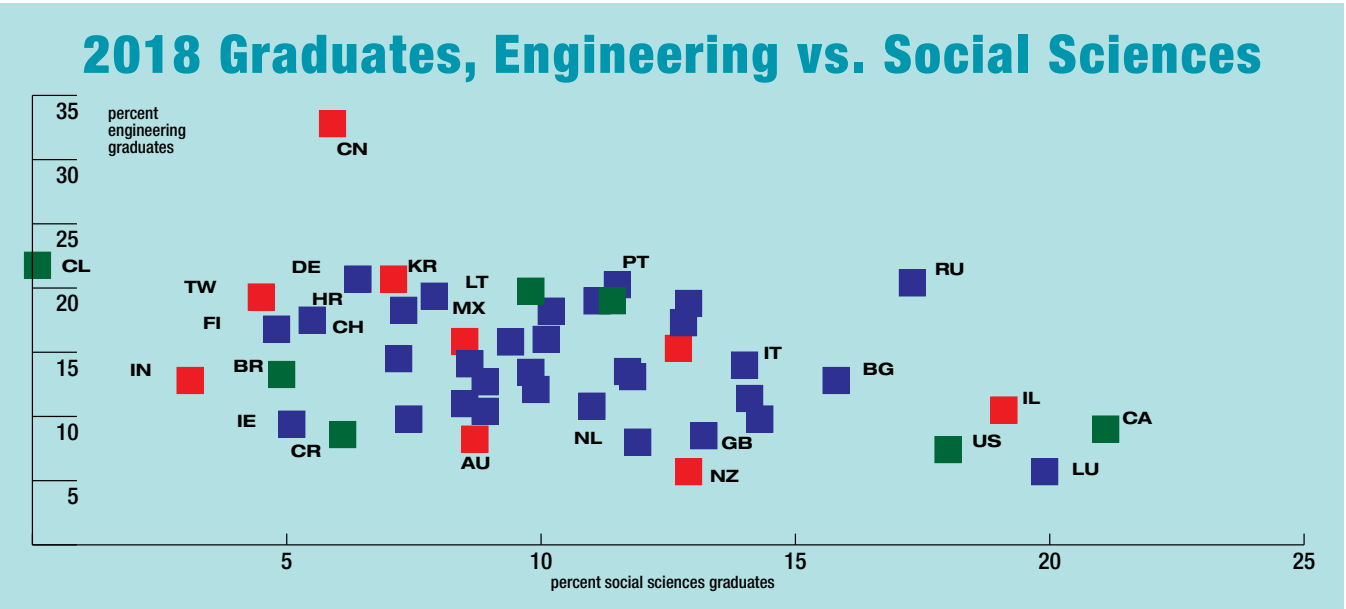
What differs is the mix of STEM degrees. While some countries, such as Canada and Israel, are like the U.S. in awarding far more social and behavioral degrees than engineering ones, that’s not universally the case. Mexico and South Korea, for instance, award twice as many engineering degrees and social science degrees, while Germany awards three times as many and India four times as many. And while the NSF data for China shows it awarded nearly one-third of all its 2018 degrees in the fields of engineering, a footnote admits that the number is inflated by the country combining engineering and computer science. Among all the countries listed in the NSF report, some 17 percent of graduates received engineering degrees, while nearly 8 percent got social and behavioral science degrees—nearly the opposite of the mix in the U.S.

What’s right for Taiwan or Finland need not be the answer for the United States. But given its outlier position, the U.S. may want to consider focusing more on the “E” in STEM and rethink what counts as “S.” **ME**

JEFFREY WINTERS

Top Nations in Producing Engineering Graduates, 2018

Country	All University Graduates	Graduates in Engineering	Graduates in Social Sciences
China	3,868,358	1,269,173	229,645
India	6,474,715	831,504	203,929
Russia	831,676	169,259	143,738
Brazil	1,264,288	163,310	61,622
United States	1,987,274	147,712	358,600
Mexico	624,411	118,690	61,452
Japan	582,020	87,835	49,476
Germany	368,985	76,211	23,543
South Korea	347,179	71,922	24,791
Turkey	454,995	69,460	57,958
France	354,407	50,011	30,396
Taiwan	231,003	44,546	10,418
Colombia	226,506	41,370	25,904
Poland	196,266	37,293	21,883
United Kingdom	405,105	34,353	53,469
Italy	238,792	33,536	33,336
Spain	195,382	24,735	19,062
Canada	198,564	17,686	41,834
Australia	206,726	15,522	17,924
Romania	73,430	13,328	7,511
Portugal	57,269	12,046	6,606
Chile	47,035	9,820	36
Switzerland	55,268	9,679	3,022
Greece	48,004	9,024	6,200



Data source: National Science Foundation, *Higher Education in Science and Engineering*

TRAINING THE FUTURE ENGINEERING WORKFORCE

Industry and academia must collaborate on programs that provide students with the skills they want—and need—to prosper in tomorrow's technology workplace.

BY SIMON LEIGH

It is an exciting time in the world of manufacturing. Industry is rapidly changing and adopting technologies, automation, and digitization as part of a new industrial revolution: Industry 4.0. Across the globe, technologies and processes that seemed impossible just a decade ago—artificial intelligence, machine learning, generative design, and digital twins, to name just a few—are now seen as the basis for growth in the coming decade. These emerging technologies will help companies meet new demands from their customers.

Through digital transformation and wholesale business innovation, Industry 4.0 will no doubt bring with it new opportunities to create the most technologically advanced, sustainable, and efficient products that the world has ever known.

If only job seekers showed the same kind of excitement for manufacturing.

There are record numbers of unfilled jobs across the globe, with many organizations predicting even greater shortfalls in the amount of skilled labor before the end of the decade. According to the Manufacturing Institute, the manufacturing skills gap in the U.S. could result in 2.1 million unfilled jobs by 2030.

The new technologies and processes of Industry 4.0 may help companies address skill gaps in their workforces, at least in the short term, but at this pivotal moment, many industry leaders are wondering: *What will the industry and workforce look like in another ten years? And what can be done to reduce the disparity between the needs of businesses and the skills available in the labor market?*

To help address uncertainty about the future of work and provide some insight, Autodesk and the American Society of Mechanical Engineers collaborated on a comprehensive research project that included an academic literature review, in-depth phone interviews, and surveys of respondents in the U.S., Canada, and U.K. The resulting white paper, *Future of Manufacturing*, was released this fall and offers perspectives from both industry and academia that help identify the future workflows and skills needed, with a focus on mechanical engineers, manufacturing engineers, and CNC machinist roles over the next decade.





One of the key takeaways was the need for educators—spanning secondary to higher education, vocational, and technical training—to better prepare students for emerging technologies while still teaching foundational concepts and theories, all while meeting accreditation standards.

How can educators accomplish all of this in a classroom and why is it so important? I've personally been in this position, asking myself and my colleagues this exact question. As a former lecturer in the School of Engineering at the University of Warwick, I have experienced firsthand the challenges of incorporating new concepts and technology into existing teaching programs. What I found—and what our research backs up—is that it's absolutely necessary for academia and industry to collaborate.

CONVERGENCE

The research we conducted to produce *Future of Manufacturing* told us that as Industry 4.0 adoption progresses, the convergence and digital transformation of job roles across the manufacturing spectrum is becoming increasingly evi-

dent. As this transformation unfolds, mechanical engineers, manufacturing engineers, and CNC machinists will work together more closely, leveraging cloud-based software and fully integrated hardware solutions to design and manufacture the products of the future. As the need for closer and quicker collaboration intensifies, the traditional boundaries between roles will blur and may even start to disappear.

These changes will fundamentally shift the job descriptions of many roles and continue to shape skill requirements at every level of the manufacturing process, requiring a new way of thinking about education and training the next generation. When I personally think about the future, I can foresee a time when mechanical and manufacturing engineers of the future may bear more than passing resemblance to the systems engineers, electrical engineers, software engineers, and data scientists of today.

While we may all have our own visions for the future of the industry, we must also know that we cannot do this work in silos. In order to build a well-rounded study, we spoke with a wide array

of industry professionals and academic leaders to help gather substantial data that paints a more realistic image of where we are today and where we're heading tomorrow.

From our research, we gained valuable insight into the anticipated changes in each of the three roles we looked at over the next five to 10 years.

Our research told us that mechanical engineers will continue to improve upon engineering designs and become more involved in manufacturing implementations and processing production data results to improve designs for manufacturability. This means they will need to have applied knowledge throughout the manufacturing process; no more "throwing it over the wall." The survey showed 80 percent of academics agree that application of technologies like generative design will be a particularly important skillset for this role.

The research also showed that the manufacturing engineer position will become even more interdisciplinary as it blends skills with both mechanical engineers and CNC machinists. They will expand their focus from manufacturing processes to managing the overall production operations and analyzing globally distributed systems, including machining tools, robotic systems, and additive manufacturing facilities. Within industry, 72 percent of respondents believe human-robotic interaction will increase and 74 percent believe automation will increase for this role.

We also saw that CNC machinists' roles will evolve dramatically, moving from being a CNC operator to an engineering technician who programs CNC machines. Over time, they will take on other manufacturing engineering functions.

Of all three roles, this one is expected to change the most. Machinists will need to develop new skills in artificial intelligence and machine learning for production, five-axis machines, additive manufacturing, and hybrid manufacturing. They will also be expected to collaborate more with engineering teams and be more involved

with upstream processes including design, which will require greater knowledge of CAM software.

The research didn't just tell us about technical skills. We also found that workers entering these rolls will need to be proficient with "soft" skills such as problem solving, collaboration, and, of course, communication.

COLLABORATION

What does all this change occurring in the next decade mean for the education and training of a new workforce?

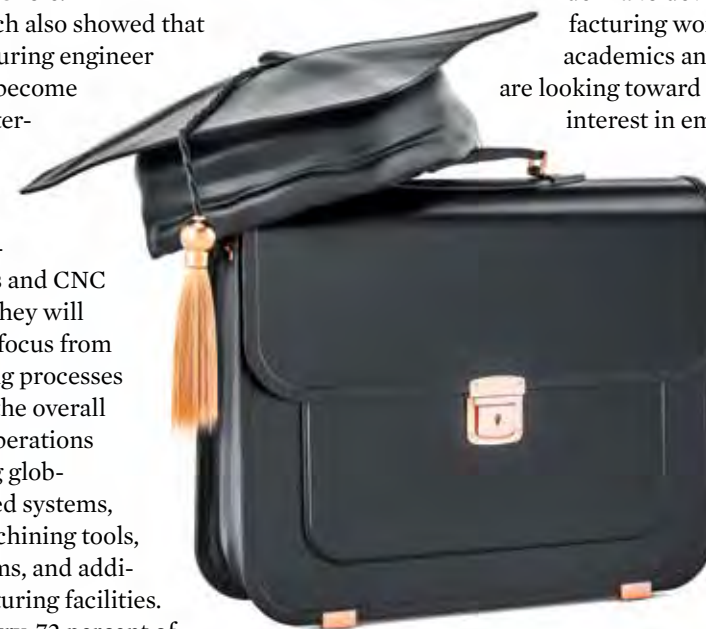
Among the research findings, there were specific indicators for actions to take, like a strong chorus of support for growing students' design for manufacturing knowledge and skills. Some 90 percent of respondents believed teaching this skillset is one of the most impactful ways for academia to develop the future manufacturing workforce. Additionally, academics and industry professionals are looking toward the future with shared interest in emerging technologies

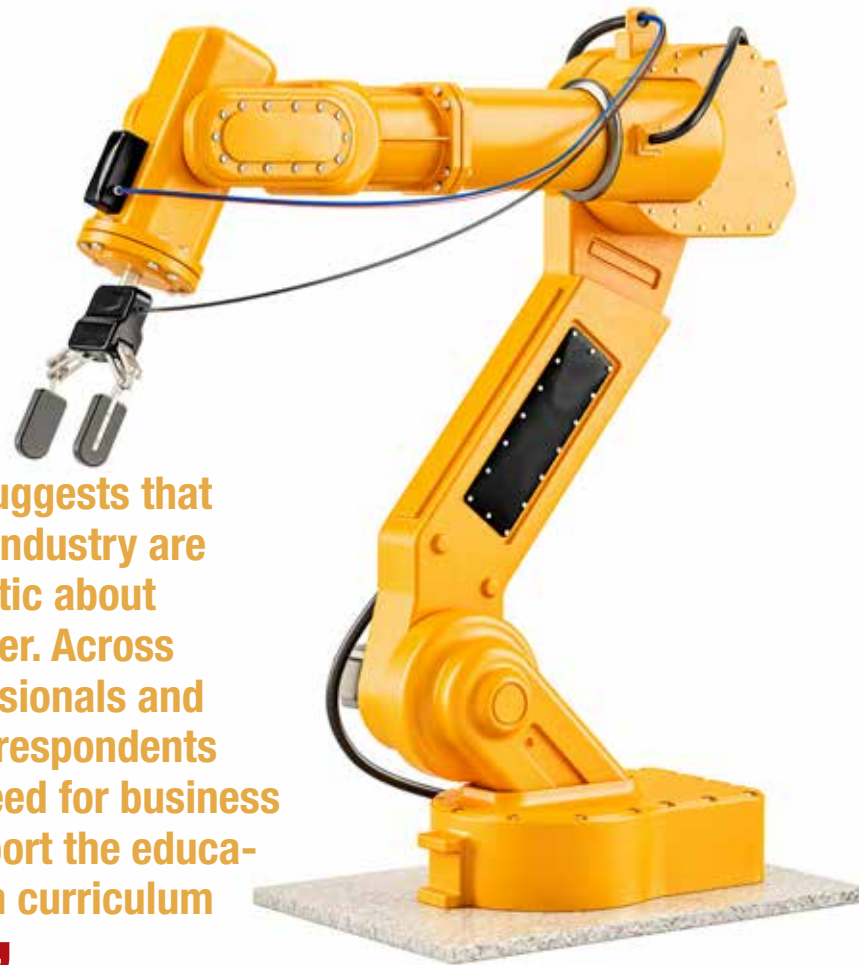
like artificial intelligence, machine learning, and 3D printing. The research pointed to these emerging skills growing in importance and application over the next decade, and fortunately, we know these technologies are fascinating topics to students themselves.

While these insights

are compelling, they also expose a delta between where the industry is heading and the current topics of academic curricula. And with business pressures driving manufacturing to adopt more Industry 4.0 technologies, it is critical for academia and industry to align on trends and requirements as soon as they can. Educators at every level are tasked with preparing students for emerging technologies while still teaching foundational concepts and theories, all while meeting accreditation standards. It's a daunting task.

At the University of Warwick, I was responsible for curriculum development and teaching mechanical engineering and design, which means I not only had to build courses that incorporated





“Our research suggests that academia and industry are each enthusiastic about working together. Across industry professionals and academics, all respondents agree on the need for business leaders to support the education sector with curriculum development.”

new concepts and technology, but I had to do so while keeping the pre-existing skillset of the students in mind.

Students often enter these programs with little or no design and manufacturing knowledge and educators need to bring them up to speed as quickly as possible. This is no fault of the student but does require the training program to broaden its scope and start at a very foundational level to establish key fundamental skills before moving on to more advanced topics and workflows.

Back when I was building courses, one of my dilemmas was whether I should introduce advanced topics like generative design early on in a program or wait until later years. I came down on the side of exposing students to these technologies in their first few weeks to help them build comfort, and then slowly refining their skills over the duration of the program.

While our research focused on speaking with people from industry and academia, I think it's also valuable to have a student perspective in mind. I reached out to some of my former students who went through traditional mechanical

engineering programs to hear their thoughts on what gaps exist between academic programs and industry requirements.

“At times it felt like there was a lack of convergence to the skills I would actually need beyond university—instead it was heavily knowledge-based,” my former student, Elliott Griffiths, shared with me. “In my mind, it would be beneficial to deliver training in workflows instead of discretized delivery of content. Working with end-to-end applied workflows helps develop the skill to learn other skills, making you a lot more comfortable with new processes and applications, in my opinion.”

Elliott's perspective provides valuable feedback on modern education programming and resonates with what we heard from so many other academics about the need for updating curricula with real-world skills.

While there will always be a need for the kind of specialization and research that can only blossom in universities, engineering education must focus on reducing the “time to talent,” that is, the speed at which schools can produce application-cen-

tered professionals. The research showed us that creating “industry-aware” curricula is going to be key in reducing the time to talent.

For this model to work, it is crucial that academia and industry collaborate. Too often there is a perception that academia and industry are at odds with their goals and requirements, and the topic of pushing academia more towards job-ready skills is hotly debated.

We should remember, however, that students are key stakeholders in these conversations. They enter engineering and technology programs with a goal to not just earn an education, but also to find a rewarding job at the end of their program.

CERTIFICATION

Fortunately, our research suggests that academia and industry are each enthusiastic about working together. Across industry professionals and academics, all respondents agree on the need for business leaders to support the education sector with curriculum development.

There is also shared interest in reducing time to talent by leveraging real-world contexts and hands-on experiences.

In addition to teaching new skills in the classroom, educators should also incorporate time for industry-recognized certifications for modern software, machines, and workflows. It may come as a surprise to some, but we learned that 86 percent of academics surveyed embrace less reliance on traditional degrees and welcome more specialized certifications developed in partnership with industry.

Using project-based, role-aligned learning pathways also embraces students' desire to be immersed in meaningful content and target specific skills that will be required in their future jobs. Role-aligned pathways are a great way to target specific skill sets and competencies in new or existing programs and it's something Autodesk has been working on for a while. To give you an example, pathways like Autodesk's

Fusion 360 CAM for 2.5 Axis Milling certification program enables students to follow a self-paced, curated playlist of videos, quizzes, and challenge assignments designed specifically for the CNC machinist role.

Certifications are also going to be increasingly helpful in ensuring students learn foundational skills but also demonstrate their competency to future employers.

In addition, embracing certifications allows educators to avoid forcing students to “log seat time” to demonstrate proficiency. Verifying competencies with industry-validated certifications allows students to make progress on building new skills once they have reached a proven level of expertise.

This approach inherently removes down time from training programs and creates a more personalized learning experience.

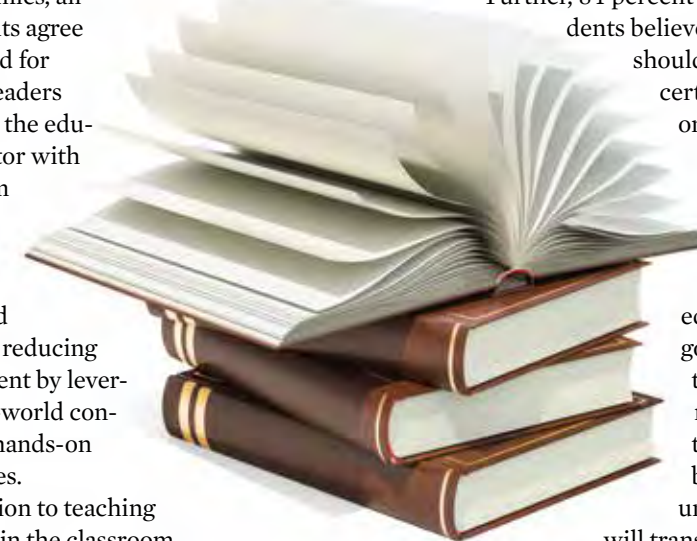
Further, 84 percent of all survey respondents believe employers and academia should partner on new types of certification programs based on employer needs, and 91 percent want new opportunities for long-term internships and co-op programs.

Closer links between education and industry are going to be vital to ensuring that the talent pipeline is robust and able to rise to the challenges of the future, both seen and unseen. It is undeniable that Industry 4.0

will transform manufacturing as we know it today. We also know that education will have to undergo its own changes to keep pace and prepare students with the necessary skills for future roles in manufacturing.

The research we conducted for *Future of Manufacturing* has told us that there is shared interest in this transformation, as both sides can see the benefits. By creating an education ecosystem that closely partners with industry and embraces new Industry 4.0 technologies, we can reimagine workforce development and engineering programs to build a better tomorrow. **ME**

SIMON LEIGH is Senior Manager Global Education Strategy at Autodesk. He is based in Coventry, England. To download a copy of the white paper, *Future of Manufacturing*, go to [ASME.org](https://www.asme.org) and search “Autodesk Future of Manufacturing.”



SPARE PARTS

How much of the human body can feasibly be replaced? It turns out that biomedical engineers are developing tools and technologies to substitute for virtually every organ.

BY KAYT SUKEL

Kazuo Ishiguro's 2005 dystopian novel, *Never Let Me Go*, describes a world in which human clones are created for the specific purpose of organ donation. Young men and women are raised until they are old enough to provide their progenitors with kidneys, livers, and other body parts. Ishiguro's characters are born to serve until they give every last part of themselves.

Fortunately, nothing like that scenario is in the offing. Due to the remarkable advances in biomedical engineering, new technologies like brain-machine interfaces (BMI), robotics, tissue engineering, gene editing, and induced pluripotent stem cell (iPSC) methods, artificial organs are being developed that can replace the function of natural ones. Even now, patients could feasibly receive a skin graft made of bioengineered materials; a bespoke hip joint, 3D-printed to a perfect fit; an artificial retina with the power to relay light signals to the nervous system; and, perhaps most dramatically, a smart neuroprosthetic arm or leg, directly connected to the brain's motor regions.

"As we further our understanding of how our bodies work, the various possibilities for different ways to replace body parts become more and more realistic," said Jeffrey Karp, a researcher at the Mas-

sachusetts Institute of Technology in Cambridge who works on bio-inspired medical problem solving. "There's very little that is actually impossible. It's really just a matter of time to gather the necessary knowledge and then invest in the right tools to create and then refine these sorts of technologies."

As these different technologies mature, one can easily imagine that patients of tomorrow may need a variety of spare parts. They may pick up one or two at a time as they age—a new knee here, a lab-grown pancreas there. Or they may undergo a significant trauma that requires multiple replacements in a short amount of time. Consider someone who is in a serious car accident, or a soldier severely injured by an improvised explosive device. The trauma care team of the future could reach for a variety of different mechanical, chemical, and biomedical tools to help stabilize the patient at the point of care and then restore their broken bodies during recovery.

While such scenarios may seem like science fiction, as Karp said, technology is advancing toward a future where very little is actually impossible.

Such progress poses a vital question for engineers and medical experts: How much of the human body can be replaced?





Robert Gaunt and Jennifer Collinger are researching brain-computer interface technology for individuals with motor impairments, including devising this neuroprosthetic limb.

Photo: UMC Pittsburgh

THE BODY AS DESIGN SPACE

The first step to solving any engineering problem is to define the design space. And that is one of the biggest challenges to answering hard and fast questions about how far we can go with body replacement. The human body is a complex and capricious domain. Once engineers move beyond the control and constraints of a laboratory environment, they can often encounter unexpected surprises about how the bodily tissues, cells, hormones, and other biological molecules respond to a new implant or engineered tissue.

That's why doing diligent research is so vital to replacement efforts. Jennifer

Collinger, a bioengineer at the University of Pittsburgh's Rehab Neural Engineering Labs, and colleagues have been working on creating neuroprosthetic limbs to help individuals with upper limb paralysis or the loss of an arm do things like raise a glass to drink or interact with a computer. Her research team spent a good amount of time trying to understand the specific design space for this kind of BMI.

"In order to move your arm around to perform functional activities, you need to be able to position your hand in space. You need to be able to open and close your hands. For more complex tasks, you need to be able to move individual digits and control the amount of

force you're applying," she explained. "You may maybe even need to feel what you're doing in case you can't rely on your vision to help. The question then becomes where can you get enough information in order to do all that?"

Her research group used electrodes to intercept brain signals from the motor cortex as individuals thought about engaging in different arm-related activities, translating them into control signals for a robotic prosthetic.

"You need to take the time to understand a bit about the biology of the brain area that is most likely to give you the most useful and detailed information about movement so you can use that," she said. "But so much depends on the specific problem you are trying to solve. Is it a high-

level function like raising your arm? Is it a more complex behavior involving grasping? Then, will the same technology work for everyone? It may not be a simple switch to use the same type of interface for someone who has a severe spinal cord injury, or is completely locked-in, as you would for an amputee."

Certainly, labs across the globe have seen remarkable progress in BMIs, particularly for arm or leg replacement. But most of those applications support quite specific functional activities: walking short distances, picking up a ball, or pouring a cup of coffee. Researchers are still working to make such prosthetics perform more generalizable tasks so they can assist patients with basic yet important activities of daily living, like tying shoes or going to a public restroom alone.

Bob Langer, an MIT professor known as the father of tissue engineering, said that is why basic research is so important to these technology advances.

"Taking the time to really learn the fundamentals is important, whatever area you happen to be working in," he said. "That means the fundamentals of biology and chemistry, the fundamentals of chemical and mechanical engineering. Then you can start to think about the biggest concerns involved with these different replacement parts, and that's clearly safety, making sure nothing can go wrong, and long-term efficacy. You also need to think about if they really work the way they should. That they are integrated with the rest of the body so there is no immune rejection or some kind of other interference issue. There's a lot to understand."

Ali Khademhosseini, chief executive officer of the Terasaki Institute for Biomedical Innovation in Los Angeles, added that it is also important to remember that it may not be necessary to replace the organ or limb itself, but simply to find a new way to restore the compromised functionality. That can open up the design space.

"Regaining the function is the most important thing—and we are learning there are different ways to do that, across a variety of different use cases," he said. "People are talking about new

ways to regenerate tissues for organ replacement down the road. But there are lots of opportunities for devices that can interface with the biological systems, too. But it's going to take a better understanding of the biology and the different engineering approaches that may be able to solve some of these different problems to know which approach is going to be the most effective."

But even replacement problems that researchers have worked on for decades can remain elusive. Consider the story of the artificial heart. What many hoped would be a simple mechanical pump has continued to stump some of the best engineers on the planet. Even the most innovative designs still have issues with blood settling and coagulating in the nooks and crannies of the device, leading to severe complications.

"The human body is a really harsh environment," Collinger said. "And, over time, it can be hard to know what it may do to different devices. For example, with our neuroprosthetics, the signal we get from the electrodes we are recording from declines fairly quickly. They just don't have the longevity. Trying to come up with options that will last for years, if not decades, is

a huge design challenge—and one that extends beyond just [BMIs]."

These are all challenging design problems in their own right. But they don't even begin to address the next steps. For instance, what interactions might occur when a patient requires a multitude of replacement parts or technologies, such as someone who has experienced a severe trauma?

"The problem with doing anything inside an animal or inside a human being is that it becomes very difficult to isolate where a particular effect comes from," said Ritu Raman, a tissue engineering researcher at MIT. "And since biological systems are adaptive by nature, it is hard to predict what a biological actuator or material may do in response to a changing environment. There's a lot of things to keep track of—and so much will be dependent on each individual application."

AN ARTIFICIAL EYE TOWARD THE FUTURE

While there are all manner of difficult ethical questions surrounding body part replacement—and no simple answers—Braden Allenby, a researcher at the School of Sustainable Engineering at Arizona State University in Tempe, said there is no doubt we are entering a transhumanist era of design, where many of these applications could be used not just for medical purposes but for individual enhancement. The newly engineered muscle tissue that helps the patient with a muscle wasting disease could easily be co-opted by an athlete trying to build up some bulk before a major competition.

"We are in the process of developing emerging technologies of extraordinary power—and, in many ways, the engineering issues are the more tractable parts of these problems," he explained.

"We haven't really thought about the implications of these emerging applications and yet the development of them is happening at speed."

That is why Langer, Khademhosseini, Raman, and Collinger all said it is important for today's researchers to engage in "convergent" science. To bring together people from multiple

The AbioCor Total Artificial Heart is the first electro-hydraulic artificial heart implanted in a human. Progress in some organs has been slower than researchers first anticipated.

Photo: ABIOMED

A researcher examines tissue produced by an automated bioengineered skin manufacturing process.
Photo: CSEM



disciplines, including the humanities, to not only tackle the engineering problems but the ethical ones, as well.

"Interacting with people from different backgrounds and with different expertise, at the end of the day, is what it will take to get these things pushed forward," Khademhosseini said. "Finding ways to remove barriers across these disciplines so you can speak the same languages and understand the design space in the same way is going to get us to a place where we can do the kind of science that can move these applications out of the lab and into clinical practice."

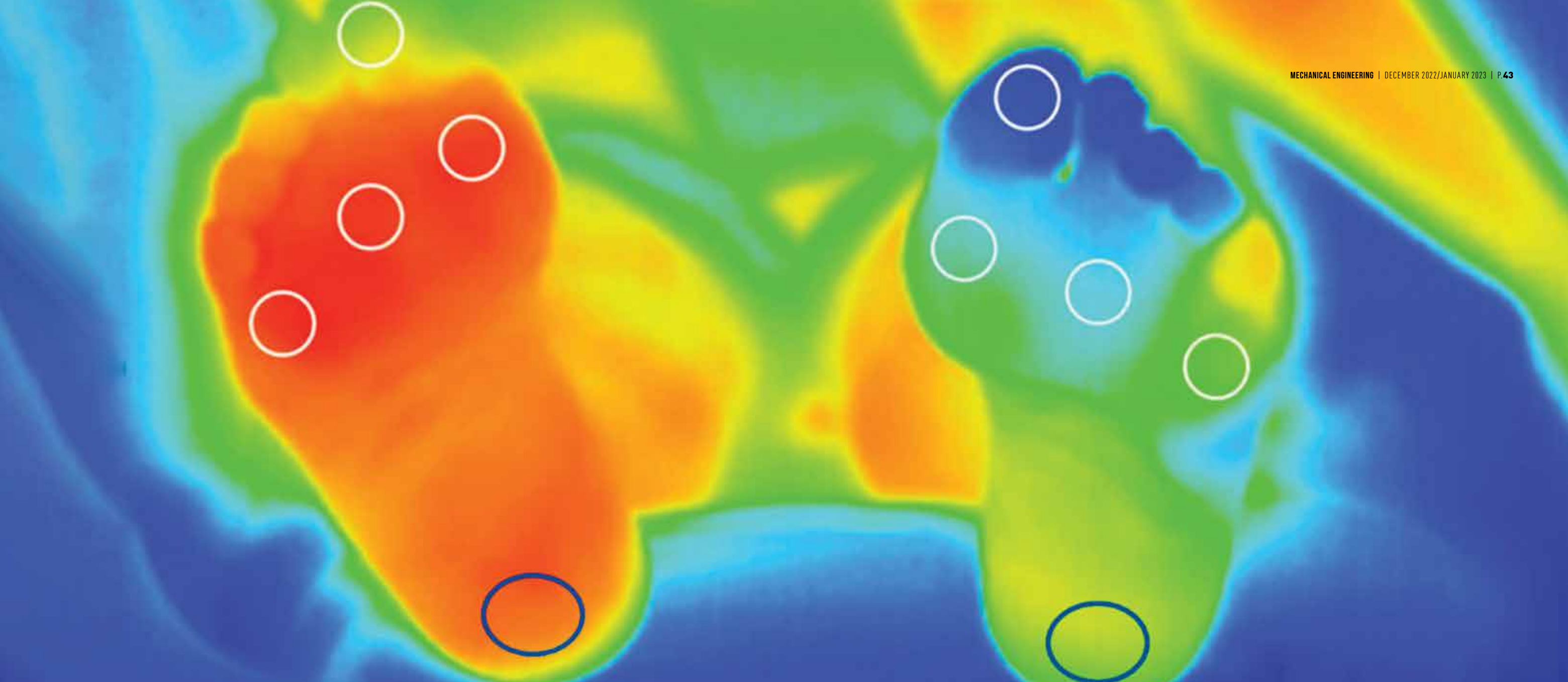
But back to the question at hand: Just how much of the human body can be replaced? Langer said there's no reason to think that engineers, one day, won't come up with novel ways to replace every piece of the human form. It's not a trivial task, he admits—and it will take significant time—but he believes we'll get there. Karp agreed,

though he added that the engineers of today may not even be able to conceive of the new technologies that will get us to that point.

"When we try to predict the future and what's possible, we limit ourselves to the thinking and the knowledge of today," said Karp. "Time and time again, we've learned that many of the most amazing achievements and advances came after a point where the status quo said that kind of approach was impossible. The very technologies we are using today were once ideas that were quickly dismissed out of hand because people thought they were impossible. But with the right research and knowledge in place, there's no reason why we can't, theoretically, at some point, replace or regenerate every part of a human. We just need to do the work." **ME**

KAYT SUKEL is a technology and business writer based in Houston, Texas.





SOLUTION

FROM THE STARS

Foot amputations are on the rise in the Canary Islands. An astrophysics research center there is developing equipment to detect the disease before it is too late to save the limb.

BY CLAUDIA ALEMAÑY CASTILLA

The island of Tenerife in the Canary Islands is something of a paradise: Its warm, sunny weather and plentiful beaches make it a destination for European vacationers. Three-quarters of the Canary Islands' economy is based on tourism, according to local government figures, and nearly 5 million tourists visit Tenerife each year. While the tourists and the money they spend buoy the economy, it doesn't reach all *Tinerfeños*. The government of Spain, of which the Canary Islands are an autonomous community, reports that the population at risk of poverty or social exclusion increased in that territory in 2021 to 37.8 percent, the third highest rate in Spain.

Poverty can have some shocking health effects.

Not long ago, a group of specialists from the Canary Islands Health Service uncovered an alarming increase in the number of lower limb amputations performed in its hospitals. "During the period from 2010 to 2015, the loss of lower limbs increased from 364 to 444 annually," said Manuel Maynar, a doctor with the Hospiten Group, an international hospital network based in Tenerife, and head of its Endolminal/Endovascular Diagnostic and Therapeutic Service. "In total, 2,350 of this kind of surgery were accounted for in just five years."



The crowded shopping district of Santa Cruz shows the influence of tourism on life in the Canary Islands.
Photo: Getty

The amputations were due to damage to lower limbs caused by diabetes mellitus. The condition is often called diabetic foot. Early detection of the damage is difficult but crucial. When left untreated, the lesions can cause the tissues to wither and die. Doctors in Tenerife wanted a tool to find the damage before it was visible to the eye, so they consulted a somewhat surprising source: the physicists and engineers working at one of the world's premier telescopes, which is also located on Tenerife.

QUIETLY DISABLING

People with diabetes can begin to lose sensation in their feet and do not notice when they bump into objects or wear ill-fitting shoes and develop bruises or cuts. Over time, round lesions appear, often on the top of the foot near the toe bones or on the soles of the foot, particularly in the heels.

In a healthy person, such wounds would heal over time, but that isn't the case for people with diabetes, who often have poor blood circulation in their extremities, and the bruises turn into open ulcers. Many times, patients ignore the wounds or expect them to heal on their own. The

damaged area can grow to several centimeters in diameter and slowly but effectively kill nearby tissues. It is not a pleasant sight, since necroses generate pus and discolor the skin. In extremely severe cases, these complications often render the foot completely useless, to the point of having to resort to amputation.

Maximo Selva, a clinical specialist at the University Hospital of Santa Cruz de Tenerife, Canary Islands, explained that these ulcers are an important cause of morbidity in patients with diabetes. On occasion, they can even lead to death.

"The lesions cause disabling situations, as a consequence of the surgical techniques used to combat them," Selva said. "Often the solution is amputation. Even so, the diabetic foot is the chronic complication associated with diabetes mellitus that is easiest and simplest to prevent."

The lack of sensation in the feet and toes complicates the early detection of these wounds. When the lesions are not caused by impacts severe enough for the patient to notice, the damage may spread for some time under the undisturbed skin. An exhaustive physical examination and a detailed interrogation of lifestyle habits are required to achieve an early diagnosis.

The uptick of diabetic foot and subsequent amputations in Tenerife is a bit of a mystery. "Local people consume mostly the varied Mediterranean diet," Selva said. Though there are not enough studies to confirm a change in diet as the culprit, Selva did note that with the increase in foreign visitors, a number of fast-food restaurants have opened in the Canary Islands, which could be leading to an increase in dietary sugar.

There are many other contributing factors, such as smoking, obesity, or even inadequate footwear. Most of them, if modified early, can be treated and their effects reversed.

However, other elements such as age or the time of development of diabetes are more difficult to modify, as are contributions from unrelated circulatory, kidney, or neurological diseases. Despite techniques to curb the impact of ulcers, physicians still have a major task ahead of them. One of the current goals of science is to prevent the presence of lesions, even before they appear.

Regardless of the cause, the high number of cases is reason enough to require new tools to allow early detection of diabetic foot ulcers, Maynar said. Together with other members of his institution, he set out to find a scientific partner who could contribute technology that could find

these wounds before they were visible.

One of the doors he knocked on was the Institute of Astrophysics of the Canary Islands (IAC). The institute operates more than two dozen astronomical and solar telescopes on Tenerife and the Canary island of La Palma, including the 10.4-m Gran Telescopio Canarias, the world's largest single-aperture optical telescope.

The observatory is known for its world-class contributions to astronomy. What could astronomers contribute to a disease of the human body?

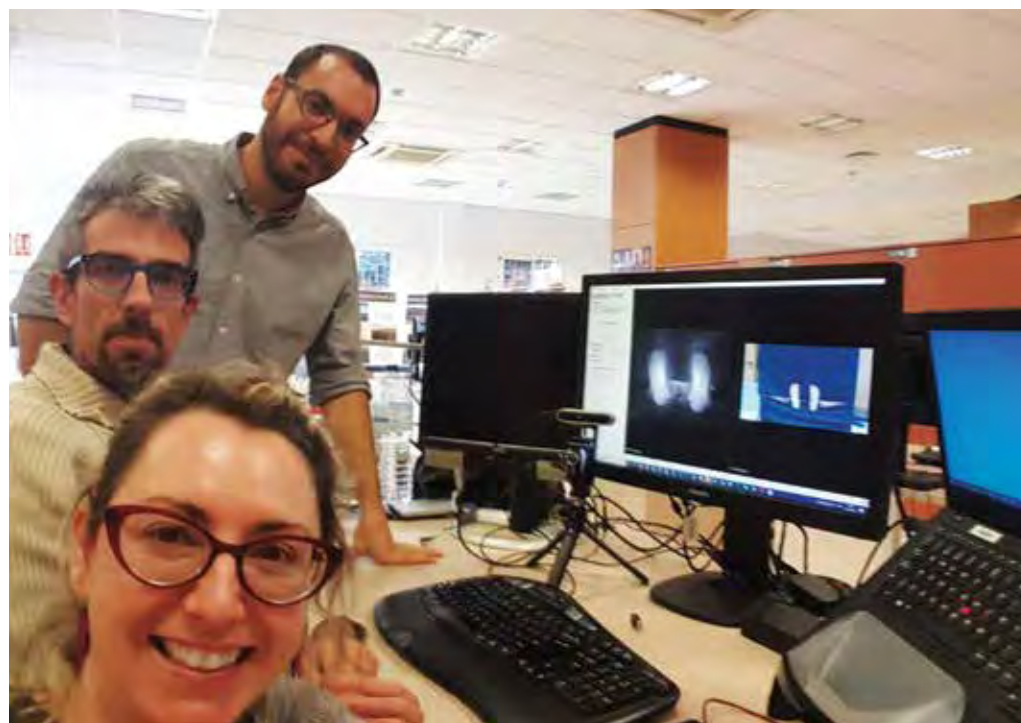
In addition to its core field of studies, however, the institute has a medical technology program called TECMED. The objective of this unit is to transfer equipment and tools used in astrophysical research to various branches of health care. When the doctors from the Canary Islands hospitals approached and laid out the challenge, the astronomers realized they had an instrument that could do the job.

SEEING INFRARED

Most people think of astronomy in terms of visible light images of stars, but due to the calm, dry air above the peaks of Tenerife and La Palma, the IAS observatory hosts instruments that look at the cosmos in a wide variety of wavelengths. Radio and microwave telescopes can see emis-

The SONG telescope is one of many world-class astronomical instruments on Tenerife.
Photo: Ruslan Merzlyakov - RMS photography





Engineers Ignacio Sidrach-Cardona (back), Carlos Luque, and Sara González developed software for the PINRELL system.
Photo: Sara González

sions from cold gas clouds, while a twin telescope MAGIC can see gamma rays produced by pulsars and the entry of high-energy cosmic rays into the atmosphere.

Several of the telescopes feature detectors for infrared light, which astronomers use to study objects cooler than stars like the Sun. In addition to helping them understand dust clouds and observe objects that are moving away from the Earth at great speed, astronomers hope that infrared detectors could one day directly image a planet circling another star, since those planets would be relatively brighter in infrared than they are in visible light.

The damage from diabetic foot is similar in that way. The medical specialists told the astronomers from IAC of the critical role temperature plays in detecting the latent damage.

“When the diabetic foot lesions begin to form, but their effects are not yet visible, there is an increase in local temperature in the affected area,” Selva said. What was needed to improve the early diagnosis of diabetic foot was a low-cost thermometer capable of measuring the heat signature in a noninvasive way.

To the astronomers, that sounded a lot like infrared astronomy.

Because the most worrisome potential damage was below the surface, it would require more than a single thermometer to get a robust signal of the location and extent of the illness. One ther-

mometer would be a camera that operated in the visible and near-infrared, while another would be geared for the thermal infrared from 8 μm to 14 μm . Between the two cameras, the system would be able to develop a subdermal model of the foot while measuring temperature gradations of 0.05 degrees.

It took five years to develop the prototype, called PINRELL (Prototype for INfraRED analysis of Lower Limbs), for clinical trials.

“In this version of the prototype, we can obtain multichannel images. In addition, all the sensors of the cameras have been assembled to support the design in the IAC laboratories. Its fabrication has been possible thanks to a 3D printer belonging to the institution,” said Juan Ruiz Alzola, a researcher at IAC and professor of signal processing and communications at the University of Las Palmas de Gran Canaria.

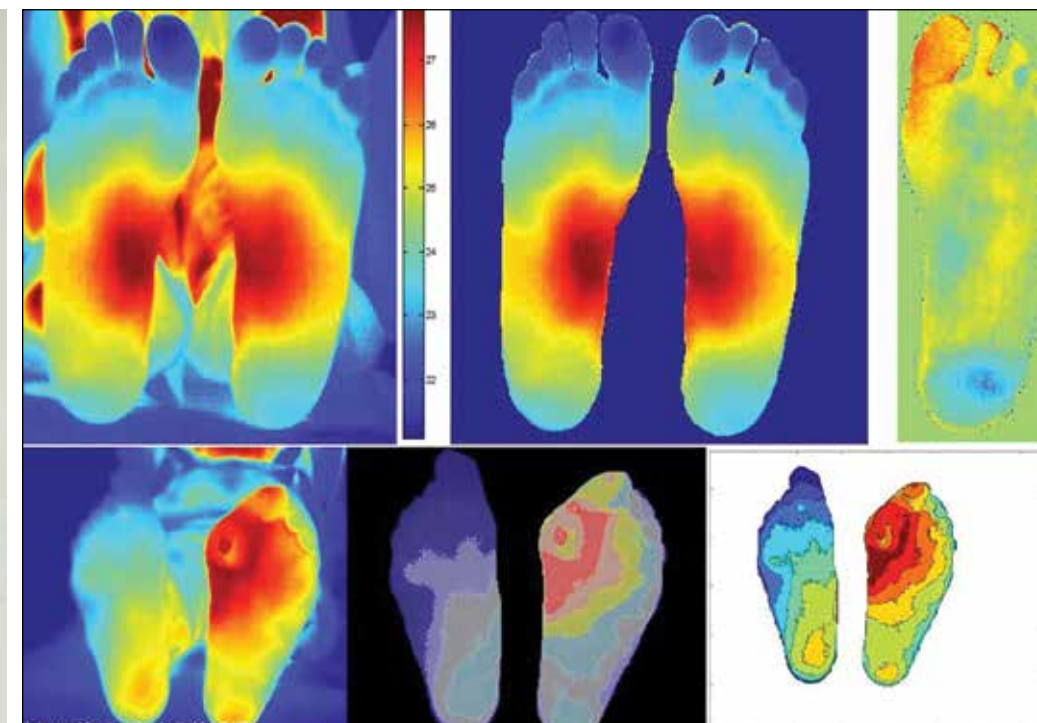
The 3D-printed structure holds the different cameras in alignment and provides robustness to the whole system. They also point out that the relatively simple way in which it is made could facilitate the technological transfer of the tool to developing countries.

However, the key to PINRELL’s progress is a software application developed for its implementation. It facilitates the acquisition of samples, the formal recording of images, as well as the analysis and processing of the information.

“Everything captured by the sensors goes



PINRELL, designed and built at IAC, features two cameras to capture the heat signature of damage below the skin’s surface.
Photo: Carlos Colodro and Sara González



Infrared images of the feet of test subjects, as captured by the PINRELL system.
Photo: Carlos Luque

through various data analysis techniques. These are applied for the segmentation of areas of interest, which are then used in the development of statistical algorithms,” explained Sara González, another of the engineers involved in the development of the equipment.

The application is currently in a desktop version that runs on both Linux and Windows. “When it came to developing and implementing the software, it was clear to us that it had to be a transferable system that would provide capabilities rather than complications,” González said. The group aims to have the camera system and software simplified enough to be used in nonclinical settings, such as the home or in the field.

A POWERFUL TOOL

Currently, the PINRELL group is working on a database with the images collected. The idea is to put together a catalogue of images during the clinical trials that can track different anomalous surface temperature patterns—imperceptible to the human eye—of the diabetic foot ulcers.

“We are equipped with the information obtained on a preliminary basis. When the clinical trial phases begin, the volume of content will increase considerably and we want to be prepared to avoid delays,” Alzola said.

These tests will be carried out in hospital facilities sponsored by the Hospiten Group. The researchers will also train technicians who will

use the system once it is approved for hospital use. After the clinical studies, the IAC, the Hospiten Group, and the Canary Islands Health Service will develop plans for the mass production of the equipment and its propagation on the islands.

The researchers of the IAC’s TECMED program take the responsibility of manufacturing and designing this prototype of medical equipment seriously. They know that patients’ quality of life is at stake.

“PINRELL will be a very powerful tool,” González said. “Early diagnosis of this kind of lesion could contribute to reducing the number of amputations, which is the main objective.”

Given the potential, the doctors working on the project are excited by its prospects. “Making it possible for every diabetic to have a technological tool like this, readily available, or even in their homes, would help to reduce the number of amputations considerably,” Selva said.

The team is hopeful that PINRELL could also be useful in detecting other diseases, such as sinusitis or pressure ulcers in bedridden people. Even though the camera system has its roots in studying the heavens, it could have its biggest impact improving the lives of people living on the earthly paradise of Tenerife. **ME**

CLAUDIA ALEMAÑY CASTILLA is a science and technology journalist based in the Canary Islands. She was the 2022 Engineering for Change Editorial Fellow.

Making a Difference

Engineers who have worked in the ASME Federal Fellowship Program reflect on their experience in Washington and the contributions they made.

Engineering is a vital tool to solving the world's problems—not just in business, industry, and academia, but also at the highest levels of our nation's government. In fact, bringing technical expertise to the nation's capitol is critically important so that Federal policy can better reflect the engineering worldview.

That's the goal of ASME's Federal Government Fellows program. For the past half century, some of the best and brightest engineers from industry and academia have spent a year in Washington assigned to a member of Congress or to a Federal agency. These Federal Fellows have immersed themselves in the creation and implementation of public policies that advance engineering, science, and technology to help solve the nation's—and the world's—greatest challenges.

The benefits are twofold. The Fellows add their engineering point of view to staffs that often are dominated by expertise in law, communications, and political science. Many contemporary issues have deep technological roots, so having an in-house expert to weigh in is invaluable.

But the experience of serving on Capitol Hill or in one of the major Federal agencies can have a profound effect on the Fellows themselves. Seeing up close how policy is made has inspired alumni of the program to get more involved with public service when they return home.

On these pages, two Federal Fellows from the 2021-2022 class share their experiences and describe what they learned from their time in D.C.





Connecting the Dots

Federal service has pushed me beyond the bounds of what I expect engineering to be.

BY JACLYN BRENNAN

I grew up in Northern Virginia in the figurative shadow of the Capitol, with family and friends who worked in politics and for government agencies, but my education and career drew me to a different path. I obtained a bachelor's degree in materials science engineering, then a master's degree in bioengineering with a focus on tissue, ultimately leading to a doctorate in biomedical engineering focused on cardioelectric physiology.

As I explain it, materials science focuses on the building blocks of how the world is made up. Bioengineering is how the human body is engineered to function. And biomedical engineering is how we can modify the body to make it function better.

I very much wanted to be a scientist because that's how my mind works. But I have always felt a pull toward politics. ASME's Federal Government Fellowship has always seemed like the perfect intersection of science and Washington, D.C., politics.

During my fellowship, I was matched with Congresswoman Anna Eshoo. Her work as chair of the Health Subcommittee on Energy and Commerce was a perfect fit with my educational background and interests. At heart, the decisions made on that subcommittee directly affect people's lives. Science can do great things, but how do we implement that in the real world?

Congresswoman Eshoo represents California's 18th Congressional District, which includes Silicon Valley and Stanford University—the epicenter

of American biotechnology and technology innovation and research. You can imagine my thrill at being able to serve as a liaison between scientists and start-ups in California, constituents, and the congresswoman on issues that are important to us all. Many scientists come at policies from a "heavy technical voice" and are not necessarily well versed in politics; I was proud to bring added value by translating and connecting those dots among key people.

One of the highlights of my fellowship was working with Congresswoman Eshoo and her staff to ultimately pass HR 5585, known in shorthand as the ARPA-H Act, which creates a new

"SCIENCE CAN DO GREAT THINGS, BUT HOW DO WE IMPLEMENT THAT IN THE REAL WORLD?"

independent agency devoted to health research to be housed within the U.S. National Institutes of Health. In my fellowship, I was able to help draft the legislation and work with stakeholders to improve it—and not just scientists but also with patient groups, past directors, and others to ensure patients will benefit.

This was perhaps the most significant experience of my year-long fellowship, having a front-row seat to the creation of new government agency, giving it the tools it needs to be successful and shepherding it across the finish line through hearings and then eventually getting it passed into law.

Where else as a scientist would you

have that kind of experience?

Also during my fellowship, the landmark CHIPS and Science Act was passed into law. Although I did not work on that legislation specifically, as a scientist I was very excited to see that move forward.

Capitol Hill is very fast-paced. Every day you are learning something new. You are constantly being challenged. As an engineer, my research mindset and background proved valuable in that environment.

It's an experience I highly recommend to other engineers wanting to learn about and ultimately shape policy at the highest levels. I'm very glad I did it—so much so, that I'm already on my next government role in a one-year fellowship as a data scientist in the executive branch working for the United States Agency for International Development.

Throughout my education, when I was working in the lab I knew I was developing new innovations that were making a difference to the world. But through this Federal Fellowship, I know I made a difference in people's lives every day.

I will always see myself as a scientist first. But I really like working in the federal government and making a broader impact. Federal service has expanded my thoughts about what "engineering" is, and has pushed me beyond the bounds of what I expect. ■

JACLYN BRENNAN told her story to Jennifer Krempin Bridgman.



I've always been interested in politics. But as a mid-career mechanical engineer working in the oil field technology business and moving around the world to new assignments every few years, there was never a time when I could pursue it.

A move to the Washington, D.C., area gave me the opportunity through the Federal Government Fellows program to work in the office of U.S. Senator Chris Coons (Del.) on issues involving smart manufacturing, small business access to capital, technology transfer, R&D, innovation, and supply chain resilience. Those areas were new to me, as was the environment I was working in. It was a whole different set of experiences that are unique to someone like me who comes from a more traditional engineering education and profession.

My days in D.C. began early as I stepped onto the Metro for an hour-long commute to Capitol Hill. This quiet time as the sun rose served as a chance to prepare for the day ahead. Then it was meetings—staff meetings with the entire team, reading up on the senator's objectives for the week, and meeting as smaller policy groups.

The value of this fellowship isn't just that you're doing engineering and technology work; in fact, there is so much more. But no matter the subject, you're leveraging your analytical mindset to propose solutions and solve policy problems. In fact, I was proud to have driven forward several bills where I personally played a role in identifying a problem and solving it.

Discovering a New Approach

Seeing real-world problems in a more complete way can carry over to engineering work.

BY MICHAEL WOODMANSEE, P.E.

One of these involved the 504 Loan Availability Act through the U.S. Small Business Administration. During a conversation I was having on behalf of the senator with the president of an educational development company, he mentioned struggling to obtain a federal loan because the authorization period kept expiring. We were able to create a viable path forward to prevent the program from going offline again. To be part of something that went from a "problem" for a constituent to being implemented into law was remarkable.

The way an engineer approaches a problem is based on physical truths to determine an optimal solution. We're used to understanding our frames of reference in a physical world. In the world of policy, however, it's more multidimensional and more relationship-driven than engineering. It's this contrast that

makes the fellowship so rewarding—you start to look at problems from many different angles, think in a more multidimensional way and really account for the "human" element in solving problems and making the world better.

After all, if you're only solving the technical problem, you're not solving the entire problem. An experience like this fellowship helps you see real-world problems from a more complete view and teaches you to collaborate and build relationships with an intensity not typically associated with the engineering profession. It was very rewarding to exercise those muscles. Although I plan to return to a career in the technical field, there is no question this experience will make me a better engineer. **ME**

MICHAEL WOODMANSEE told his story to Jennifer Krempin Bridgman.

ABOUT THE ASME FEDERAL GOVERNMENT FELLOWSHIP PROGRAM

ASME was the first engineering society to establish a Federal Government Fellowship Program. Since its inception in 1973, ASME's Fellows program has been used as a model for other engineering and scientific societies to develop their own fellowship programs. This program enables selected ASME members to devote a year to working in government, providing engineering and technical advice to policy makers in the U.S. Congress, the White House, and federal agencies.

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The 2022-2023 Federal Fellows class with ASME CEO Thomas Costabile.

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FEATURED

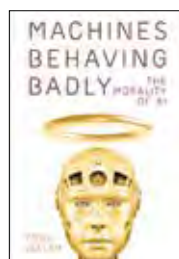
INTEGRITY TRAINING: THE PLANT INSPECTOR'S GUIDEBOOK

CRAIG COUTTS AND PAUL WILKINSON

ASME Press Books, 2 Park Ave, New York, NY 10016. 2022

The subtitle, *The Plant Inspector's Guidebook*, is a tip-off that this book is intended for existing in-service inspectors of pressure and other static equipment, as well as those preparing to sit for in-service inspector certificate examinations. In-service inspection is a broad subject involving a wide variety of mechanical engineering disciplines. The book, co-published with Wilkinson Coutts Engineering Training, Ltd., covers a wide array of topics, including introduction to pressure system code design, material types and mechanical properties, pressure testing, non-intrusive inspection, and the inspection of vessels, pipework, storage tanks, and pipelines. Special focus is given to statutory regulations, fitness-for-service studies, and written schemes of examinations. The guide provides content of relevance for inspectors preparing for the ASME Plant Inspector and API Individual Certificate Program training and examinations.

366 PAGES \$124; ASME MEMBERS, \$99 ISBN: 978-1-5658-1231-4



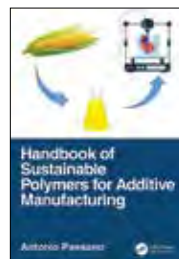
MACHINES BEHAVING BADLY: THE MORALITY OF AI

Toby Walsh

Flint Books, 97 St. George's Place, Cheltenham GL50 3QB, United Kingdom. 2022

The fear of our creations turning on us is as old as time. So it makes sense that artificial intelligence, which threatens to outpace humanity in the one edge we hold over animals, scares a lot of people—including those researching AI itself. But as Walsh, a leading expert in the field, suggests, the problem may be less with AI as a tool and more in whether its human operators wield it unethically. AI is written and trained by computer scientists, so whatever ill intents or unexamined biases these humans have will be embedded in those systems. Walsh contends that the overrepresentation of male transhumanists and acolytes of Ayn Rand among AI researchers is creating a challenge to designing systems that work for the good of all humanity.

288 PAGES \$29.95 ISBN: 978-0-7509-9936-6



HANDBOOK OF SUSTAINABLE POLYMERS FOR ADDITIVE MANUFACTURING

Antonio Paesano

CRC Press, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487. 2022

The enthusiasm for additive manufacturing has run into the desire for more sustainable and less polluting supply chains. Sustainable polymers, which are derived from feedstocks such as plants or microorganisms and have the potential to be recycled or at least reused, could meet both objectives. Paesano, a mechanical engineer who is the AM lead at Boeing, has had the opportunity to investigate various materials for their planet-friendly properties. Currently, he writes, sustainable polymers are not preferred for engineering or load-bearing applications, which makes them somewhat unsuitable for most industrial needs. This handbook details experimental and some commercial applications for printing a wide variety of natural materials, including polylactic acid, cellulose, and even bamboo filaments.

554 PAGES \$180 ISBN: 978-1-1384-7888-6

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AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME Gas Turbine Technology Group / 11757 Katy Frwy, Suite 1500 Houston, Texas 77079 / go.asme.org/igti

Performance Benefits of Intercooling



By Lee S. Langston, Professor Emeritus, University of Connecticut, lee.langston@uconn.edu

Gas turbine intercooling is the removal of heat from gas path flow during compression, thereby reducing compressor work. It can be achieved commonly by the use of an heat exchanger (the intercooler) mounted between the low and high compressors [1] or between any two stages of gas path compression [2].

Because of the cost and complexity of adding an intercooler, usually no more than one is used. Best performance occurs when the pressure ratio of both high and low compressors are the same which dictates that the high compressor inlet temperature is the same as the inlet temperature of the low compressor [3], for ideal operation of the intercooler.

In recent years, gas turbine designers have found various ways to use intercooling to not only reduce compressor work, but to also provide the means of increasing engine thermal efficiency for marine and land-based gas turbines. Recent studies show that if intercooler weight and size can be optimized, their use in turbojet engines could be beneficial.

Parameters for Intercooling

In many gas turbine [3] and thermodynamic textbooks, intercooling is introduced as a way to reduce compressor work, which increases gas turbine specific work. The temperature-entropy (T-S) diagram in Fig. 1(a) [4] shows an ideal Brayton cycle, 1-2-3-4, where intercooling is introduced at 1a-1b-2'-2. This is the usual textbook intercooling example, holding the overall pressure ratio (OPR) and the turbine inlet temperature (TIT) constant, to achieve reduced compressor work. The resulting cycle thermal efficiency is thus reduced, scaled by the extent of heat removed by the intercooler 1a-1b, to maintain the same OPR and TIT. (Also, since the ratio of the area enclosed by the cyclic curve to the area under the heat addition curve represents the cycle thermal efficiency, comparison of the ratio for 1-2-3-4 to that of 1-1a-1b-2'-2-3'-4' in Fig. 1(a), confirms the intercooling reduction in thermal efficiency.)

Figure 1(b) [4] is a T-S diagram for the same ideal Brayton cycle, 1-2-3-4, where intercooling is introduced, and a higher OPR is set. This forms the higher thermal efficiency cycle with the increased OPR at 1-1a-1b-2'-3'-4', as shown in Fig. 1(b).

Similarly, as shown by the T-S diagram in Fig. 1(c) [4], for the case of increased TIT, intercooling lowers the high compressor exit gas temperatures. This provides colder turbine cooling air, allowing for the increased TIT, buttressed by more effective turbine cooling. The

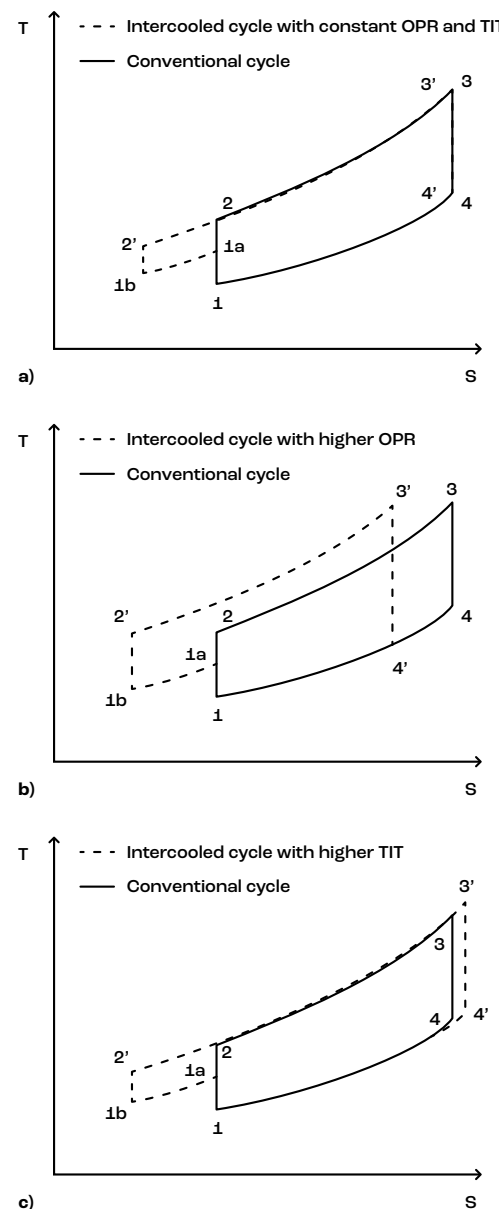


Figure 1. Conventional Brayton cycle with various intercooled configurations on Temperature(T)/Entropy(s) plots (Zhao [4]).
OPR-Overall Pressure Ratio; TIT-Turbine Inlet Temperature

lowered high compressor gas temperatures also allow the last stages of the high compressor to avoid high temperature stresses at the higher TIT, as well as lowering compressor work required.

Intercooling Yields Most Efficient Gas Turbine

In December 2003, General Electric introduced their intercooled 100 MW-class LMS100 electric power gas turbine, hailing it [1] as the most efficient gas turbine. Through the use of intercooling technology, GE announced that the LMS100 reached a simple cycle efficiency of 46%, some 10% greater than their then record holding LM6000 gas turbine, and setting a world record for simple cycle gas turbines.

As shown in Fig. 2, the LMS100 (Land-Marine-Supercharged) unit is a three-spool gas turbine combining frame (MS6001FA) and aeroderivative (CF6-80) gas turbine technology. It is aimed at the mid-merit and daily cycling segments of the electric power market - the difficult-to-predict, must-be-ready-to start electrical peak and intermediary power providers. Current industry sources indicate that since 2006, about 80 LMS100 units have been installed worldwide, with many of them in North America.

Earlier, I wrote [5] about LMS100 Unit 14 which went into service in 2009, at Waterbury, Connecticut, fueled by natural gas, with low sulfur distillate as a backup. At 100 MW the Waterbury power plant is not large, but the unique intercooler is. Shipped from its manufacturing site in Korea, the air-to-water intercooler was barged up the Connecticut

River. Then the 225,000-pound cylindrical heat exchanger, at about half the length of the gas turbine unit, was transported overland to Waterbury at 6 mph on a 96-wheel trailer truck.

Intercooling in Turbojets

The LMS100 is an outstanding example of the use of an intercooler to improve gas turbine thermal efficiency. However, it is a land-based gas turbine where weight and size of the intercooler are not primary concerns.

Such is not the case of intercooler use in a jet engine for flight propulsion. As Zhao [4] and others have pointed out, it is important to achieve a light weight, compact intercooler design for a turbojet application. Increased engine weight would offset gains in intercooler derived fuel economy. The intercooler installation raises the prospect of increased engine volume, leading to more nacelle drag and the difficulty of fitting the intercooler as an effective heat exchanger into confined engine space.

Many of the recent jet engine intercooler studies in the literature I have seen, call upon the research carried out at Stanford University on compact heat exchangers by professors Kays and London [6]. My 1960s graduate studies at Stanford under the two faculty authors, show that using compact heat exchange technology for successful jet engine intercooler design will be challenging. If the challenges can be met, successful intercooled jet engines, akin to the outstanding LMS100, could be in our future.

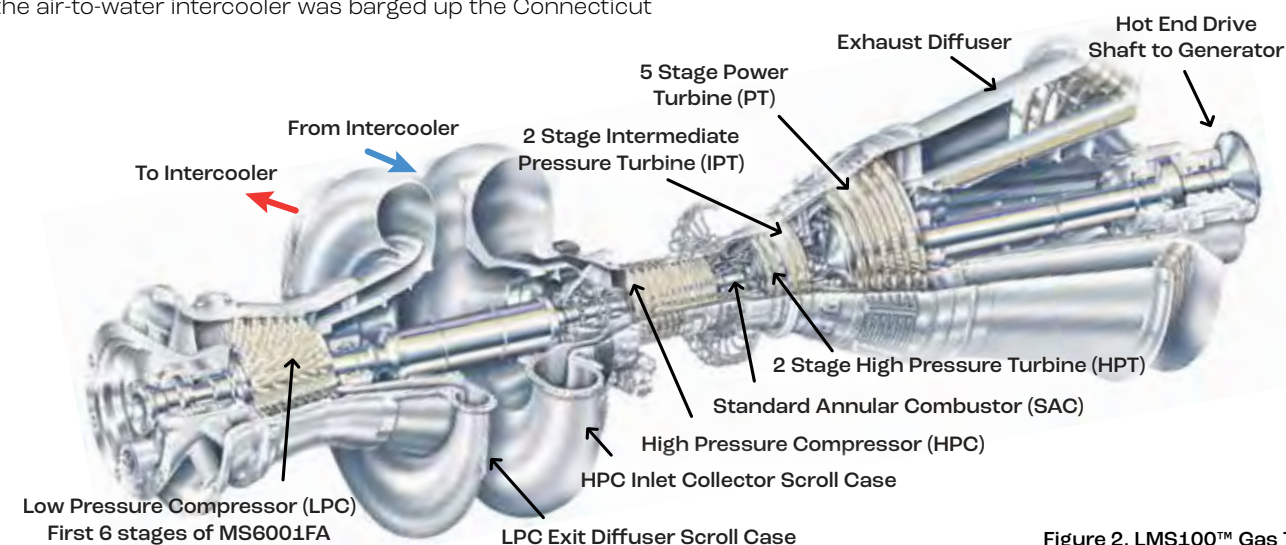


Figure 2. LMS100™ Gas Turbine

References

1. Reale, Michael J., 2004, "New High Efficiency Simple Cycle Gas Turbine - GE's LMS100", GE Energy, GER-4222A (06/04), pp. 1-16.
2. Moore J. Jeffry, et al, 2012, "Development of an Internally Cooled Centrifugal Compressor for Carbon Capture and Storage Applications", *Proceedings ASME Turbo Expo 2012, June 11-15, Copenhagen, Denmark*, GT212-69911.
3. Bathie, William W., 1996, *Fundamentals of Gas Turbines*, 2nd Ed., pp. 142-144.
4. Zhao, Xin, 2016, *Aero Engine Intercooling*, Ph.D. Thesis, Chambers University of Technology, Gothenburg, Sweden.
5. Langston, Lee S., 2009, "Plowing New Ground", *Mechanical Engineering Magazine*, May, pp. 40-44.
6. Kays, W.M. and London, A.L., 1984, *Compact Heat Exchangers*, 3rd ed., McGraw-Hill.

Aviation Fleet Management: Transformation Through AI / Machine Learning

Dinakar D , VP- Data Science and Analytics, GE - Aviation

The application of Artificial Intelligence (AI) and Machine Learning (ML) technologies for health monitoring of aircraft components and propulsion systems is pushing the envelope of Prognostics and Health Management (PHM) capabilities and changing the way PHM has traditionally been viewed.

Engine health monitoring has been in place for more than two decades. The key things that changed in the last decade are the data revolution and the platforms to harness the variety of data sources. This naturally led to an explosion in the digital transformation domain as companies attempted to realize the value of their data through initiatives and analytics. With terms such as Digital Twin, Internet of Things (IOT), Data Analytics, Industrial Internet, and Artificial intelligence (AI), more companies have begun to take up the banner of applying these to the core of their business. Alongside these initiatives are the expansion of groups and companies providing support for these major industrial applications in the area of digital and analytics.^[1,2]

Artificial Intelligence and Machine Learning Framework for Digital-Twin Based Health Monitoring

Digital twin can be defined as a collection of digital data that represents certain characteristics of a physical object, system, or real-world process. When expanded to combine models with data, a digital twin can also capture the behaviors of the real-world physical asset.

The idea of a digital twin is well-known at the consumer level. Amazon has a digital twin of each of their customers, which includes demographics, preferences and appetites, past purchases, shopping behavior, and so on. This idea can be applied to physical assets such as airplanes, aircraft engines, manufacturing processes and supply chains, and

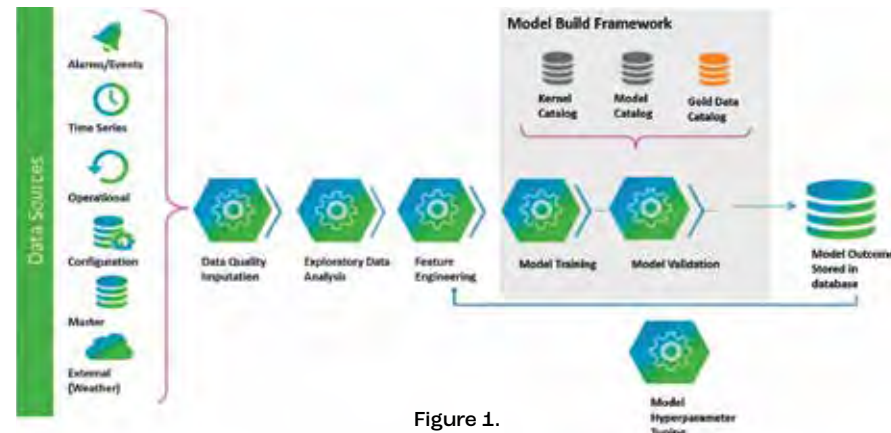


Figure 1.

financial systems, to name just a few.

The concept of digital twin can be applied iteratively at the level of a component, sub-system, or system. A digital twin can even be a collection of lower-level digital twins. In this manner, a digital twin of an aircraft may comprise data and models at the vehicle level, along with digital twins of the airframe, engines, APU, landing gear, etc. Similarly, this aircraft digital twin may be one member of a virtual fleet of aircraft digital twins that are part of a higher-order airline operation digital twin. These twins unlock significant value when both a physics-based understanding and data driven technologies such as AI/ML are fused together. Figure 1 illustrates a framework to build these twins.

The following aspects need to be considered as part of this framework.

Data Exploration:

Data exploration is a key step in building any AI/ML models. It's very important to look at the problem from a higher dimension and ensure that all possible data sources are considered as inputs to this exercise.

Feature Engineering:

This is a key step in fusing the domain knowledge with data driven insights. Statistical and machine learning techniques

coupled with domain knowledge are applied to select the key data sources or data segments that help in understanding or segregating the problem. These engineered features are input to the AI/ML driven digital twin model. The quality of these features determines the efficacy and validity of the final AI/ML.

Model Building and Validation:

By the nature of jet engine operations, the problems we encounter are "class imbalance" problems (i.e., the total number of problem instances is far less than the total number of healthy instances). This requires a special attention and care while building these ML/AI models in order to avoid over fitting and aid the explainability of these models.

Advanced machine learning model selection is dependent on the type of the problem and business outcome desired. Examples of desired business outcomes are:

- Tell me when Asset XYZ is 5 days away from failure
- Tell me when Asset XYZ is below X% risk of failure in the next Y days
- Alert me when Asset XYZ has an indication that correlates to "a" problem
- Alert me when Asset XYZ is behaving differently compared to other assets in its class

The above framework is being applied to solve many problems at GE Aviation, and an example is illustrated in Figure 2.

These digital twins are built at the asset-by-asset (component) level, capturing the variations from operations and environmental parameters. This level of knowledge extraction

and sophistication helped to achieve the following outcomes for a middle east operator using analytics and platform .

- 56% decrease in disruptions
- 15% decrease in overhauls
- 12 additional days of utilization per year

Conclusions and Future Direction

Aviation industry is applying AI and ML to all areas of its business. The application of these revolutionary digital technologies is a "multi-disciplinary sport". Players from different parts of an organization (customer, digital, engineering and business/product management etc.) need to come together to drive differentiated outcomes. The experts are projecting an increase in the application of AI/ML in all aspects of the Aviation business. A significant, and still largely unrealized benefit of a digital twin has the potential to be utilized for multiple outcomes. For example, the same digital twin could be used to assess the current health and deterioration state of an asset for scheduling maintenance; to forecast the remaining useful life under current operating conditions for planning shop visit schedules; to estimate the future state of health for work scope planning and MRO inventory management; and finally, to optimize the design of product improvements and future products by virtually testing the impact of design decisions. The future of Aviation fleet management is set to witness a huge transformation with the advent of AI/ML technologies.

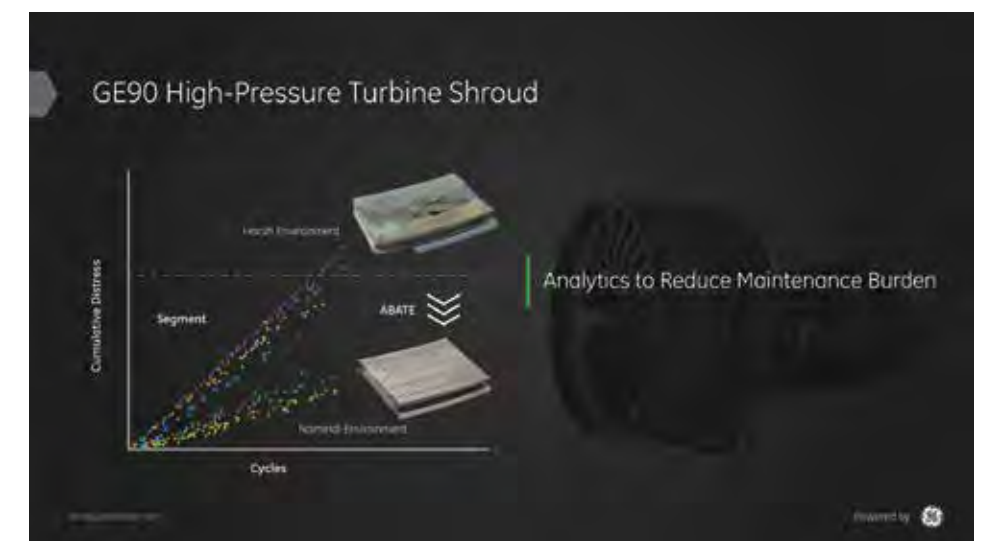


Figure 2. Framework application example.

References

1. <https://aviationweek.com/shownews/ge-turns-big-data-personal-healthcare-engines>
2. <https://www.ainonline.com/aviation-news/aerospace/2018-07-17/digitalization-big-data-driving-advances-pratt-whitney>
3. <https://aviationweek.com/special-topics/optimizing-engines-through-lifecycle/emirates-cuts-unscheduled-engine-removals-one>

Ammonia as Jet Fuel: One Path to Zero-Carbon Aviation

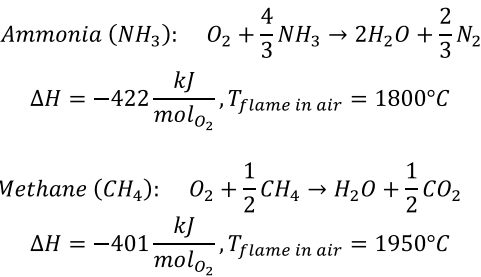
Lance L. Smith, Technical Fellow, Raytheon Technologies Research Center

In November 1960, long before global warming was a concern, an ammonia-fueled rocket plane propelled itself through the sky above the California desert leaving behind only a trail of water vapor and some extra nitrogen. Sixty years later that first flight of NASA's ammonia-powered X-15 airplane has new significance: it was a demonstration not only of speed, but of carbon-free flight.

In recent years hydrogen has received significant attention as a “green” fuel, but the X-15 serves as a reminder that ammonia has unique advantages which are worth revisiting. Like hydrogen, ammonia is carbon-free. Unlike hydrogen, ammonia can be stored as a liquid at non-cryogenic temperatures, and it has an existing worldwide infrastructure for transport and handling^[1]. Furthermore, it was chosen for the X-15 in part because ammonia exhibits excellent heat-transfer properties that are valuable in both rocket and gas-turbine applications. For these reasons, ammonia is now being evaluated as a carbon-free fuel for commercial aviation under an ARPA-E program at Raytheon Technologies^[2]. These evaluations are especially focused on the unique efficiency improvements offered by ammonia's physical properties, which help to offset ammonia's heavier weight as a fuel compared to Jet fuel (lower heating value of 18.6 MJ/kg for ammonia, versus 43 MJ/kg for Jet fuel).

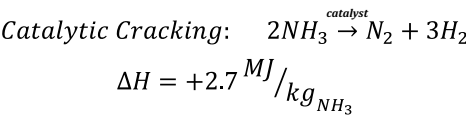
Combustion of Ammonia

Although typically thought of as a fertilizer or refrigerant, ammonia is in fact an energetic fuel. When combusted in oxygen or air, ammonia's heat-release (ΔH) per mole of oxygen consumed is similar to a hydrocarbon fuel, so ammonia's flame temperature (T_{flame}) is also similar to a hydrocarbon fuel^[3]. For comparison, the overall combustion reactions of ammonia versus methane (the simplest hydrocarbon) in oxygen are written below, along with their corresponding values for ΔH and T_{flame} :



The above chemical equations highlight the motivating difference between these fuels: only the hydrocarbon fuel produces CO_2 as a product of combustion; in contrast, ammonia's products of combustion are water and nitrogen, H_2O and N_2 . An important practical difference between these fuels, which is not evident from the overall chemical equations, is that their rates of combustion (or flame speeds) are very different. The laminar flame speed for most hydrocarbon fuels is roughly 40 cm/s (at ambient, stoichiometric burning conditions), as compared to a much slower 7 cm/s for ammonia^[3]. Ammonia can burn, but it doesn't burn as well as conventional fuels. For this reason, the combustion properties of ammonia are also being studied at Raytheon Technologies, under a DOE program to evaluate ammonia combustion in power-generating gas turbines^[4].

One way to aid the combustion of ammonia is to co-fire it with another fuel such as natural gas or kerosene^[5], or hydrogen. If hydrogen is used, it can be obtained directly from the ammonia fuel itself before combustion, by catalytically cracking a portion (or all) of the ammonia:



Initial studies indicate that Jet-fuel-like combustion properties, especially flame speeds, can be obtained for a fuel composition comprising only about 5% hydrogen by weight^[3].

The cracking of ammonia fuel can also provide an efficiency benefit, if a higher percentage of it is cracked. Because ammonia cracking is endothermic, the energy content of the cracked fuel (H_2 and N_2) is about 15% higher than the ammonia from which it came. For an engine (thermodynamic cycle) this opens up the possibility of “chemical recuperation” by using exhaust waste heat (after all work extraction) to drive the cracking reactions, thus recapturing what would have been lost heat energy by converting it to fuel energy that is returned to the highest-temperature point of the cycle, at the engine's combustor. In addition to this chemical recuperation effect, simply heating the fuel to raise its temperature can also return waste-heat to the highest-temperature point of the cycle, and can provide additional efficiency gains. Ammonia is especially well suited to heating because unlike hydrocarbon

fuels, which form carbonaceous deposits or “coke” when exposed to high temperatures, ammonia can be heated from its low storage temperature (e.g. -33°C for liquefaction, or colder at cruise altitude) to the temperature of any heat source (e.g. jet engine exhaust at $\sim 300 - 500^\circ\text{C}$), absorbing significant energy and enabling recovery of some of the work required for its liquefaction. As a result, exhaust-heat recapture to the fuel can provide well over 15% efficiency gain in an ammonia-fueled engine.

Ammonia as a Working Fluid

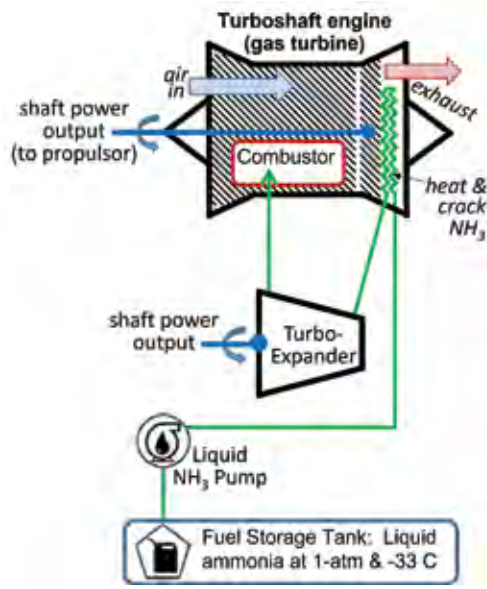
For ground-based gas turbines, such as those studied under the DOE ammonia combustion project, exhaust waste-heat is often recaptured in a bottoming cycle that uses water as the working fluid: in these systems, ammonia cracking is a useful tool for improving combustor performance, but is not necessary to achieve high efficiency. For an aircraft gas turbine, however, it is preferable to use the fuel itself as a working fluid for heat recapture, avoiding the undesirable weight of a water system. Because ammonia does not coke, and because it has favorable physical properties for heat transfer and phase change, it is an ideal working fluid for this purpose – see Table 1 below and compare ammonia's conductivity, heat capacity, and heat of vaporization to water or Jet fuel. In addition to having favorable properties, because the ammonia fuel is consumed in the engine (and not returned to the storage tank) its use as a working fluid enables an open bottoming cycle that does not need a cooling heat exchanger. This avoids the weight and drag

penalties associated with such a heat exchanger, and makes this type of fuel-based bottoming cycle especially attractive for an aircraft engine.

By making simultaneous use of ammonia's capabilities as a fuel, a heat absorber, and a working fluid with favorable phase-change properties, ammonia can be used in a combined-cycle heat engine that converts waste-heat to useful work in at least three distinct and complementary ways: i. chemical recuperation, by cracking ammonia to increase the fuel's energy before burning; ii. fuel heating, to bring more thermal energy to the combustor; and iii. bottoming-cycle work generation, using ammonia as a Rankine cycle working fluid. Figure 1 illustrates an ammonia-fueled propulsion engine cycle that uses all three methods, and which we are currently studying under our ARPA-E project. In this ARPA-E propulsion engine the ammonia fuel system comprises an open Rankine bottoming cycle wherein ammonia, from its stored liquid state, is pumped to high pressure before entering a heat exchanger in the gas turbine's exhaust. The exhaust waste-heat raises the ammonia temperature above its critical value, bringing it to a gaseous state for subsequent turboexpansion (work extraction) and catalytic cracking. The heated, cracked ammonia is then delivered to the gas turbine's combustor as its fuel. Key technology development for this project includes ammonia cracking at high pressure (above combustor pressure), ammonia turboexpander operation, ammonia combustion, and cycle optimization to achieve thermal efficiencies approaching 70% at cruise, where most of the aircraft's fuel is consumed and efficiency improvements provide the most benefit.

Table 1: Comparison of Working Fluid Properties			
Thermal Property	NH_3 - anhydrous (-33°C liquid)	H_2O (ambient liquid)	Jet-A (ambient liquid)
Conductivity, k (W/m-K)	0.6 W/m-K	0.6 W/m-K	0.1 W/m-K
Heat Capacity, C_p (kJ/kg-K)	4.5 kJ/kg-K	4.2 kJ/kg-K	2.0 kJ/kg-K
Heat of Vaporization, h_{fg} (kJ/kg)	1360 kJ/kg	2260 kJ/kg	350 kJ/kg
Heat of Cracking reaction (kJ/kg)	2700 kJ/kg	N/A	coking issue

Figure 1. Ammonia-fueled aircraft propulsion engine, using ammonia as the working fluid to recapture exhaust-heat to an open Rankine bottoming cycle and to endothermic cracking, with resulting overall efficiencies near 70% for reduced aircraft fuel burn and zero CO_2 emissions.



References

1. A. Valera-Medina, H. Xiao, M. Owen-Jones, W.I.F. David, and P.J. Bowen. “Ammonia for Power,” Progress in Energy and Combustion Science, Vol. 69, pp. 63–102 (2018).
2. <https://arpa-e.energy.gov/technologies/projects/zero-carbon-ammonia-powered-turboelectric-zapturbo-propulsion-system>
3. H. Kobayashi, A. Hayakawa, K.D.K.A. Somaratne, E.C. Okafor. “Science and technology of ammonia combustion,” Proceedings of the Combustion Institute, Vol. 37, pp. 109-133 (2019).
4. <https://www.energy.gov/fecm/articles/additional-selections-funding-opportunity-announcement-2400-fossil-energy-based>
5. O. Kurata, N. Iki, T. Matsunuma, T. Inoue, T. Tsujimura, H. Furutani, H. Kobayashi, A. Hayakawa. “Performances and emission characteristics of NH_3 –air and NH_3 – CH_4 –air combustion gas-turbine power generations,” Proceedings of the Combustion Institute, Vol. 36, pp. 3351–3359 (2017).

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The 3-day exhibition starting June 14th attracts the industry's leading professionals and key decision makers, whose innovation and expertise are helping

to shape the future of the turbomachinery industry.

In addition, ASME Turbo Expo focuses on the future generation of turbomachinery experts providing an opportunity for students to showcase their works during the Student Poster session. Tutorials of Basics lectures are offered as an introduction on topics such as heat transfer, energy storage and cycle innovations. An Early Career and Student Reception is hosted on Sunday night so attendees may foster connections that will benefit them through the weeklong conference and exposition.

Don't miss the opportunity share your vast knowledge, grow your network, and contribute to the future of turbomachinery at Turbo Expo 2023!

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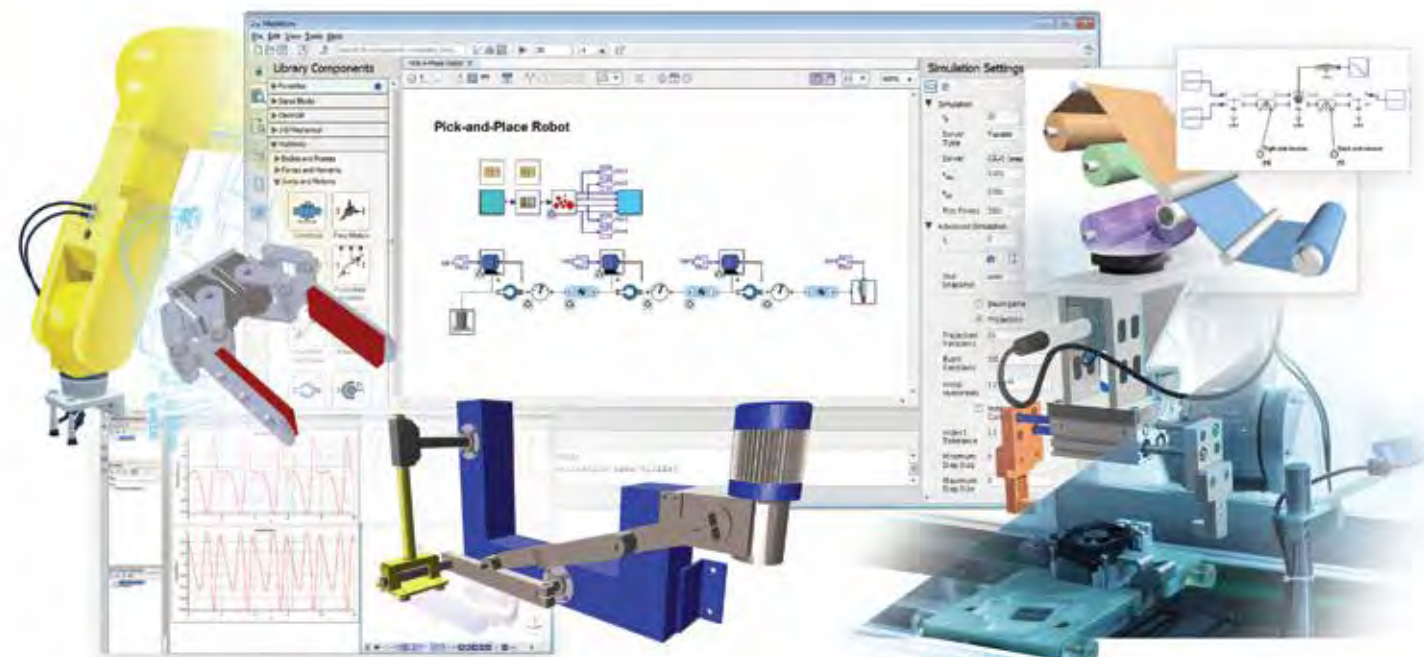
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TOOLS//SOFTWARE

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MODELING AND SIMULATION

MAPLESOFT, WATERLOO, ONT.

THE RELEASE OF MAPLESIM 2022 is intended to enable engineers to improve the design of machines that incorporate elements from multiple engineering domains. It adds to the range of components, apps, and settings to expand the modeling scope, and makes it faster for engineers to build models and explore designs, reducing the effort required to produce more effective machines. Some newly added features include a new app for creating custom configurations for directional control valves that allows more design flexibility. Also, updates to several add-on libraries provide additional modeling support, including new components for modeling flow through air orifices and for heat-related flow changes in air and water, and the ability to model laminating in web handling systems. An update to the add-on MapleSim CAD Toolbox extends connectivity to recent releases of popular CAD tools, allowing engineers to import their 2D and 3D diagrams into MapleSim.

TERRAIN SIMULATOR

BOHEMIA INTERACTIVE SIMULATIONS, ORLANDO, FLA.

Mantle Enterprise Terrain Management is a custom-built platform based on proven COTS components and expert design/development services for creating simulated terrain for training, mission rehearsal, visualization, and terrain analysis. The application delivers a cloud-capable custom terrain pipeline that works with the user's data, processes, servers, and runtimes, integrating with existing terrain capabilities or delivering a full end-to-end terrain creation and management solution from scratch. For instance, the company claims the application can take geospatial terrain data from almost any source and to provide a high fidelity, procedurally improved base globe to multiple simulations or visualization runtimes. Mantle ETM is intended to reduce staff hours needed to develop and deploy terrain by offering a high degree of automation at every stage, and it offers curated global base data and extended support for new runtimes and streaming terrain formats.



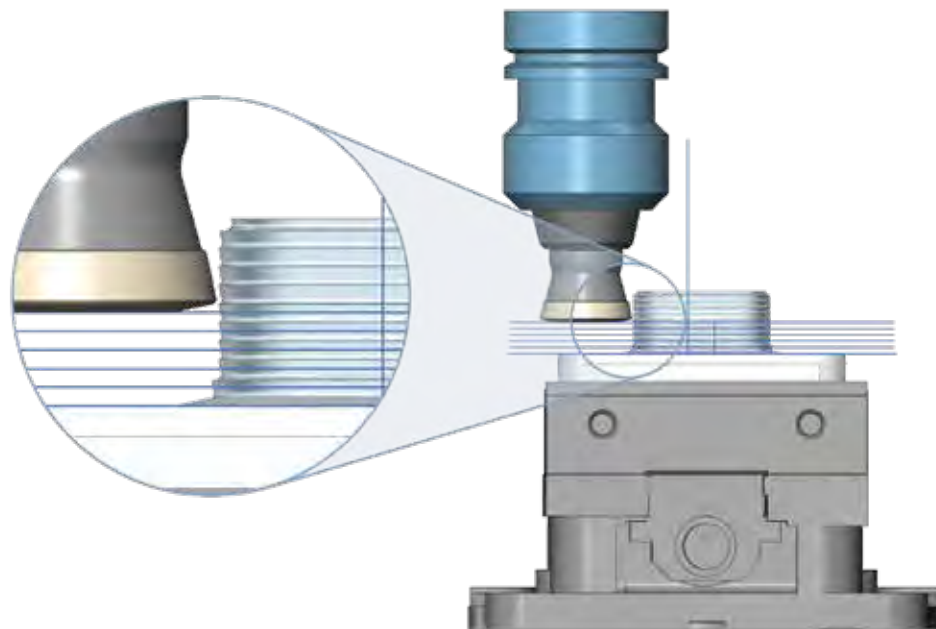
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DIGITAL MANUFACTURING ▶

MODULEWORKS, AACHEN, GERMANY

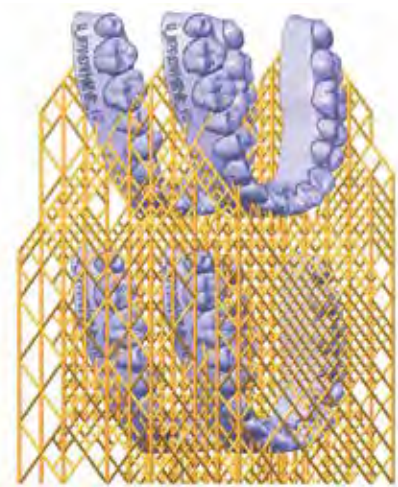
ModuleWorks 2022.08 CAD/CAM software components for digital manufacturing contains new and enhanced features across the entire product range, including new custom tool shapes for roughing, automatic tool axis control, and vector interpolation for the machine simulation. Operators can customize the shape of the cutting and non-cutting parts of the tool for all triangle mesh-based roughing strategies, which avoids over-simplifications because the application takes specific features of the tool shape into account during the toolpath calculation to deliver a realistic simulation of the material removal process. In addition, the RTCP ON command in the ModuleWorks Machine Simulation has a new option that interpolates the tool's movement to ensure the tool tip points are located on a line and the tool vectors are located on a plane. The size of the interpolation steps can be controlled.



BUILD PREPARATION ▼

VOXELDANCE, SHANGHAI

Voxeldance Additive 4.0 is the latest version of the additive manufacturing build preparation application, which now includes a shrink wrap function to accurately calculate and wrap a layer around the part while ignoring its inner details and a mesh smooth feature to help remove sharp details and return a more appealing geometry for printing. Version 4.0 also includes border reinforcement for SLM printing to provide stronger support restraint, ensuring that the part is held stable on the base plate before stress relief annealing,



thereby improving the print success rate. A feature called BP Special Volume is intended for parts with thin walls, sharp details, or lattice structures. The new BP special volume feature in Voxeldance Additive 4.0 allows users to assign a special volume and configure different laser scanning strategies where it intersects the part.

COMPUTER-ASSISTED DESIGN

KUBOTEK KOSMOS, MARLBOROUGH, MASS.

KeyCreator 2023 provides expanded and updated drafting capabilities, productivity enhancements to various functions, and extensive updates to CAD translators. Among the revised features are improvements to match international drafting standards. A Reference tolerance specification and a user-customizable system for defining ISO Fit tolerances allow both types of new tolerance options to be added to associative dimension entities. ASME Y14.5 support for geometric tolerance feature control frames has been updated to provide additional placement options and match the latest edition of the standard including the new dynamic profile modifier. Support for the Japanese JIS standard has also been expanded to include additional types of surface texture symbol modifiers and improve text position and justification. In addition, translators to support data from nine separate CAD applications have been updated since the previous major release.

USER-INTERFACE DESIGN

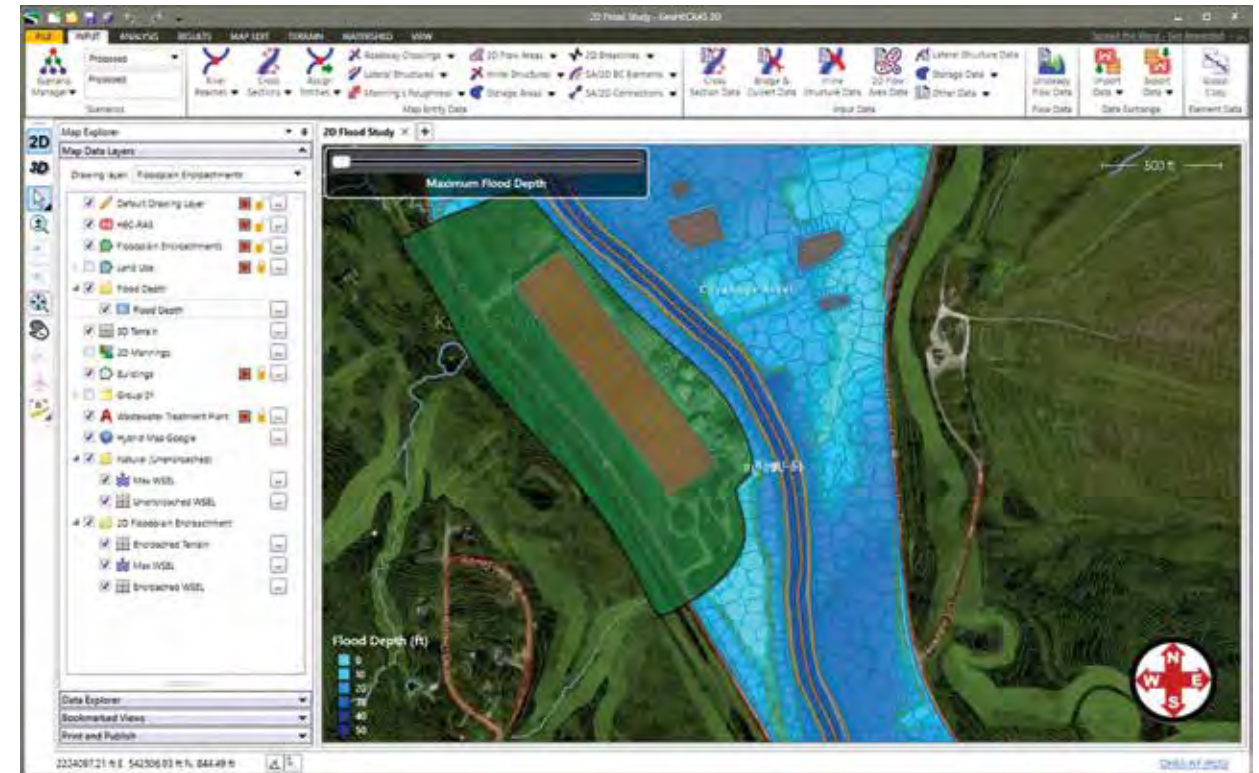
STMICROELECTRONICS, GENEVA

Version 4.20 of the TouchGFX user-interface design software for STM32 microcontrollers include support for the new NeoChrom graphics accelerator marketed by STMicroelectronics, which is integrated in advanced MCUs such as the new STM32U5 series. Developed from the company's Chrom-ART Accelerator that manipulates pixels and shapes, NeoChrom allows full-screen rotation at any angle and supports texture mapping for smooth, fluid graphics, and enhanced ease of use. TouchGFX 4.20 adds new features for developers, including support for importing and exporting custom widgets. Fully integrated with the STM32Cube MCU-development ecosystem, TouchGFX provides a complete end-to-end workflow that simplifies design and accelerates time to market. ouchGFX 4.20 is available now, free of charge, and can be downloaded directly from the company.

3D RENDERING

ENSCAPE, KARLSRUHE, GERMANY

Enscape for Mac is a version of the real-time rendering application for turning models into immersive 3D experiences, now available as a direct plug-in for SketchUp 2021 and 2022. Users can control an integrated real-time visualization and design workflow, the company says. The application provides real-time walkthroughs of rendered



projects with the walk, fly, and perspective modes; a range of atmosphere, image, capture, and rendering settings; and a material editor that applies height maps and adjusts textures to increase the level of realism. Views can be rendered in batches to save time, and an asset library enables users to choose from more than 3,000 high-quality, low-poly 3D models to add to a project. The application is available in a variety of languages, including English, German, Italian, Polish, and Dutch.

WIREFRAME MODELING

JYTRA TECHNOLOGY SOLUTIONS PVT. LTD., HYDERABAD, INDIA

The new features in JTS IntelliCAD 11 are focused on new view and visualization productivity tools such as the ability to use section planes to visualize cross-sections of a model, the use of a view cube to check and switch viewing directions, and new view and visual style controls to apply a different view and visual style to a model. New commands include Facet Model Pipe, Reverse, Break at Point, Map Service, Update Field, Model, Hatch Generate Boundary, and Match Cell. Version 11 uses the IntelliCAD 11 Engine, Open Design Alliance, dwg/dxf Libraries, and the ACIS 3D modelling kernel. It supports file formats such as .dgn, .step/.stp, .iges/.igs, .stl, .obj, 2D PDF, 3D PDF, and .dae, and the interface and commands intended to be intuitive for users familiar with other popular CAD applications.

LANDSCAPE MODELING ▲

CIVILGEO, MIDDLETON, WIS.

CivilGEO, a leading provider of civil engineering software, has released version 4.0 of its GeoHECRAS software. The application constructs HEC-RAS models as it pulls data from an ever-expanding variety of sources. It computes water surface profiles for steady and unsteady flow conditions, analyzes and designs bridge and culvert roadway crossings, generates floodplain and flood hazard maps, performs river and stream restorations and realignments, computes flood inundation maps for possible dam and levee failures. The new release supports HEC-RAS versions 6.1 and 6.2 analysis engines, in addition to all previous HEC-



RAS analysis engines, and can perform both steady and unsteady flow computations for both 1D, 2D, and hybrid 1D & 2D model domains. GeoHECRAS 4.0 is compatible with AutoCAD, Bentley MicroStation, and ESRI ArcGIS.

COMPUTER-AIDED DESIGN

PTC, BOSTON

Creo 9, recently released by PTC, updates such features as usability, productivity, ergonomic design, and generative design capabilities. For instance, updates to the model tree make it faster to structure, document, and understand design intent, and a new function for dividing surfaces improves analysis and product definition. Expanded ergonomic tools help designers recognize the uniqueness of users while helping ensure products comply with safety, health, and workplace standards. Using the new Vision Field Analysis capability, engineers can analyze users' line of sight and field of view when driving or using equipment. Creo 9 also was designed to improve control over stochastic and formula-based lattices and user-defined support structures for advanced additive manufacturing use cases. The company says the subtractive manufacturing focus on 5-axis finishing toolpaths for use in turning, mold design, and adaptive feed rates for milling was also improved over previous versions.



80-PIECE TOOL ROLL

DECKED, KETCHUM, IDAHO

This complete portable truck tool bag with an internal tool roll is intended to provide users with everything needed, organized in one place. The 80-piece set kit, which includes a 61-piece tool roll housed inside a high-quality Cordura Nylon duffel with heavy-duty zippers, incorporates an exterior molle webbing system for attaching and securing the bag just about anywhere. The Off-Road Tool Bag features five removable tool bags, with a full complement of metric sockets, wrenches, pry bar, tire repair kit, an electrical circuit tester, pliers, hammers, and other repair items. Designed to nest neatly in the company's Drawer System or Tool Box, the Off-Road Tool Bag is an essential for any vehicle owner, from pickup to Prius.



MILLING SYSTEM

SECO TOOLS, TROY, MICH.

Built for difficult applications involving ISO P, M, K and S materials, the new Seco Helical SN8-13 milling system features double-sided helix inserts with eight cutting edges that significantly lower cost per edge to boost slotting, side milling and circular rough milling efficiency. The cutters offer application-specific subfamily designs featuring left or right-hand helixes, half- or full-effective teeth options, two front insert and many radii choices for long tool life and maximum chip evacuation. Reliable and user friendly, the Helical SN8-13 also eliminates incorrect indexing of front and helix inserts, reducing operator error, machine downtime, quality issues, and scrap, and offers an economical alternative to milling products for depths-of-cut from 50 mm up to 100 mm.

SHAFT MEASUREMENT

OPTICAL GAGING PRODUCTS, ROCHESTER, N.Y.

TurnCheck Series-14 is the latest precision optical measurement instrument to be added to the company's TurnCheck Shaft Measurement Systems. The TurnCheck line offers three models and can measure shafts, cylinders and other turned, ground, or extruded parts up to 140 mm in diameter and 1,000 mm in length and stand up to even the most demanding shop floor environments. The fully telecentric large field of view optics combined with highly collimated light at a constant wavelength results in a crisp, uniformly magnified image with no edge effects or exclusion zones. TurnCheck systems scan and measure all points and features automatically, handling the full range of dimensions and tolerances found on shafts and cylinders.



POWER TRANSMISSION

JKF AMERICAS, HOLMDEL, N.J.

JKF Americas Inc, a subsidiary of JK Fenner (India) Ltd., has introduced their extensive Top Drive line of power transmission products to the North, Central, and South American markets. The launch of the Top Drive brand is especially timely for businesses that have seen delays and shortages in the supply chain, within the context of the emerging sourcing model across the world. Top Drive industrial power transmission products include, Belts (classical V, wrapped, raw-edge cogged, poly-V, banded, synchronous, harvester and specialty); V cool pulleys, couplings and SMSR; hydraulic and industrial hoses (radiator, air intake, branched, silicon, fuel); and auto tensioners.

SUBMISSIONS



Submit electronic files of new products and images by e-mail to memag@asme.org. Use subject line "New Products." *ME* does not test or endorse the products described here.

PRECISION BALL SPLINES

THOMSON INDUSTRIES, INC., RADFORD, VA.

A leading manufacturer of linear motion control solutions, Thomson has introduced a line of precision ball splines that provide an elegant, single shaft solution for integrating rotary and linear motion on a single shaft assembly. The new line of high-precision ball splines is intended for high-speed operation in compact spaces such as laboratory automation or semiconductor pick-and-place assembly. They can automate human-like functions, like opening the cover of a sample jar and pouring it in a test tube; are especially cost-effective in industrial robotic applications that require high-speed, precise integration of rotary and linear motion without the wide freedom of movement of robots; and give designers more flexibility to compress an assembly, extend a stroke, distribute a load or otherwise meet modern automation demands.



PRESSURE TRANSDUCER

ASHCROFT, STRATFORD, CONN.

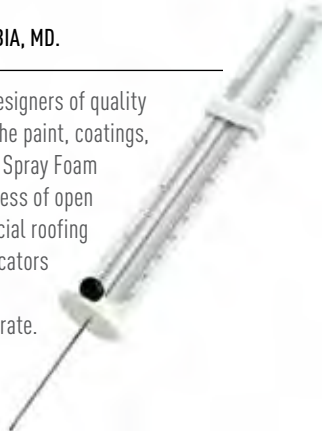
Reliable and repeatable pressure measurements in corrosive environments are the goal of Ashcroft's new ZL95 Fluoropolymer Pressure Transducer, which is intended for cleaning equipment for semiconductor and cleaning equipment for Flat Panel Displays (FPD), wet stations, and chemical supply systems. This transducer features a 4-digit LED display with NPN switch outputs, capacitance sensor for excellent thermal stability and PTFE/PFA wetted parts that combine with a patented vent design to provide extended cycle life and corrosion-resistance to chemicals such as hydrofluoric acid. It's compatible with pipe diameters from 0.25 to 0.5 in. O.D. and has multiple mounting options, including tube connections, press fit nuts, flared nuts and threaded nuts.



SPRAY FOAM DEPTH GAUGE

PAUL N. GARDNER COMPANY, INC., COLUMBIA, MD.

Worldwide distributors, producers, and designers of quality physical and inspection instruments for the paint, coatings, and related industries introduces its new Spray Foam Depth Gauge. The gauge measures thickness of open and closed cell foam and allows commercial roofing contractors and spray polyurethane applicators to test the depth of the foam quickly and easily while being applied on a roof substrate. Constructed of sturdy plastic and weighing only one pound, this gauge can read depths up to 5 3/4 inches. It has an easily adjustable stainless-steel pin and easy to read numbers. The gauges are also designed for measuring the depth of fireproofing (SFRM-spray fire resistive material) to ensure consistent depth from one area to another.



VACUUM MONITORING

BUSCH VACUUM SOLUTIONS, MAULBURG, GERMANY

VACTEST vacuum measurement equipment is designed to combine the latest advances in vacuum measurement technology with exceptional manufacturing quality to provide an innovative and comprehensive portfolio of active vacuum gauges and controllers. The company now offers active sensor controllers, mobile gauges, and both digital and analog transmitters. The products enable a range of measurements from 1,600 to 5×10^{-10} millibar covering all vacuum levels with accuracy. For instance, the digital transmitters in the VACTEST line use an intelligent micro-controller architecture to enable an optimum sensor control, as well as many setting options, and are based on Pirani sensor technology. The mobile gauges are battery-operated and can be used under vacuum; in one application suggested by the company, these gauges can be sealed in vacuum packaging to measure the pressure within the packaging.



ROD BEARINGS

IGUS, EAST PROVIDENCE, R.I.

Rod ends are found in many applications in the food industry, from filling plants to meat-processing machines and packaging systems, where they transmit dynamic forces to pivoting, tilting, and rotating movements. Motion plastics manufacturer igus has introduced a new range of maintenance-free igubal spherical bearings for rod ends that are intended for higher loads. The new models are equipped with a stainless-steel housing and a self-lubricating polymer inner ring. The solid lubricant in iglide A160 is released in microscopic amounts over time to ensure a low-friction dry operation between the inner ring and the stainless-steel spherical ball. The plastic is designed in blue to further increase food safety, since food residues and mold spores can be quickly detected on the part during cleaning inspections. The bearings are resistant to moisture, acids, alkalines, and UV rays and are suitable for temperatures between -40 °F (-40 °C) and 194 °F (90 °C). The new rod ends are available in sizes M6, M8, M10, M12, M16, and M20.

LEVER HOIST

OZ LIFTING, WINONA, MINN.

Dyno-Hoist is a lever hoist that includes a dynamometer to provide users a real-time reading of the load (in kilograms or pounds) they are applying to the hoist, whether it be a lifting or pulling application. The product is available in 0.75, 1.5, 3, 6, and 9-ton capacity, matching the ranges of the company's industrial and premium (overload protected) lever hoist offerings. An overload alert is triggered at 126 percent. The net weight of the unit ranges from 16.5 lbs. to 96.8 lbs., while the effort to lift the safe working load (SWL) ranges from 31.4 lbs. to 81 lbs. The dynamometer runs on AA batteries with a run time of 150 hours, though it can also be plugged into a standard 115 W outlet.



SPECTROPHOTOMETER

BYK-GARDNER USA, COLUMBIA, MD.

The color2view Benchtop spectrophotometer introduced by BYK-Gardner uses a circumferential illumination at 45° with 0° viewing to measure color. The circumferential illumination from 10 directions ensures repeatable measurement results on textured surfaces. Simultaneously with color, 20° and 60° gloss are measured to clearly differentiate medium gloss and high gloss samples. An integrated camera permits a live preview of the measurement spot to help prevent false readings on imperfections or scratches. In addition, the color2view has a fluorimeter integrated to predict lightfastness by quantifying fluorescence. The combination of a spectrophotometer and a fluorimeter allows for a better degree of control on color quality and long-term color stability. A Jetness Mode measures deep and deepest black with highest accuracy.



LEVER LATCH

SOUTHC0, CONCORDVILLE, PA.

The push-to-lock C2 lever latch provides a new auto-relock feature to comply with industry regulations such as ISO-TS 28923, which require a key to access equipment panels. With adjustable grip that overcomes manufacturing tolerances and prevents gasket setting, and multiple locking styles, the C2 series can be customized to fit a variety of applications. An integrated bumper helps to absorb vibration and noise, while preventing scratches to the panel frame. Additionally, the push-to-lock C2 lever latch has been redesigned with a more modern industrial appearance, providing a fresh option for manufacturers and design engineers.



REMOTE MONITORING

ATC DIVERSIFIED ELECTRONICS, NEWELL, WVA.

SENSERT remote monitoring and alert system offered by ATC Diversified Electronics is a scalable technology that makes it possible to remotely monitor critical processes for a wide range of conditions. A variety of sensors can be hardwired directly to the SENSERT base unit or wirelessly connected via a wireless interface to provide data in real time and alerts are triggered based on customizable thresholds, easily configurable through the SENSERT mobile app or web portal. Each channel can be configured for a high and low threshold value as well as custom alerts, and the company claims the platform works with any commercially available 0-20 milliamp, 4-20 milliamp, 0-5 volt or 0-10 volt sensor. By providing a modular approach to whole-plant remote process measurement and monitoring, the system can provide value to industries as diverse as communications, manufacturing, electronics, medical, oil and gas, and agriculture.

CABLE CONNECTORS

BINDER USA, CAMARILLO, CALIF.

The company, a subsidiary of the German manufacturer, has introduced the 823 and 824 series M12 cable connectors, designed to meet the testing and certification requirements of the North American market. The M12 K- and L-coded connectors include both male and female cable and angled connectors and feature M12x1 threads, 8-mm to 13-mm cable outlets, and IP67-rated screw clamp terminals. In industrial automation, the transmission of high electrical power via compact M12 components has become a fundamental requirement. The K coding indicates 5-pin connectors that are particularly suitable for power supply in AC applications, such as drives or frequency converters, with up to 630 V(AC) and up to 12 A, while DC compact drives, decentralized I/O modules, and various other DC-powered automation components connected to fieldbus systems are among the target applications of the 5-pin connectors with L coding. They are designed for rated voltages up to 63 V(DC) and for rated currents up to 16 A.





AUBURN

Multiple Open Rank Tenure-Track Faculty Positions

The Department of Aerospace Engineering at Auburn University invites applications for multiple **open rank tenure-track faculty positions (Assistant, Associate or Full Professor)**. Applications are invited in all areas related to aerospace engineering. Candidates are especially encouraged to apply with expertise in: flight dynamics; aerospace structures and mechanics of materials in extreme environments; aerodynamics and propulsion; and space systems and hardware. Candidates will be expected to fully contribute to the department's mission through (i) the development of a strong, nationally recognized, funded research program, (ii) teaching aerospace engineering related courses at both the undergraduate and graduate level, and (iii) professional service. Successful candidates will have a demonstrated track record of scholarship, a creative vision for research, an active interest in engineering education, and strong communication skills. For applications at the rank of Associate or Full Professor, an emphasis will be placed on the strength and caliber of the candidate's existing research program and the candidate's ability and desire to provide mentorship and leadership to junior faculty members in a rapidly growing department. Candidates must have an earned Ph.D. in aerospace, mechanical, electrical engineering, or a closely related field at the time of employment.

Candidates should log in and submit a cover letter, CV, research vision, teaching philosophy, statement on diversity, equity and inclusion, and three references at <https://www.auemployment.com/postings/32330>. Cover letters may be addressed to: Dr. Brian Thurow, Search Committee Chair, 211 Davis Hall, Auburn University, AL 36849. To ensure full consideration, candidates are encouraged to apply before December 1, 2022 although applications will be accepted until the positions are filled. The successful candidate must meet eligibility requirements to work in the U.S. at the time the appointment begins and continue working legally for the proposed term of employment.

Auburn University is understanding of and sensitive to the family needs of faculty, including career couples. See "Guidelines for Dual Career Services" <http://www.auburn.edu/academic/provost/policies-guidelines/#guidelines>
Auburn University is an EEO/Vet/Disability Employer

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香港中文大學
The Chinese University of Hong Kong

Applications are invited for:-

Department of Mechanical and Automation Engineering Professors / Associate Professors / Assistant Professors (Ref: 220002KJ)

The Chinese University of Hong Kong (CUHK) is ranked one of the top 50 universities worldwide according to the QS and THE World University Rankings of 2022/23. It is also named the Most Innovative University in Hong Kong by Thomson Reuters in four consecutive years (2016-19). In the 2020 Research Assessment Exercise, 100% of our impact cases achieved the highest rating 4*, meaning "outstanding impacts in terms of their reach and significance". The overall quality in mechanical and production engineering of CUHK is also the highest, up to 94%, among all universities in Hong Kong by adding both categories of 4* (world leading) and 3* (internationally excellent). Further information about the Department is available at <http://www.mae.cuhk.edu.hk>.

The Department of Mechanical and Automation Engineering (MAE) at CUHK is seeking excellent candidates in the following areas:

- Robotics, in particular with expertise of medical sensors, robot actuators, and soft robotics with connection to the CUHK T Stone Robotics Institute, which focuses its primary research on medical and service robotics through collaboration among experts in engineering, medicine and social science;
- Design and manufacturing: CAD/design optimization and automation, digital manufacturing;
- Dynamic systems and control;
- Engineering materials and structures;
- Green building and building automation, environmental engineering.

Applicants should have (i) a PhD degree in Mechanical Engineering or a related discipline; and (ii) a proven record of academic scholarship and high potential for excellence in teaching and research.

The appointees will (a) teach undergraduate and postgraduate courses; (b) develop an externally funded high impact research programme; (c) supervise postgraduate students; and (d) provide service to the Department/Faculty/University, professional organizations and the community.

Similar to tenure tracked positions at universities in USA, appointments will normally be made on contract basis for up to three years initially commencing August 2023, which, subject to mutual agreement, may lead to longer-term appointment or substantiation. Outstanding candidates with substantial experience for Professor rank may be considered for substantive appointment forthwith. The rank and exact start date will be negotiated with the successful applicants.

[Those who have responded to the previous advertisement for the posts (Ref. 210002DC) are under consideration and need not re-apply in this instance.]

Application Procedure

Applicants please upload the full resume with a cover letter, copies of academic credentials, publication list with abstracts of selected published papers, details of courses taught and evaluation results (if available), a research plan, a teaching statement, together with names, addresses and e-mail addresses of three to five referees for providing references.

The University only accepts and considers applications submitted online for the post above. For more information, please contact Ms. YL Kan at ylkan@mae.cuhk.edu.hk, or visit <http://career.cuhk.edu.hk> to apply online.

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USC University of Southern California

The Department of Aerospace and Mechanical Engineering (<https://ame.usc.edu>) in the USC Viterbi School of Engineering invites applications for tenure-track or tenured faculty positions at all levels in all disciplines of Aerospace or Mechanical Engineering with particular interests in *Energy and Sustainability* and *Advanced Manufacturing* including candidates whose research integrates Artificial Intelligence / Machine Learning into these disciplines. The USC Viterbi School of Engineering is committed to increasing the diversity of its faculty and welcomes applications from women; individuals of African, Hispanic and Native American descent; veterans; and individuals with disabilities.

Successful candidates are expected to develop a world-class research program within a stimulating interdisciplinary environment and demonstrate a strong commitment to teaching at both the graduate and undergraduate levels. Priority will be given to the overall originality and promise of the candidate's research work.

Positions are available starting August 16, 2023. Applicants must have earned a Ph.D., or equivalent, degree in Aerospace or Mechanical Engineering or a related field by the beginning of the appointment. Applications must include: a cover letter; curriculum vitae detailing educational background, research accomplishments, and work experience; a research plan; a teaching and service plan; and contact information of at least four professional references. Applicants are also required to include a succinct statement on fostering an environment of diversity and inclusion. In order to receive full consideration, candidates should apply on-line at <https://ame.usc.edu/facultypositions/>, and all materials should be received by January 15, 2023, although earlier application is encouraged; applications received after this deadline might not be considered.

The USC Viterbi School of Engineering is committed to enabling the success of dual career families and fosters a family-friendly environment. USC is an equal opportunity, affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, protected veteran status, disability, or any other characteristic protected by law or USC policy. USC will consider for employment all qualified applicants with criminal histories in a manner consistent with the requirements of the Los Angeles Fair Chance Initiative for Hiring ordinance.



JOINT INSTITUTE
交大密西根学院

Tenured Track Positions All Levels

The University of Michigan-Shanghai Jiao Tong University (UM-SJTU) Joint Institute invites applications for tenure-track or tenured positions at all levels (Assistant, Associate, and Full) in Mechanical Engineering. All related areas will be considered while the Joint Institute particularly seeks strong candidates in the areas of Manufacturing and Robotics. Applicants must hold a doctorate degree in a relevant field. The candidates are expected to establish vigorous research programs and contribute to undergraduate and graduate education. Salaries are highly competitive and commensurate with qualifications and experience.

The UM-SJTU Joint Institute receives strong support from both partner universities and the Chinese government. It offers B.S., M.S. and Ph.D. degrees in Mechanical Engineering and related fields. Its ME program is the first ABET accredited mechanical engineering program in the mainland of China, and its students are among China's best. The Joint Institute models itself after the world class U.S. research universities, in terms of its tenure review and promotion system, academic environment, research program, and undergraduate curriculum. English is the official language.

For full consideration, please send a CV, statement of research interests and teaching goals, copies of three key publications, and the names and contact information of five references, as a single PDF file, to the Search Committee of the Joint Institute at ji-search@sjtu.edu.cn. More information is available at <http://ji.sjtu.edu.cn/>.

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IDEA LAB IS ASME'S NEW INCUBATOR

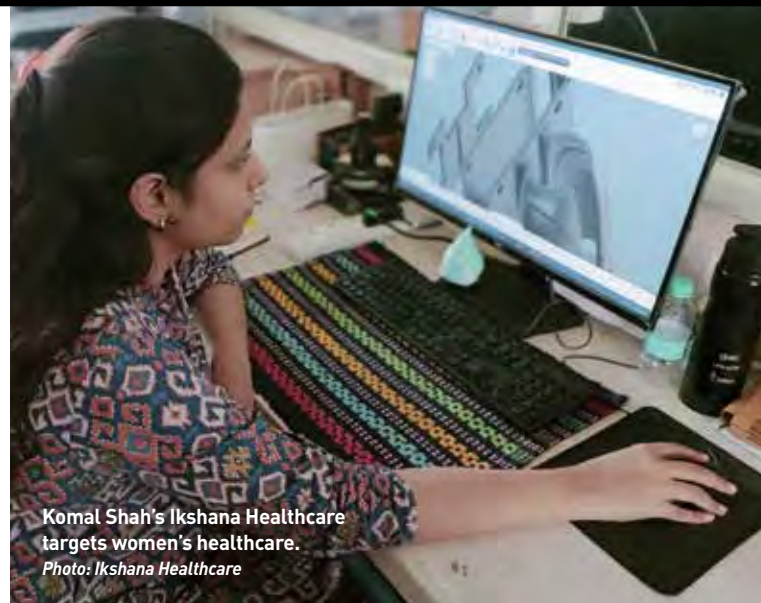
The first three innovators for the inaugural class of ASME's Idea Lab incubator, a new program that extends the reach of the ASME Innovation Showcase (ISHOW) hardware accelerator platform, have been selected. ASME received nearly 200 applications for the first round of Idea Lab from aspiring social entrepreneurs in 40 countries. Idea Lab is open to individuals and teams who have identified a pressing social or environmental challenge they think could be addressed through a hardware-led innovation that, once developed and scaled, will have a positive impact on vulnerable populations. The selected innovators are addressing needs in hydropower, women's health, and environmental sustainability.

HatchTank is a Texas startup developing its PikePower water turbine. Founder Matthis Herrera and project lead Byron Hairston are modeling a turbine-generator that can be fully submerged in rivers, tidal, and deep ocean currents. They hope to help address the need for a renewable baseload energy source to keep pace with growing electrification and carbon reduction goals.

In New York City, Flow Period LLC's co-founders, Taya Voronko, Daniela Durón García, and Andrew Parda, are developing their flow menstrual cup cleaner, a device to clean and sanitize insertable menstrual cups. It is designed to empower women to choose a cup for environmental and cost-saving benefits compared to other less sustainable menstruation products.

India's Ikshana Healthcare is developing a wearable urinary incontinence solution. Komal Shah, founder and design development lead, and Manish Arora, co-founder and technical development lead, and their team are committed to helping some 200 million people worldwide who suffer urinary incontinence. Their solution will use a novel adaptive stimulation method to significantly improve the effectiveness and efficiency of treatment over existing solutions in a convenient, discrete wearable device.

The goal of the Idea Lab engagement is to support innovators from the conceptual phase through the production of a low-fidelity prototype suitable for the next phase of technology development, the focus of the ASME ISHOW accelerator. The inaugural class of Idea Lab innovators will be engaged in the program for six to 18 months, depending on their stage of development, technical knowledge, and mentorship needs. They will receive a range of benefits, including guidance through the design process, assessment and a tailored curriculum, access to design services, design and engineering software and tools, positioning innovators for



Komal Shah's Ikshana Healthcare targets women's healthcare.
Photo: Ikshana Healthcare

potential funding to cover prototyping expenses. They will spend an average of six to eight hours per week split between flexibly scheduled meetings and self-paced learning modules. Mentors include industry professionals with expertise in research, design, engineering, business development, and more. Idea Lab innovators will work closely with Engineering for Change Fellows who will help coordinate activities throughout their technology development journey.

With the addition of the Idea Lab incubator, ASME moves "upstream" to aid budding social entrepreneurs in developing and implementing their social impact hardware concepts from the pre-prototype stage and filling the pipeline for future ISHOW participants poised to bring those innovations to the communities who need them. The prestigious ISHOW international accelerator of hardware-led social innovation has enabled more than 200 startups from 30 countries to solve critical quality-of-life challenges for underserved communities worldwide.

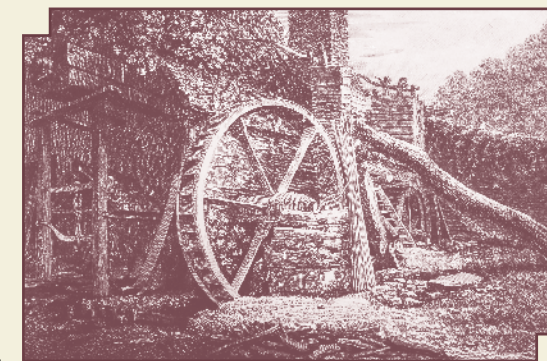
ASME thanks Keith and Elizabeth "Brownie" Roe and the ASME Foundation for their support of Idea Lab. [ME](#)

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REIMAGINING THE WATERWHEEL

Forces acting on a moving waterwheel defied the analysis of early engineers. It took applying a then-new form of math to make sense of them.



Before the steam engine produced the Industrial Revolution, windmills and waterwheels powered industry in Europe. Both had limitations based on geography and weather, but since flowing streams were more common and more reliable than strong, steady winds, waterwheels were the preferred power source. Countless thousands of watermills dotted the countryside of 17th century Europe.

Despite their ubiquity, waterwheels had always been designed, erected, and operated empirically. When scientists in the Age of Enlightenment sought to improve on these longstanding designs, they soon realized they needed new tools to understand the forces at work.

One such scientist was the Frenchman Antoine Parent, who was dedicated to the idea that mathematics should have practical applications. In 1700, he visited water-powered plants in and around Paris and tried using geometric and algebraic methods to calculate the power of the wheels he viewed. He quickly recognized that existing techniques worked only on machines at rest, not moving waterwheels and thus had limited practical use.

It took four years of study, but Parent eventually discovered how to calculate the optimum speed and maximum load for a waterwheel to achieve the maximum power from flowing water. In the process, he became the first scientist to apply calculus, then a new form of mathematics, to an engineering problem.

In his classic 1704 paper delivered to the French Academy of Sciences, Parent pointed out that a waterwheel received the maximum impact from a stream

when held stationary so the stream could strike it at full strength. But in this position it could do no work, since it was not moving. On the other hand, he noted, if the wheel moved at the same velocity as the flowing water, the stream could exert no pressure on the wheel and hence, once again, the wheel could do no work.

Parent defined the maximum available power (output of an ideal machine) as the product of these two maximums (maximum impact and maximum velocity). He recognized that working water wheels operated at some point between those two extremes and set out to determine which of the infinite number of combinations of impact and speed between the extremes would produce the maximum "effect," defined as the product of the impact of the water on the wheel's blades and the wheel's velocity.

Recognizing that traditional geometrical and algebraic methods could not solve the problem, Parent turned to differential calculus, invented a few decades earlier by Isaac Newton and Gottfried Wilhelm Leibnitz. Up to that point, differential calculus had been applied only to problems in mathematics or pure sciences such as astronomy. Parent realized the mathematical tool could be applied not only to idealized systems such as the orbits of planets but also to the very messy study of machinery.

His results indicated that the maximum effect a water-powered mill could achieve was 4/27 (around 15 percent) of the maximum possible effect. Moreover, to achieve this effect, a mill's waterwheel would have to move at one-third the velocity of the stream, and the load

applied to the wheel would have to be only four-ninths of the maximum possible stationary load. Any other combination would yield less effect.

Parent's paper was probably the first use of calculus to solve an engineering problem and certainly its first use in hydraulic engineering. He also compared the output of an ideal machine with the calculated output of a working machine, the germ of the key engineering concept of efficiency.

As groundbreaking as this work was, it received little attention. (Parent was not a popular figure in French scientific circles.) However, in the 1730s, decades after Parent's death, French engineer Bernard Forest de Bélidor discovered the work. The author of several early engineering textbooks, Bélidor considered Parent's analysis the most interesting thing he had ever learned in mechanics and believed Parent had made one of the most important discoveries in the history of science.

In his text Bélidor demonstrated how engineers could apply Parent's findings to the wheels that powered the pumps that supplied Paris with water.

Parent's analysis dominated water-power theory throughout the rest of the 18th century, but it had limitations. It was in revising and experimentally testing Parent's work that engineers such as John Smeaton and Lazare Carnot clarified those limitations and evolved the definition of efficiency we use today. [ME](#)

TERRY S. REYNOLDS is emeritus professor of history at Michigan Technological University in Houghton and a longtime member of ASME's History and Heritage committee.



Photovoltaic arrays shade crops in an agrivoltaics research plot outside Biosphere 2 in Arizona.
Photo: University of Arizona

MADE IN THE SHADE

Defusing the conflict between agriculture and photovoltaic power, researchers are testing the practicality of agrivoltaic farms.

Photovoltaic solar panels are sprouting up all over the country in response to the increasing demand for zero-carbon power. These sprawling solar farms require a lot of acreage, and often, the cheapest option is to site them on existing farmland.

Enter agrivoltaics. It's a concept that's as much a mashup as the word, co-locating agriculture and photovoltaic panels on the same plot of land. Researchers at the University of Arizona are now investigating how to grow plants in the shade of overhead solar arrays—in the process, doubling a field's yield—at Biosphere 2, a research facility that investigates the planet's living systems.

Greg Barron-Gafford, a professor of geography and development at the University of Arizona in Tucson, likens the work his team is doing outside to the work going on inside the domed, greenhouse-like research center.

"When we first had idea, people said, it's crazy—it will never work," he said. But his team had been modeling the concept on the natural savannahs replicated inside Biosphere 2.

"In the wild, plants grow in the shade of other plants and trees. We thought, solar panels could provide natural shade like a mesquite tree does," Barron-Gafford said. "Could they provide that canopy, but without competing for water?"

After eight years of work at the Arizona research site, his team believes the answer is yes.

The site is an AV farm, where the solar panels sprawl about 10 feet above the crops. The solar panels act as a plant umbrella during the hottest part of the day. That way, the

crops are less affected by heat waves and high temperatures, which are becoming more pronounced with climate change, Barron-Gafford said.

The shade also helps to cut water consumption, another environmental consideration.

"If you spill water in the shade versus the sun, where does it stay wet longer?" Barron-Gafford said.

"We've shown you can produce equal amounts of food with half as much water," he added.

Andrea Gerlak wants to "understand the human element, how people make decisions to adopt technologies like AV farms." She's a colleague of Barron-Gafford's at the University of Arizona.

"We're building a national portfolio of AV projects—to understand by region, climate, and by space—what you get and what you give up when you make decisions about AV," she said.

The team's research will give politicians, farmers, and other interested parties information on how AV farms would function in local environments.

For those concerned about the visual impact of towering solar panels on the rural landscape, Barron-Gafford pointed out that AV farms will never sprawl across countless miles of agricultural fields. "We're talking about converting a small percentage of the farms to have an impact across the entire country," he said. **ME**

JEAN THILMANY is an science and technology writer in Saint Paul, Minn.



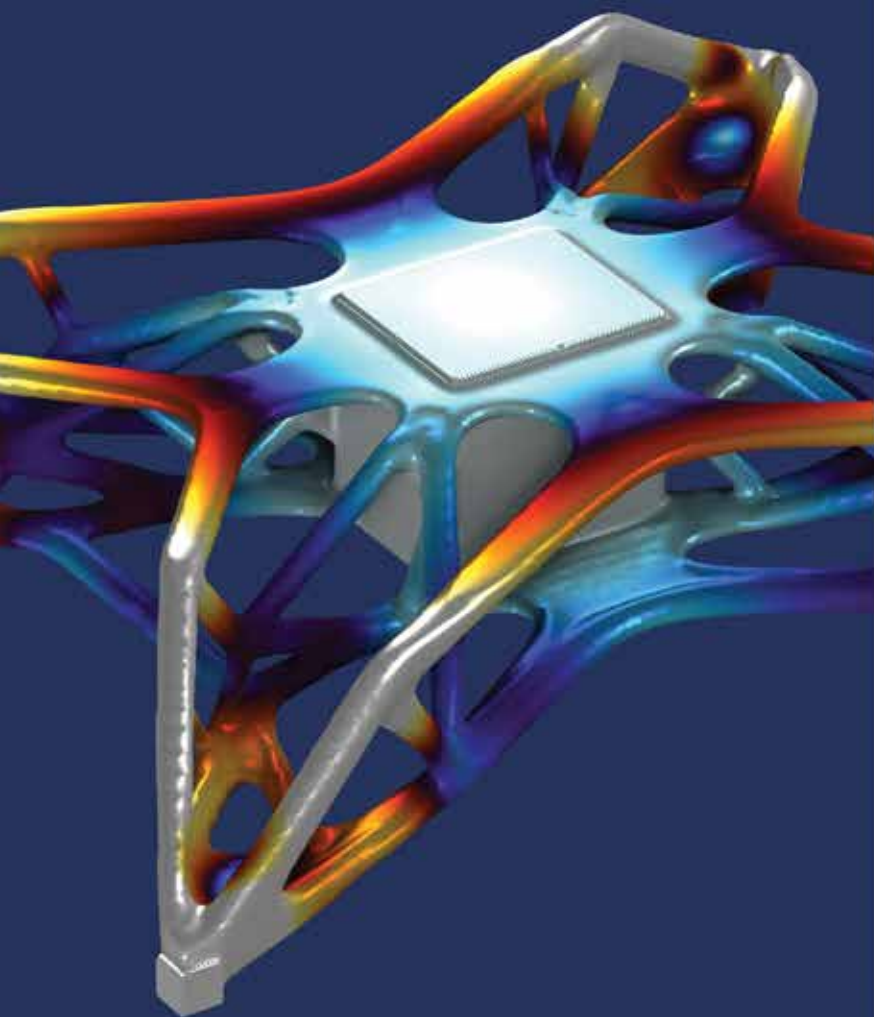
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