MECHANICAL
ENGINEERING
Technology that moves the world
THE MAGAZINE OF ASME
No. 12
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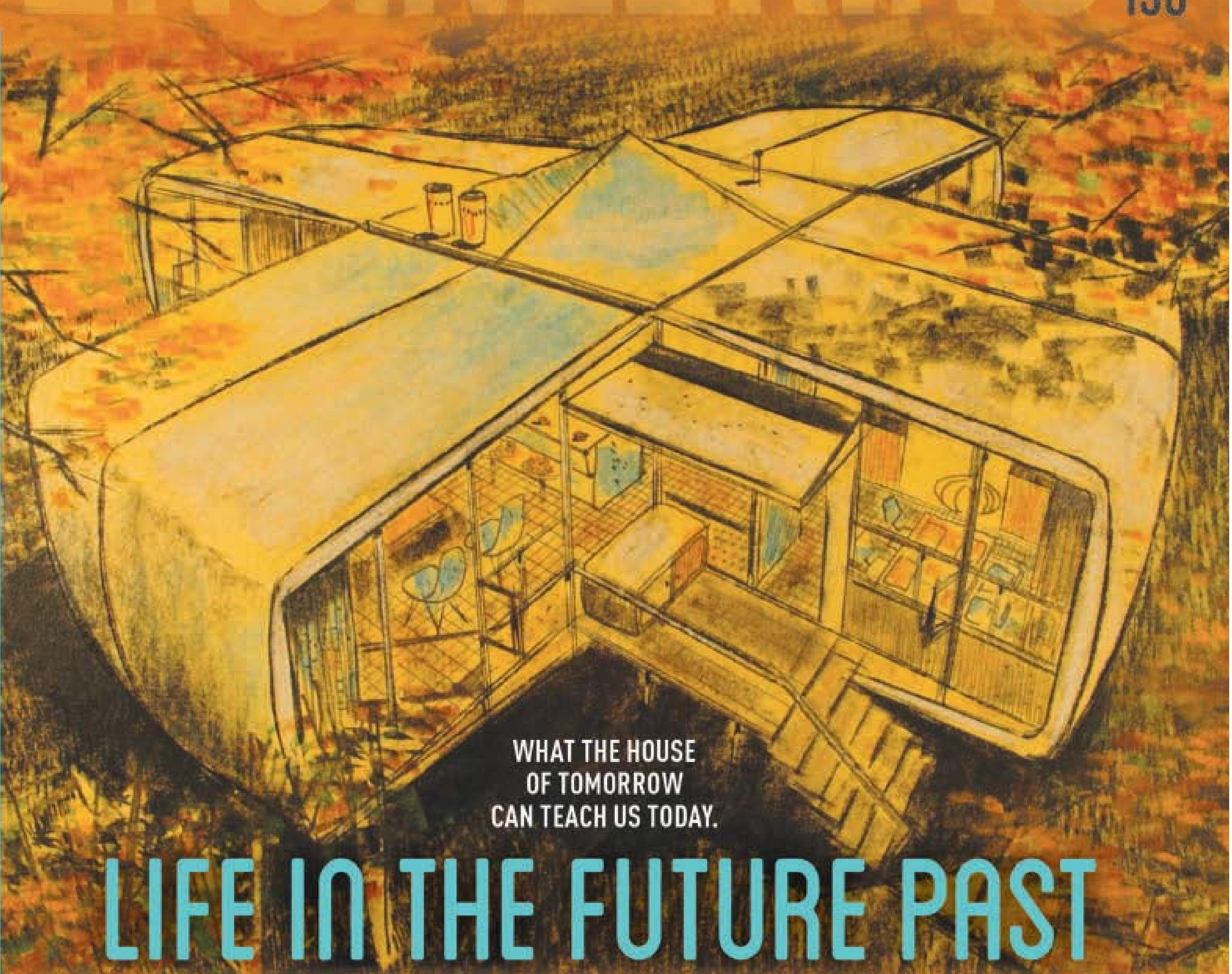

WHAT THE HOUSE OF TOMORROW CAN TEACH US TODAY.

LIFE IN THE FUTURE PAST

3-D PRINTING HOUSES

CONTOUR CRAFTING, DEVELOPED BY University of Southern California professor Behrokh Khoshnevis, is a system that can print a 2,500-foot home in a day. The walls of the printed houses will be stronger, cheaper, and greener than conventional houses. And because they can be printed from CAD files, the structures can be in any shape the designer or architect can imagine.

FRACKING RIGS CLEAN UP

A well services company is said to have groundbreaking results from its newly patented technology, which is claimed to be the industry's first fully mobile, fully electric hydraulic fracturing system. Recently implemented by Antero Resources, the technology has demonstrated dramatic environmental gains as well as significant cost savings for oil and gas exploration companies. The system is powered entirely by natural gas, and conventional diesel engines have all been replaced with electric motors.

INVISIBLE TO THE EARS

Researchers at Duke University are turning fiction into reality by creating a cone of silence with a pyramidal sound cloak made of metamaterials.

For these articles and other content, visit **asme.org.**

MORE THAN SKIN DEEP

The latest in healthcare technology is a small, tattoo-sized patch that continuously monitors biology through the skin. This technology can go on any part of the body and can be an implantable device as well.

NEXT MONTH ON ASME.ORG

VIDEO: ADVANCED MANUFACTURING METHODS AT NASA

James Free, director of NASA's John H. Glenn Research Center, talks about advanced manufacturing techniques being used by NASA for space research and missions.

PODCAST: USING HEAT TRANSFER FOR DEVELOPING MEDICAL DEVICES

Dr. Kenneth Diller of University of Texas discusses how heat-related processes in living tissues can be applied in the design of therapeutic devices.

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A mechanical watch drive you wind once a month.
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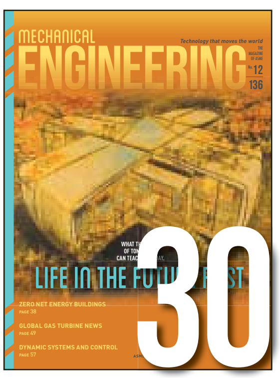

Cover image courtesy: Goody Clancy.

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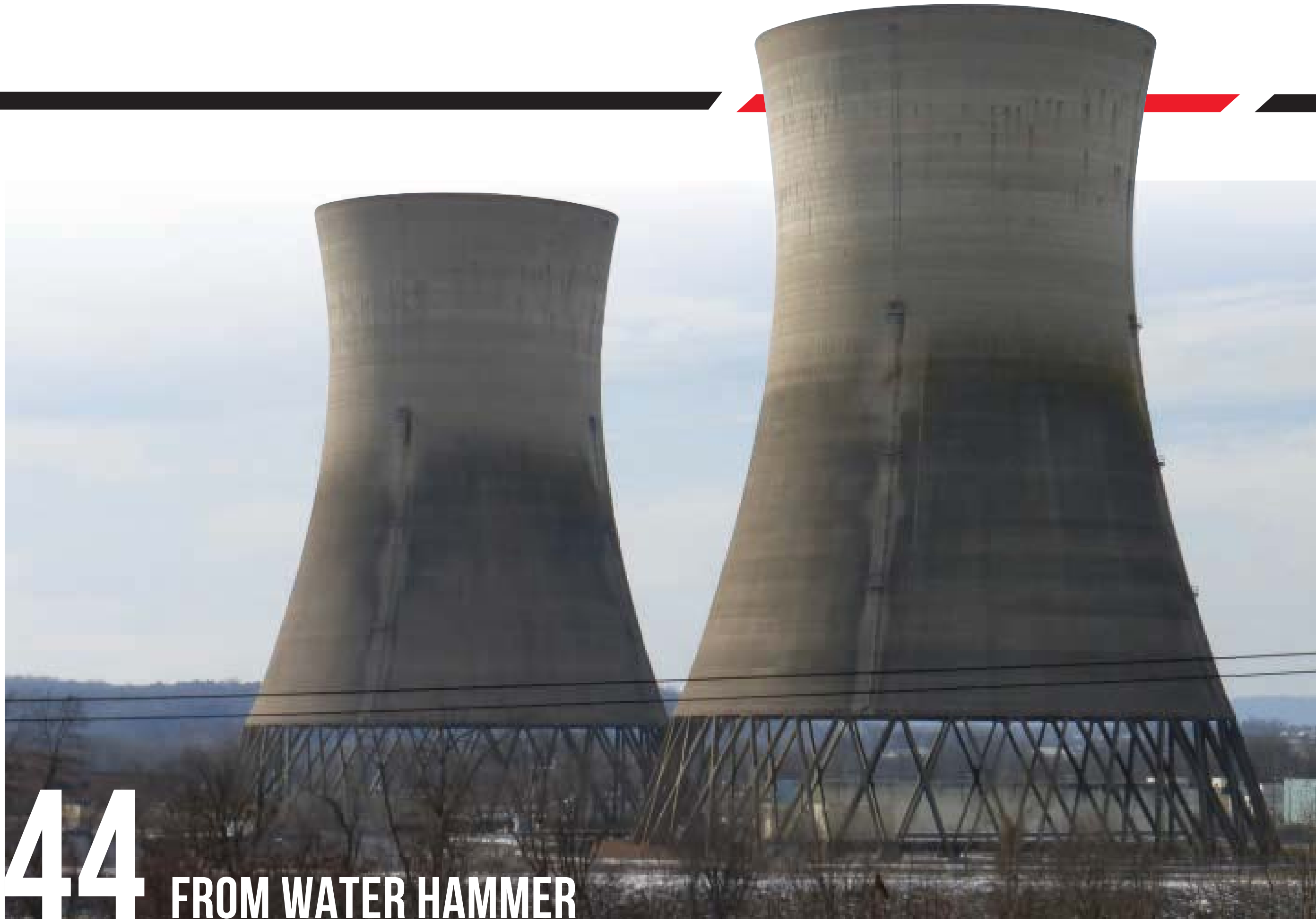
SETTING THE STANDARD



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ENGINEERING // THE MAGAZINE OF ASME

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asme.org
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Published since 1880 by the **American Society of Mechanical Engineers (ASME)**. *Mechanical Engineering* identifies emerging technologies and trends and provides a perspective on the role of engineering and technology advances in the world and on our lives. Opinions expressed in *Mechanical Engineering* do not necessarily reflect the views of ASME.

Give me the place to stand, and I shall move the earth
—Archimedes

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Mechanical Engineering (ISSN 0025-6501) is published monthly by The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990. Periodicals postage paid at New York, N.Y., and additional mailing offices. POSTMASTER: Send address changes to Mechanical Engineering, c/o The American Society of Mechanical Engineers, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300. Return Canadian undeliverable addresses to P.O. BOX 1051, Fort Erie, On, L2A 6C7. PRICES: To members, annually $32 for initial membership subscription, single copy $7; subscription price to nonmembers available upon request.

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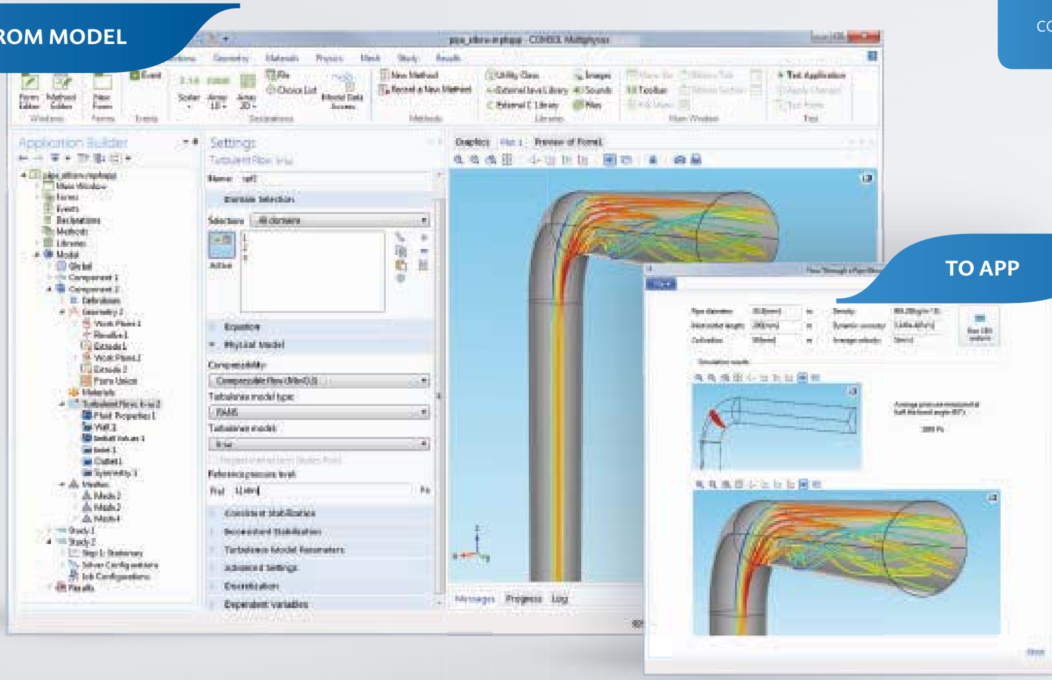

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John G. Falcioni
Editor-in-Chief

PLANNING YESTERDAY FOR TOMORROW

My friend Gary used to come over to my house almost daily when we were kids, but I secretly prized the times he invited me over to his parent's place. I had more board games than he did and had gained a bit of a reputation for being a killer table-hockey player, so Gary and a lot of other kids always wanted to test me out. But Gary's house had gadgets—lots of gadgets. By today's jargon, I'd call Gary's mom and dad early adopters.

For example, Gary was among the first kids in school to brag about owning a color TV; he was the first to get a cassette player and a movie camera. I also remember that his folks had kitchen appliances that shined—maybe because they went out to eat a lot. Oh, and they had a car, not that this was necessarily a big deal, except for families like mine that didn't. For me, entering Gary's house was like walking into Walt Disney's Carousel of Progress.

Both figuratively and literally Disney has been on the vanguard of innovation since the iconic movie maker opened Disneyland in 1955. Our cover story this month, "What the House of Tomorrow Can Teach Us Today," opens with a photo spread, across pages 30 and 31, showcasing the Monsanto House of the Future, a popular Disneyland attraction from 1957 to 1967. But the Monsanto house was more than a simple attraction, it was a presumed beacon for how we would live in the future—a future, 1986, that has long passed us. You can see the kitschy promotional video for the house at http://bit.ly/1vC9Cxt.

One of the takeaways from the House of the Future is that, in some ways, technology has far outpaced even the imagination of what the future would hold. But we also see some accurate projections.

The paradox of any archetype that looks ahead in time—a house, a car, a [fill in the blank] of the future—is either that the prototypes are built too many years ago to be considered futuristic today, or those created today are too fundamentally ill-informed to provide realistic projections of tomorrow. Still, they're valuable as benchmarks of innovation.

Earlier this year, Samsung introduced its own house of the future, the Samsung Smart House. It features a home environment containing technology that's available today to you and me. You can see Samsung's promotional video on the house at http://bit.ly/1A29EXl.

Samsung's and other visions of the house of the future are a showpiece for connectivity. They're defined by the burgeoning buzz phrase, the Internet of Things (IoT), which delivers the backbone for interconnectivity, be it household devices or industrial chains. In a home environment, the IoT is represented by appliances controlled through voice recognition, or from outside the home through cell phones, tablets, and other mobile devices.

Even as I admired the gadgets in his home, Gary and I preferred to debate the trades of our favorite baseball team more than the future of technology. Not that we didn't daydream about space stations, visits to Mars, oversize televisions, and wristwatch phones. We didn't think then that these things would really exist one day. Much like we don't know today what 2015 will bring, let alone what the home might look like in 2045. **ME**

FEEDBACK

What will the home look like in 2045? Email me.

falcionij@asme.org

LETTERS & COMMENTS

JUNE 2014

Reader Love is glad he didn't stop getting the magazine.

One reader sees jobs in countering global warming. Another says MEs aren't getting due credit. And a third reviews the June issue.

NEW JOBS ARE WAITING

To the Editor: The letter from J.W. Baker in the August 2014 issue ("Why the Rust Belt Rusted") made a convincing argument regarding the cause of the "manufacturing collapse in America," laying all blame at the feet of the ownership class.

However, as with most great historic issues, there were and yet remain multiple causes. (I would modestly like to reference here my own third rule regarding worldly affairs: an investigation of any real-world issue will prove far more complicated than you anticipated when you began to investigate.)

Equally to blame for the rusting (if finding blame is really what we want to do) are the enormous technological advances made during the past three centuries—advances that have completely reshaped our culture.

Back during the middle of the twentieth century, some labor union leaders were already warning their members to beware the consequences of what they called "automation"—the development of self-controlling machine tools that would eliminate the jobs not only of unskilled workers but also of many skilled workers. Their dire predictions have been fully realized, even though they could not have foreseen the advent of computer-controlled production processes.

But, to borrow a term coined by economists, this transition has been a process of "creative destruction"; many of the positions thus lost were dirty, dangerous, or boring.

At the same time, better jobs are being created—albeit not nearly as many as are being lost. Our only viable option at this point is to upgrade our macroeconomic structure—on an international basis—to make the best of this new world.

One seemingly obvious step would be to actually implement properly vetted programs designed to counter global warming—programs structured on a global scale. This would create many new and extremely satisfying jobs, worldwide, including engineering jobs.

Marvin A. Moss, North Hills, Calif.

STILL IMPRESSED

To the Editor: Congratulations on the work that you have done in the improvement of the magazine.

When I was a student majoring in mechanical engineering (1946-47), we were required to take a two-semester course in which we were each assigned to present an oral review of an article from *Mechanical Engineering*. Then we would lead a discussion of the article.

I was impressed at the time at the range of current engineering topics. During the nine years that I spent in industry, I often profited from articles in the magazine.

This continued throughout my teaching career. I have now been retired for 25 years, but still enjoy reading the magazine. However, without being specific, *Mechanical Engineering* seemed to wander away from technical topics. In fact, I almost was ready to ask that I be dropped from the mailing, even though I am not charged for it.

I am very glad that I did not ask to be dropped from the roll, since I have again become a fan of the magazine.

The June issue covers a number of very important topics that are facing not just our nation but the entire planet.

It seems that many people believe that humans do not have the ability to cause climate change. Think for a minute that, for each gallon of gasoline you burn, you put approximately 18 pounds of CO_2 into the atmosphere.

There is no question that carbon dioxide content of the atmosphere does influence the energy balance of our planet (as well as the acidity of the oceans.).

This brings us to the excellent article in *ME* on the current status of nuclear possibilities. I personally think that, if the public can get over the fear of nuclear, this will be the solution to the world's energy problem.

The most interesting article, however, has to do with the recovery of industry in the United States.

I really cannot thank you enough for the great job you are doing. It is not just the current issue but all of the issues since you have become editor. I sincerely appreciate what you have done for ASME.

Tom Love, Norman, Okla.

SCIENTIFIC INTOLERANCE

To the Editor: This comment refers to a letter in the August 2014 issue headlined "Unsettled Science," which is skeptical about climate change. Normally I completely disagree with these folks, but this writer did mention an important point that must be more widely appreciated.

It is shocking that sometimes climate change researchers who disagree with the main results of climate change science are ostracized by their scientific colleagues. The most famous victim is John Christy, whose case is described in a July 15 *New York Times* article (http://tinyurl.com/NYTChristy). This is horrible, and undermines the credibility of the vast majority of scientists who are not climate change skeptics.

Dudley Jones, Life Member, Princeton, N.J.

NO MOMENTUM LOST

To the Editor: The letter titled "Working at a Disadvantage" in the March 2014 issue talks about limitations of mechanical engineering. It starts by saying, "Nothing in mechanical engineering has come close to the advances electrical engineers have made ..." and continues, "Nothing in ME has produced anywhere near the technological progress, job opportunities, the social and economic changes, ... which are based on work done almost entirely by electrical engineers."

There is no doubt concerning the advances that electrical engineers have made. However, one should not underestimate the status of mechanical engineering among engineering disciplines.

Many examples of progress that are mentioned in "Working at a Disadvantage" are not results of what electrical engineers have done alone.

Most of them have been results of unprecedented interdisciplinary research and collaboration among engineers from various disciplines.

Take developments in microelectromechanical systems, mechatronics, and biomechanics, for example. How can one even imagine such advances without seeing the strong roles of mechanical engineers who work on the robotics, fluid mechanics, and strength of materials aspects of such problems?

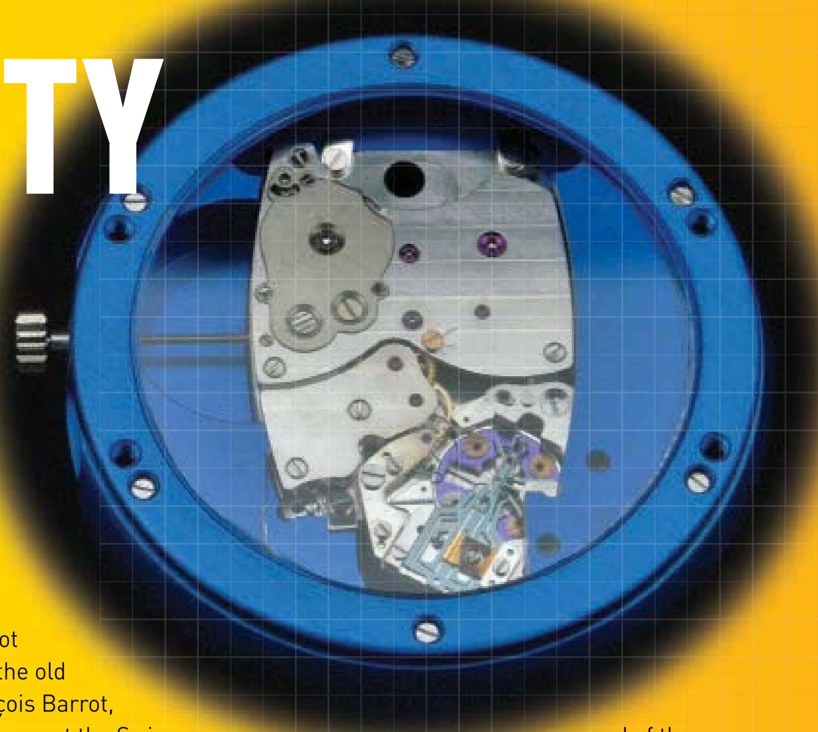
So, it is not that mechanical engineering has lost its momentum: it has found new ways to grow.

Mehrdaad Ghorashi, P.E., Gorham, Maine

FEEDBACK

Send us your letters and comments via hard copy or e-mail memag@asme.org (use subject line "Letters and Comments"). Please include full name, address, and phone number. We reserve the right to edit for clarity, style, and length. We regret that unpublished letters cannot be acknowledged or returned.

A MIGHTY WIND



MECHANICAL WATCHES NEED TO REPOWER THEIR SPRINGS EVERY DAY. A NEW SWISS DESIGN MAY TURN THAT TO A MONTHLY CHORE.

THE POOR MECHANICAL WATCH: once ubiquitous, it's now cherished only by those with an eye, and a wrist, for either novelty or luxury. In keeping with the march of time, the killer of the analog was cheap, accurate, and digital. But the great advantage of the battery-powered timepiece was not its precision, or its price, but its ability to mark time with little in the way of maintenance.

Now a company in Switzerland—of course—has a mechanical watch so efficient that it rivals the digital. Wind it once and you're good for a month.

The key to the mechanism is a piece of technology borrowed from the world of aerospace. In essence, thin blades vibrate, unencumbered, at a constant frequency. Inventor Pierre Genequand realized that this Flextech technique could be shrunk down and used to power a watch. So he built a massive 20 to 1 scale prototype out of wood and iron.

"He's a physicist, does everything theoretically, does his equations by hand, not on a computer, the old way," says François Barrot, the project manager at the Swiss Center for Electronics and Microtechnology. "At the beginning, we didn't even know if it would tick tock." Having proved it would do both, Genequand convinced CSEM to shrink it down the rest of the way.

To do that, CSEM put away the wood and iron and turned to silicon. It also partnered with a venerable watch company, Vaucher. The more up-to-date material allowed them to etch each part with incredible precision and to produce multiple components on a single piece. And it needs no lubrication.

"We don't have the fatigue aspect with silicon," says Frédéric Ganny, an engineer at Vaucher who worked on the project. "If it works, it works for life."

At the moment there's only a single prototype at actual size. It ticks, to be sure, but there are still a few areas for improvement. Though it's well equipped to handle the forces encountered at the end of the arm, it doesn't do as well with the shock of a whack against a table. And temperature can also toy with its timekeeping abilities (not any more than a conventional mechanical watch, but this is not meant to be any conventional mechanical watch).

Once these trifles are smoothed out, the Genequand will be ready to compete with any quartz watch in terms of maintenance and precision. Price, though, will be another matter. The watch is likely to be worn (and affordable to) only those passionate about mechanical watches—the kind who "take pleasure to see how the watch is breathing and living," as Barrot puts it.

"For the mechanical world, it's something very different. It's a revolution, in the engineering respect and the end product." **ME**

MICHAEL ABRAMS

The Genequand mechanism (top) features three silicon parts: (below, from left) isochronism compensator, Wittrick oscillator, and pallet.

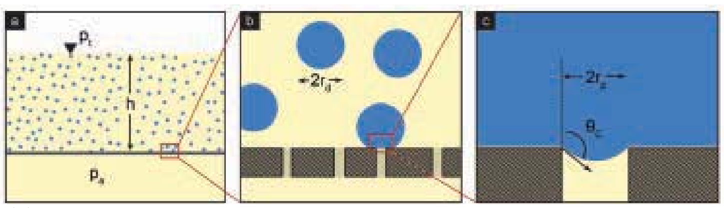
PULLING OUT THE SMALLEST DROP

MEMBRANES THAT FILTER BY PARTICLE SIZE CAN ALLOW emulsified liquids to slip through pores smaller than the nominal droplet size. A polymer with one layer of nano-pores and another layer of micro-pores can better separate oil from water.

After the release of petroleum into open waters, oil and water can mix in the form of an emulsion. The oil may appear to be gone, but it can linger in concentrations great enough to harm marine life and disrupt ecosystems. The *Deepwater Horizon* oil spill, for example, released about 5 million barrels of petroleum into the Gulf of Mexico. Years after the well was capped dolphins in the Gulf were still dying in record numbers.

The underwater use of dispersants in response to the spill may have increased the emulsion of oil and water. The denser than normal oil emulsion may also have disrupted lower levels of the food chain in the northern Gulf.

In the case of nano-emulsions, when suspended oil droplets are smaller than 1 micrometer, the combination is difficult to separate. That's why researchers at the Massachusetts Institute of Technology turned their attention to the issue and came up with a membrane designed to separate nanoemulsions of oil and water.



(a) Schematic of a water-in-oil emulsion being filtered through a membrane showing (b) water droplets near the membrane pores. (c) Close-up diagram of a rejected droplet on the surface of the membrane.

The research team—Kripa Varanasi, an associate professor in the department of mechanical engineering; Brian Solomon, a graduate student, and Nasim Hyder, a post-doctoral researcher—described their work in the July issue of the journal *Scientific Reports*. Their paper, "Separating Oil-Water Nanoemulsions Using Flux-Enhanced Hierarchical Membranes," pointed out: "A variety of techniques have been implemented in industry, including gravity separation, skimming, and dissolved air flotation. More recently, new techniques incorporating aerogels, magnetic materials, and fluorosurfactant polymers have been introduced. Though promising, these approaches are ineffective for separation of small-scale emulsions, especially for those with droplets below a micron in size."

According to the authors, membranes that filter by particle size can be effective in removing solids, but droplets in emulsified liquids can deform to slip through pores smaller than the nominal droplet size.

The team's solution combines a polymer with a layer of nano-pores and another layer of micro-pores for a structural reinforcement. The structure is treated so the surface and pores resist or attract oil or water, to suit the strategy of separation.

They said the membrane can be produced on an industrial scale.

To form the membrane, the team mixed polysulfone and polyvinylpyrrolidone and dissolved them in dimethylacetamide. The next step was to cast the PSf-PVP mixture onto a glass plate and cure it in water. The polysulfone remained and the PVP macromolecules migrated to the surface.

The result was a porous matrix with a thin skin layer riddled with nano-scale pores, roughly 30 to 80 nanometers in diameter, and below that was a thicker layer with micropores, about 10 to 20 micrometers across. Because the structure was a single sheet, there was no need to bond layers together.

The membrane was treated with octadecyltrichlorosilane, which attracts oil and repels water.

The group's experiment to test the membrane used an emulsion that contained 3 percent water by weight and 97 percent n-hexadecane. The goal was to strain the oil through the membrane and leave the water behind. They added a surfactant, Span 80, to keep the emulsion stable for the length of the test.

Water droplets formed as spheres in the n-hexadecane and had a mean diameter of 1.5 μm, although there was considerable variation in size. Some droplets, detected by dynamic light scattering, were as small as 200 nm.

Little, if any, water passed through the membrane under a pressure drop of 275 kilopascals. The membrane successfully resisted even the 200 nm droplets. Dynamic light scattering returned evidence of the presence of water droplets around 10 nm across.

The authors said that a separate DLS analysis of n-hexadecane containing no water and 1 percent Span 80 showed similar results. They said that the reading may have been the result of instrumentation error or the presence of the surfactant.

The strategy of the experiment described in the paper was to separate an emulsion of water suspended in oil. The authors said the same principles could be applied to emulsions of oil in water, by treating the membrane to be hydrophilic and oleophobic.

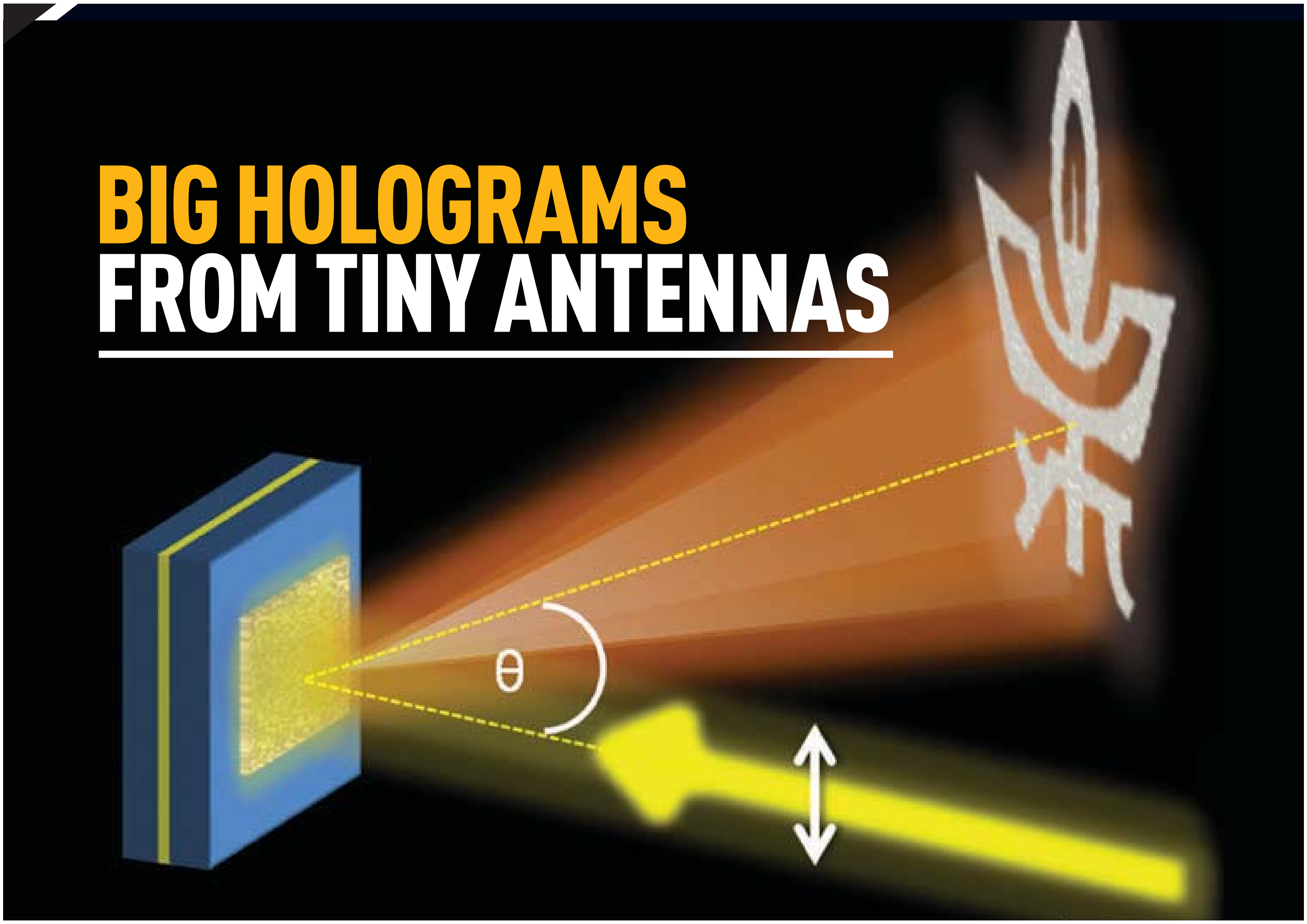
The researchers also reported that they found a means to control the thickness of the nanoporous skin layer by mixing polyethylene glycol with the PVP as a sacrificial material.

The research was supported by Shell, through the MIT Energy Initiative.

A copy of the paper is available at http://varanasi.mit.edu/publications/. **ME**

HARRY HUTCHINSON

BIG HOLOGRAMS FROM TINY ANTENNAS



By controlling the amplitude, direction, and phase of reflected light, a nanoscale antenna was able to project a static hologram. Illustration courtesy: Yael Hanein, Tel Aviv University.

Antennas receive, antennas transmit. It's thanks to this long-established technology that our TVs, radios, and cell phones can harvest signals from waves on the electromagnetic spectrum. Usually these waves are on the long side, of course. For smaller waves, say, on the visible part of the spectrum, antennas would have to be much smaller. Impossibly small, in fact, were it not for the age of nanotechnology.

"Antennas scale pretty well," says Yuval Yifat, a doctoral student studying nanotechnology at Tel Aviv University. "Theoretically you should be able to push them down to optical frequencies, should be able to do whatever a classical antenna does."

Several years ago, researchers took that idea out of the theoretical realm and into the actual, by showing that nano antennas could control the amplitude, direction, and phase of light. They put tiny antennas on lasers and split beams in two, with one half breaking off at an angle.

Yifat saw the potential to make a hologram.

To do that, though, the nano antennas of 2012 had to be made more efficient. Those older nano antennas performed their tricks on about 5 percent of the light that hit them, with 95 percent of it passing through unaffected. They used simple dipole configurations, not unlike the rabbit ears on the TVs of the pre-digital age.

"We went back to classic antenna theory," Yifat says. He and his colleagues settled on a dipole and patch configuration. They fabricated the antennas over a reflective slab of gold, so light passes through the antennas again as it bounces away.

"WE WROTE SOME HOME GROWN CODE, FABRICATED A CHIP IN OUR NANO-CENTER, AND—VOILA—IT ACTUALLY WORKED."
YUVAL YIFAT, DOCTORAL STUDENT, TEL AVIV UNIVERSITY

With the new configuration, they managed to get efficiencies in the 40 to 50 percent range.

With the ability to efficiently control phase, they simply needed to put the antennas in the right place to make a hologram that would project the right depth information to the human eye. "We needed to determine a phase map," Yifat says. "We wrote some home-grown code, fabricated a chip in our nano-center, and—voila—it actually worked."

Yifat and his colleagues created a hologram of the Tel Aviv University logo in infrared. It was not only more efficient, but it also projected a much wider angle than any hologram before it.

To increase the efficiency, Yifat's team is currently trying to come

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BIG HOLOGRAMS FROM TINY ANTENNAS

up with a better algorithm. They may also use 12 phase elements instead of the current six. "The more you have, the more fidelity you have to the original phase map," he says. "You go point over point and decide which antenna element to use for each point." With such techniques he hopes to get the efficiency up a few more tens of percentage points.

The uses for the new holograms are many, including data storage, particle trapping, and security applications. Shoppers could use a scan of a couch, or create their own in a CAD file, and project it in their living room to find the perfect spot for the furniture before buying it. Three-D movies may ditch the need for glasses, and television may move into the third dimension as well, able to project different images to different viewers.

The Tel Aviv University logo, was, of course, static. To create a hologram for moving images would require a dynamic setup at the nano level. "People have pretty interesting ideas about how to control the phase of light," Yifat says. Some of those ideas involve changing the antennas, some changing the environment they sit in, by heating it up or injecting electrons.

"But, long story short," he says, "no one has been able to do it so far at our scale." ME

MICHAEL ABRAMS, ASME.ORG

THIN-SHELL

A rediscovered concrete covering could replace the common corrugated metal roof on houses in the tropics.

Since architect Anton Tedesko introduced the concept of thin-shell, mesh-reinforced concrete architecture, it has attracted a small but dedicated fandom around the world, including the sweeping lines of the TWA Flight Center at JFK Airport in New York City and the roof of the Hersheypark Arena, designed by Tedesko and built in 1936.

Now, a return to simple shapes in thin-shell construction is fortifying architecture in developing countries. Simple, single-curve thin-shell barrel roofs can resist the corrosion of the tropics, minimize earthquake damage, and don't cost much, according to Scott Hamel.

Hamel, an assistant professor of engineering at the University of Alaska Anchorage, led a team that tested the toughness of thin-shell barrel roofs with

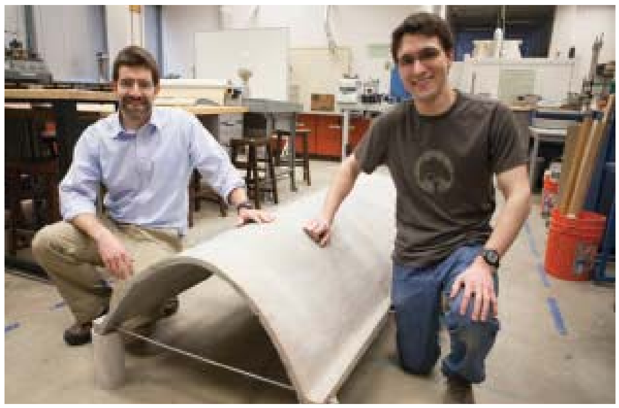
ROOFS IN HAITI

an eye toward construction in earthquake-prone Haiti.

Barrel roofs bend in a single curve like an upside-down halfpipe, distributing loads along their length as a beam, and transversely from edge to edge as an arch, Hamel said.

The roofs are technically easy to build. They are made from ferrocement, which is reinforced with steel mesh rather than with thick rebar, to allow for thinness. Drape the roof over a wooden form on the ground to shape and harden, then hoist each one as a single unit to top a structure. The simple construction process coupled with the frugal use of concrete and steel keeps costs low, Hamel said.

In Haiti, thin shells could serve as upgrades over two common types of roofs: thick concrete slab, popular in Port-au-Prince until they collapsed during the earthquake in January 2010, and corrugated metal, which rusts.



Professor Scott Hamel, left, and Nathaniel Cox, an undergraduate civil engineering student, with their jointly designed concept for a lighter, less expensive, and safer roofing system than what is currently used in most developing nations.
Image: Philip Hall/University of Alaska Anchorage

The Alaskan team set out to find the best concrete mix for the roofs and the best shape to set it in. They put their structures through stress, shear, and bending tests before settling on a few specifications.

The optimum concrete includes 15 percent latex paint, added to make the shells more flexible and less likely to crack. Their favored water-to-cement ratio is 0.40, and the best cement-to-sand ratio is 0.50. They also discovered how the mixture should best be reinforced to avoid cracking and to support a 300-pound mid-span load, Hamel said. ME

ENGINEERING FOR CHANGE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MAINTENANCE MATTERS

Funders of global development programs **continue to incentivize construction.** But the most cost-effective interventions often involve **helping communities maintain what they already have.**

Driving along rural dirt roads in many developing countries, you see frequent evidence of the generous intent of global humanitarian aid agencies. Most tangible are hand-driven water pumps that dot the landscape.

These pumps are the concrete and steel outputs of a global intent to provide more clean water to more people. Thousands, funded and implemented by organizations large and small, are installed every year in developing countries.

But, sadly, you can never predict whether the next water pump you pass will be surrounded by people, often women and children, filling their jerry cans, or will stand as a decrepit artifact of wasted resources.

Studies show that between 30 and 80 percent of water pumps fail within a year of their installation. While the proximate failures may be a leaky seal, a broken riser, or a missing handle, these are only symptoms of the ultimate failure in how we fund, incentivize, and monitor these efforts.

Some experts suggest that for the cost of installing a new hand pump, operation and maintenance could be funded on its neighbor pump for a century. Or, put another way, an implementer with 500 installed pumps, could choose either to install 100 new hand pumps in a year or to maintain the original 500 for 20 years.

But the choice is possible only if funders can be persuaded to consider maintenance as interesting as new construction.

Instead, funders continue to focus on construction, and sustainability is usually addressed through "participatory community development," where local communities are, in theory, empowered to manage their own water supplies. In reality, this approach has often not resulted in cost effective interventions.

And these challenges exist not just for hand pumps, but for a myriad of health and environmental interventions both in developing and developed countries.

Some organizations are now testing alternatives that focus on outcomes rather than intent. Instead of pushing money toward projects based on promises, some implementers are showing how funders could support programs that demonstrate successful results and not just good intentions.

HOW CAN FUNDERS SUPPORT PROGRAMS THAT DEMONSTRATE SUCCESSFUL RESULTS, NOT JUST GOOD INTENTIONS?

Technology can also play a role. Our team at Portland State University has designed sensors that are connected to cell phone networks to automatically report to the world how things are going with interventions like water pumps.

With support from the U.K. Department for International Development and the GSM Association and in partnership with Living Water International and the Rwanda Ministry of Natural Resources, our team is testing new approaches.

This summer we're installing over 200 sensors and running a study of three different models for maintenance of hand pumps. We're going to compare the current model of operation and maintenance against two others. One experiment is a "call us" model that requires communities to report pump outages, and the other is an "ambulance service" model in which the sensors directly notify technicians that maintenance is required.

Data will be collected by sensors in all three models, but only in the ambulance service case are the technicians going to see what the sensors are saying.

With over half of water pumps failing in some countries, if we reduce that failure rate even by a quarter through better maintenance and accountability, these fancy sensors will pay for themselves.

These and other approaches can start to align intent with impact, and start to ensure that pictures of kids drinking clean water match the reality on the ground. ME

EVAN THOMAS is an assistant professor of mechanical engineering at Portland State University, COO of DelAgua Health, and CEO of SweetSense Inc.

Q&A KARL W. REID

THIS MONTH, *MECHANICAL ENGINEERING* SPEAKS with Karl Reid, elected in May 2014 as executive director of the National Society of Black Engineers, a 30,000-member student-governed organization for precollege and college students interested in careers in science, technology, engineering, and math. Founded in 1975, NSBE includes more than 300 chapters, and is headquartered in Alexandria, Va.

Reid has served as senior vice president of research, innovation, and member college engagement at the United Negro College Fund. Prior to joining UNCF, Reid was associate dean of undergraduate education and director of the Office of Minority Education at Massachusetts Institute of Technology.

Reid earned both his bachelor's and master's degrees in materials science and engineering from MIT, and his Ph.D. in education from the Harvard Graduate School of Education.

ME: How has your background helped you get where you are today?

K.R: As director of engineering outreach programs at MIT, I learned the challenges and best practices associated with increasing readiness of underserved and underrepresented populations for careers in STEM. While working in the software industry, I led cross-functional teams to bring to market new and upgraded products, which proved helpful as I gained an appreciation for the discipline of the product management process that I apply to new program development in the nonprofit sector. These opportunities also exposed me to the global economy, working with affiliates in Europe, Asia, and South America.

Then, as an associate dean and freshman seminar leader at MIT, I developed an approach for improving the retention and success of college students of color in STEM, particularly those who were first-generation college students. Much of this work was drawn from my doctoral studies in which I developed a student achievement model based on self-efficacy (confidence), skills development, positive identity development, and faculty and peer engagement.

As a chapter officer and then later serving as national chairperson of the National Society of Black Engineers, I was exposed to the regional and national (and now global) impact of the society on student success and professional development, and the potential for intentional leadership development opportunities.

ME: As a kid, what did you want to be when you grew up? Is your life today different from how you envisioned it?

K.R: My father saw in me an early love for trains. Growing up on Long Island, it was always a treat to ride the Long Island Railroad or the subway system. My dad, who left college to join the Navy, told me when I was about five years old that "engineers drive trains." That was it. I was going to be an engineer!

I ultimately earned engineering degrees at MIT and worked as a systems engineer at IBM. I was reasonably successful and I enjoyed the intellectual and professional stimulation, but later I realized that my major hadn't captured my heart.

At the end of my college sophomore year, I was elected to a position in the MIT chapter of the NSBE with the responsibility to resurrect a program that exposed local junior high and high school students to engineering. In that role, I worked to increase opportunity for those who are traditionally underrepresented in this field. This avocation and my vocation came together nearly 16 years later when I returned to MIT to run the Office of Engineering Outreach Programs and the Minority Introduction to Engineering and Science (MITES) summer enrichment program for rising high school seniors. I later discovered the need to prepare students earlier than high school. This led to the start of middle school programs.

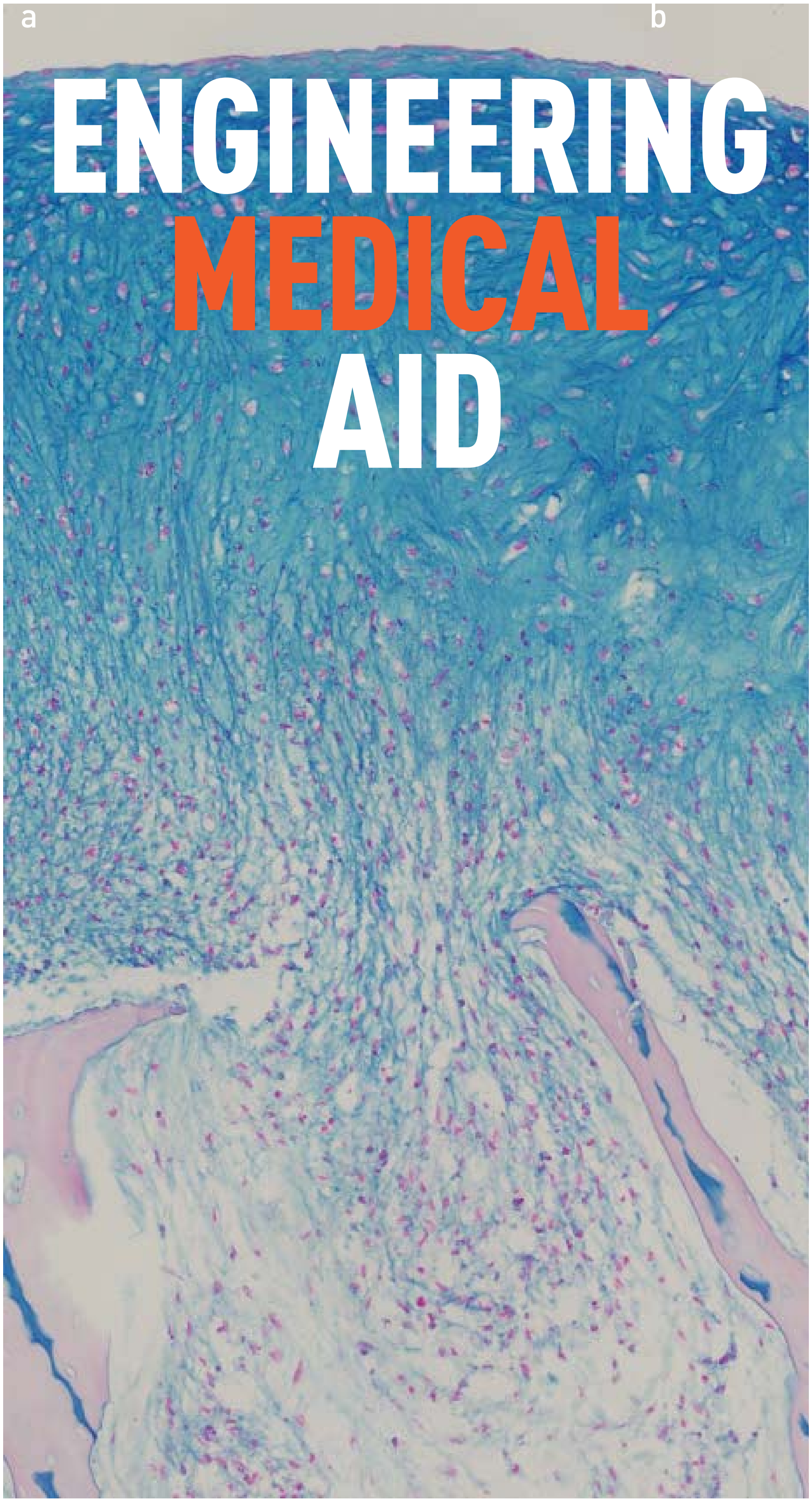
ME: What are your goals for the NSBE?

K.R: To continue and expand on the mission of NSBE, which is to increase the number of culturally responsible black engineers who excel academically, succeed professionally, and positively impact the community.

ME: What do you wish you could change?

K.R: The disparate opportunities that are available—or unavailable—simply because of a child's birthplace, or to whom they were born. According to Change the Equation (a nonprofit coalition with a mission to improve STEM learning), only 57 percent of African Americans attend high schools with a full complement of math and science courses. We need to remove these and other structural barriers to opportunity across the country and the African diaspora. **ME**

ENGINEERING MEDICAL AID



This is a full section of a tissue construct created at Columbia University, with cartilage at the top and bone substrate underneath. The blue stain marks proteoglycan, one of the two key components of cartilage, and red marks the nuclei of the cells.
Image: Sarindr Bhumiratana/Columbia Engineering

Mechanical engineers often play a pivotal role today in medical developments. This month, we visit a lab that's testing human cartilage grown from stem cells and another creating a device that depicts how drugs directly affect cancerous tumors.

Researchers in the Laboratory for Stem Cells and Tissue Engineering at Columbia University have generated fully functional human cartilage from mesenchymal stem cells by mimicking in vitro the developmental process of mesenchymal condensation. Mesenchymal stem cells can differentiate themselves into a variety of cell types.

The lab-grown cartilage could be used to repair a defect or to serve in complex tissue reconstruction, said Gordana Vunjak-Novakovic, who is also a professor of biomedical engineering and of medical sciences at the university.

The general approach to cartilage tissue engineering has been to place cells into a hydrogel and culture them in the presence of nutrients and growth factors, and sometimes subject them to mechanical loading. But using that technique with adult human stem cells has produced mechanically weak cartilage, Vunjak-Novakovic said.

The Columbia team wondered if a method that resembled the normal development of the skeleton could lead to a higher quality of cartilage.

Sarindr Bhumiratana, postdoctoral fellow in the lab, induced the mesenchy-

TISSUE GROWTH FOLLOWING NATURE'S PROMPT

THE LAB Laboratory for Stem Cells and Tissue Engineering, Columbia University, New York; Gordana Vunjak-Novakovic, director.

OBJECTIVE Engineering human tissue through integrated use of stem cells, biomaterial scaffolds, and bioreactors.

DEVELOPMENT Strong and sound human cartilage generated from stem cells via a new growth method.

mal stem cells to undergo a condensation stage as they do in the body before starting to make cartilage. This resulted in a quality of cartilage not seen before.

Gerard Ateshian, a mechanical engineering professor at the university, and Sevan Oungoulian, a mechanical engineering Ph.D. candidate, measured the tissue and found the lubricative property and compressive strength—the two most important functional properties of the tissue-engineered cartilage—approached those of natural human cartilage.

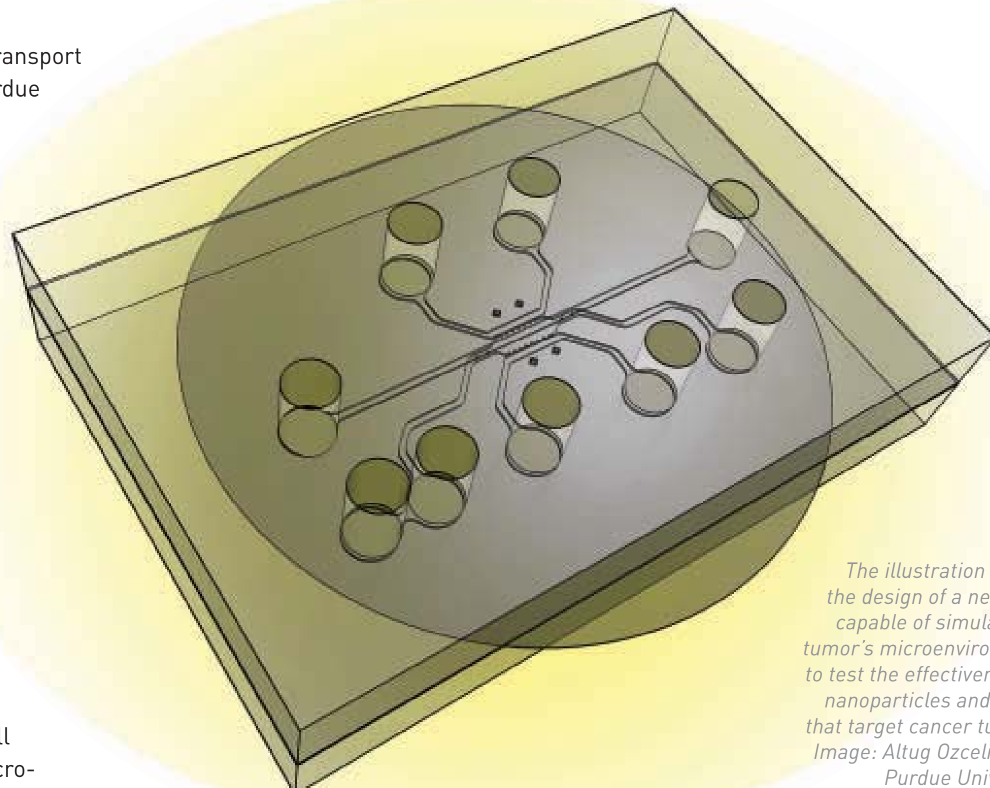
The researchers then used their method to regenerate large pieces of anatomically shaped and mechanically strong cartilage over the bone and to repair defects in cartilage.

"We were really surprised to see that our cartilage, grown by mimicking some aspects of biological development, was as strong as normal human cartilage," Vunjak-Novakovic said.

The team plans next to test whether the engineered cartilage tissue maintains its structure and long-term function when implanted into a defect, she said.

Researchers in the Biotransport Phenomena Lab at Purdue University have developed a chip that simulates a tumor's microenvironment and that could be used to test the effectiveness of nanoparticles and drugs that directly affect cancer tumors.

Many scientists are trying to selectively attack tumor tissue by targeting drugs directly at the tumor. Among pharmaceutical agents being studied for this are tiny nanometer-size structures, Han said.



The illustration shows the design of a new chip capable of simulating a tumor's microenvironment to test the effectiveness of nanoparticles and drugs that target cancer tumors. Image: Altug Ozcelikkale/ Purdue University

The Purdue researchers call their new system a tumor-microenvironment-on-chip (T-MOC) device. It can be used to study the complex environment surrounding tumors and the barriers that prevent the targeted delivery of therapeutic agents, said Han, an associate professor of mechanical engineering.

The T-MOC system simulates the complex environment around tumors and provides information about how nanoparticles move through this environment. Such information could help perfect targeted drug delivery methods, Han said.

For instance, one approach toward targeted nanoparticle delivery is to design particles small enough to pass through pores in blood vessels surrounding tumors but too large to pass though the pores of vessels in healthy tissue.

"It was thought that if nanoparticles were designed to be the right size they could selectively move toward only the tumor," Han said.

The T-MOC chip is about 1.8 inches square and contains microfluidic channels where tumor cells and endothelial cells are cultured.

The chip also incorporates extracellular matrix—a spongy, scaffold-like material made of collagen found between cells in living tissue.

The new chip offers an alternative to conventional experimental methods, Han said. Studies using cancer cells in Petri plates don't include the complex microenvironment surrounding tumors, and research with animals does not show precisely how proposed therapies might work in people. **ME**

TUMOR TARGETS TESTED

THE LAB Biotransport Phenomena Laboratory; Purdue University, West Lafayette, Ind.; Bumsoo Han, principal investigator.

OBJECTIVE To develop bioengineering applications for tissue engineering and cancer therapies.

DEVELOPMENT A device that simulates a tumor's environment and could demonstrate how anticancer drugs and nanoparticles affect tumors.

U.S. FUEL ECONOMY HITS AN ALL-TIME HIGH

ACCORDING TO THE U.S. ENVIRONMENTAL Protection Agency, model year 2013 vehicles achieved an average of 24.1 miles per gallon, a 0.5 mpg increase over the previous year and an increase of nearly 5 mpg since 2004. Fuel economy has now increased in eight of the last nine years. The average carbon dioxide emissions reached a record low of 369 grams per mile in the model year.

The latest of the EPA's annual fuel-economy reports, "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2014," tracks average fuel economy of new cars and SUVs sold in the United States. The report also ranks automakers' achievements in model year 2013.

VEHICLES IN THE 2013 MODEL YEAR AVERAGED 24.1 MILES PER GALLON.

According to the report, the recent fuel economy improvement is a result of automakers' rapid adoption of more efficient technologies such as gasoline direct injection engines, turbochargers, and advanced transmissions.

Mazda vehicles averaged the highest fuel economy and lowest greenhouse gas emissions. Nissan achieved the greatest improvement in average fuel economy and greenhouse gas reductions.

SUVs achieved the greatest improvement in all classes of new personal vehicles.

The EPA's data for model year 2014 is preliminary, but according to the report, adjusted values for fuel economy and CO_2 emissions are 24.2 mpg and 367 grams of CO_2 per mile. If they are achieved, they will represent record levels and a slight improvement over model year 2013. According to EPA, the preliminary 2014 model data "suggest that truck production share will increase by 2 percent, vehicle weight will increase somewhat, footprint will remain unchanged, and power will reach an all-time high."

The report is available at epa.gov/otaq/fetrends-complete.htm#report.

ENERGY EFFICIENCY MAKES A LEADING, AND GROWING, MARKET

ENERGY EFFICIENCY IS THE WORLD'S first fuel, according to the International Energy Agency. Global spending on energy efficiency is growing, and the market is currently worth at least $310 billion a year, according to a new report from the agency.

The report, "Energy Efficiency Market Report 2014," also finds that energy efficiency finance is becoming an established market segment, with innovative new products and standards helping to overcome risks and bringing stability and confidence to the market.

The report shows that investments in energy efficiency are helping to improve energy productivity, the amount of energy needed to produce a unit of GDP. Among 18 IEA member countries evaluated in the report, total final energy consumption was down five percent between 2001 and 2011 primarily as a result of investments in energy efficiency. Cumulative avoided energy consumption over the decade from energy efficiency in IEA countries was 1,732 million tons of oil equivalent, a total larger than the energy demand of the United States and Germany combined in 2012.

The IEA estimates that transportation efficiency alone can reduce up to $190 billion in fuel costs globally by 2020 and can help alleviate local air pollution and even address critical congestion issues in rapidly developing urban transport systems.

An executive summary of the report is available at www.iea.org/Textbase/npsum/EEMR2014SUM.pdf, and a fact sheet at www.iea.org/media/news/2014/press/EEMR14_Factsheet.pdf.

The full report is available for purchase at www.iea.org/w/bookshop/b.aspx?new=10.

CEMENT PLANT TESTS CARBON CAPTURE

A TECHNOLOGY COMPANY, WITH funding support from the U.S. Department of Energy, has launched a carbon capture demonstration project at a San Antonio cement plant.

The $40 million project will capture 75,000 tons of carbon dioxide and convert the gas into other commercial products, including sodium carbonate, sodium bicarbonate, hydrochloric acid, and bleach. In addition to CO_2, the facility will also remove sulfur oxides, nitrogen dioxide, mercury, and other heavy metals from flue gas streams.

According to the company, Skyonic Corp., the process uses less energy than current systems.

Skyonic's CEO, Joe Jones, developed the patented technology, which is marketed under the name Skymine. It captures CO_2 emissions by a mineralization process.

The project is funded in part by the 2009 American Recovery and Reinvestment Act. It includes $28 million in support from the DOE. The project was paired with over five years of research and laboratory testing from Skyonic, as well as other private investment.

The project has successfully completed its phase 2 implementation plan, which included a testing and process optimization effort to collect technical and cost data for the process and an update to the overall process techno-economic analysis and CO_2 life cycle study.

LOOKING BACK

The federal government was preparing new rules for civilian uses of nuclear power when this article was published in December 1954.

THE NEW ATOMIC ENERGY LAW —WHAT IT MEANS TO INDUSTRY

BY EVERETT L. HOLLIS, GENERAL ELECTRIC CO., NEW YORK.

Commercial, civilian use of nuclear power was a goal about to be achieved 60 years ago.

The Atomic Energy Act of 1954 is a wholly new Act—not a mere tinkering with the old Act. This new Act does two main things:

It affords private industry a larger role in the development of atomic energy.

It provides a framework for a greater degree of co-operation with other nations in the field of atomic energy.

Probably the dominant change in the new Atomic Energy Law is that the Government monopoly in the field of atomic energy has been substantially reduced. In 1946 the Congress felt that the Government must retain ownership of both fissionable material and of the facilities, like reactors, which produce that material in significant quantities. The new Act, while continuing to address the necessity for close Government scrutiny, moves in the direction of control by Government regulation other than control by Government ownership. Private industry may now own and operate "production facilities"—like reactors. The new Act does not, however, go all the way in eliminating the Government monopoly since it retains the requirement for Government ownership of all "fissionable material"—now called "special nuclear material." This new term is broadly defined so that materials essential to the fusion process could be found to be "special nuclear material." The term "fissionable material" has been dropped since it was deemed to have too restrictive a connotation—that of covering the fission process only. Apparently one of the decisive reasons for retention of Government ownership of this material was the fear of an emergency in which all special nuclear materials might be needed for military use. It was felt that retention of ownership would make it easier to recapture all that material, if the need should ever eventuate. ...

It is clear that the situation of a privately owned factory using, and also producing, material which is entirely owned by the United States will create many problems not the least of which is that of pricing; for industry will have to pay the Government for the special nuclear material it uses, and the Government will have to pay for material which industry produces. The amounts of these payments are not spelled out in the Act—only general rules are set forth. For example, if you are a commercial licensee you must pay the AEC [Atomic Energy Commission] a "reasonable charge" for the use of the special nuclear material you acquire from the AEC. Conversely, the AEC will pay you a "fair price" for the special material which you may produce in your privately owned facility.

Furthermore, the AEC is authorized to establish guaranteed prices for all special material delivered to it within a specified period, not to exceed seven years from the date of the announcement of the guaranteed price. This guaranteed-price technique has been employed for some years now by the AEC in regard to raw materials delivered to it. This provision may be of importance in the fashioning of arrangements for dual-purpose reactors. ME

ATOMS ONLY FOR PEACE

In September 1954, shortly before Everett Hollis's article appeared in the magazine, construction began on the Shippingport Atomic Power Station in Pennsylvania. It was not the first nuclear plant to generate electricity for the grid, but it was the first dedicated solely to the commercial production of electricity. It is now an ASME Historic Mechanical Engineering Landmark.

Shippingport Atomic Power Station, Pennsylvania.

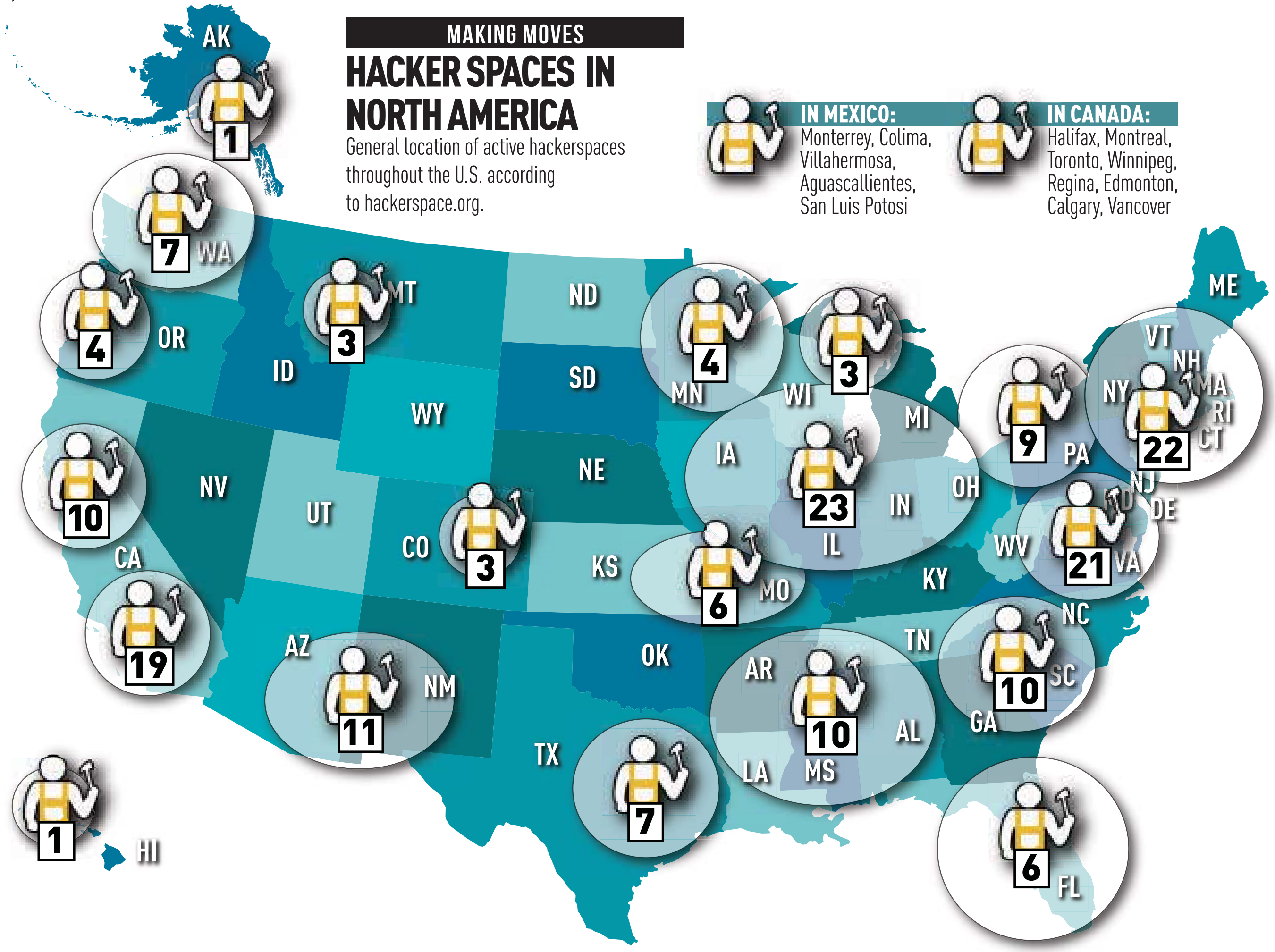
MAKING MOVES

HACKER SPACES IN NORTH AMERICA

General location of active hackerspaces throughout the U.S. according to hackerspace.org.

IN MEXICO: Monterrey, Colima, Villahermosa, Aguascalliententes, San Luis Potosi

IN CANADA: Halifax, Montreal, Toronto, Winnipeg, Regina, Edmonton, Calgary, Vancouver



THE MAKER MOVEMENT AND THE U.S. ECONOMY

You've likely heard the term "maker," but what exactly is the maker movement? Why now, and what does its growth mean for the future in the United States?

Martha Stewart, the celebrity of housekeeping, has looked into the maker movement in connection with her American Made program. She calls the maker movement the third-wave industrial revolution because it celebrates the values of self-reliance, skilled labor, and creative expression. Her company, Martha Stewart Living Omnimedia, partnered with the marketing research firm GfK for the 2013 State of the Maker Report, which estimates that about 135 million U.S. adults are makers of some kind. They make clothing, jewelry, baked goods, or works of craft or art. Ninety percent of those surveyed said they enjoyed making things with their own hands, because "making makes me happy."

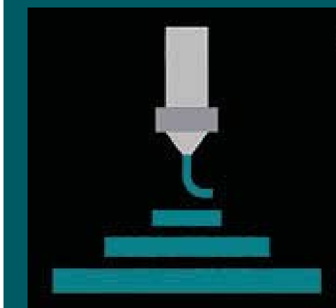
By 2025, the crowdfunding investment market is projected to hit **$92 BILLION**

The success of Maker Faire, launched by *Make Magazine* in the San Francisco Bay area in 2006, suggests that growing numbers of people are taking an interest in "making." The Faire is an all-ages gathering of tech

There has been a **62%** rise in visitors to the National Maker Faire from 2009 to 2013.

of U.S. adults are Makers.

(135 MILLION AMERICANS)



By 2025, the 3-D printing industry is poised to grow to

$4 BILLION

enthusiasts, crafters, educators, tinkerers, hobbyists, engineers, science clubs, commercial exhibitors, and more.

In 2014, 130,000 people attended the flagship Maker Faires in the Bay Area, which featured 1,100 maker entries, and 85,000 attended the second flagship event held in September in New York, where there were 830 entries. More than 120 mini-Faires were held around the world this year, while in 2013, 98 independently produced events and fairs took place around the world, in cities as far flung as Tokyo, Rome, Santiago, and Oslo.

3 MILLION

people pledged over

$480 MILLION

to crowdfunding projects in 2013.

More than 530,000 people attended some type of a Maker Faire in 2013, which is 335 percent more than attended 2011, according to *Make Magazine*.

Meanwhile, the international Fab Lab Network has grown to more than 400 international facilities, joined most recently, in September, by the Fab Lab at California State University Bakersfield's School of Natural Science, Mathematics, and Engineering. That lab offers hands-on, project-based learning to the community with an emphasis on STEM education for students in grades kindergarten through high school, according to the Fab Foundation.

The nonprofit Fab Foundation was formed in 2009. It emerged from the Massachusetts Institute of Technology's Center for Bits & Atoms Fab Lab Program.

The fab labs provide access to tools, information, and finances to digital fabrication so anyone can make (almost) anything, thus improving lives around the world, according to the Fab Foundation.

Hacker spaces, community-operated physical places where do-it-yourself electronics hobbyists can meet to work on their projects, have cropped up more or less spontaneously. The website hackerspaces.org maintains a list of 1,824 hacker spaces around the world (as of October 2014), 1,081 listed as active and 353 as planned.

The hackerspace movement got started with computer programmers in Germany in 1995 and came to the United States with the founding of the NYC Resistor space and the HacDC space in 2007, according to *Make Magazine*.

These spaces soon started adding electronic circuit design and manufacturing and physical prototyping to their lists of interests, and started expanding their offerings to include classes and access to tools via membership payments, according to the magazine.

The spaces have produced commercial enterprises. The company that makes one of the key tools of the Maker Faire, MakerBot Industries, was born out of NYC Resistor. It now has a hand in expanding and changing the 3-D printing industry.

JEAN THILMANY

THE MAKER MOVEMENT: Creating real business

Chart data courtesy: thegrommet.com

It contributes to 28M small businesses

2 OUT OF EVERY 3 NEW JOBS

In 2013, VC's pumped

$848 MILLION

into hardware startups—nearly twice the prior record of $442 million set in 2012.

8 MILLION

new jobs were created by small businesses since 1990. In the same time, big bisinesses eliminated

4 MILLION

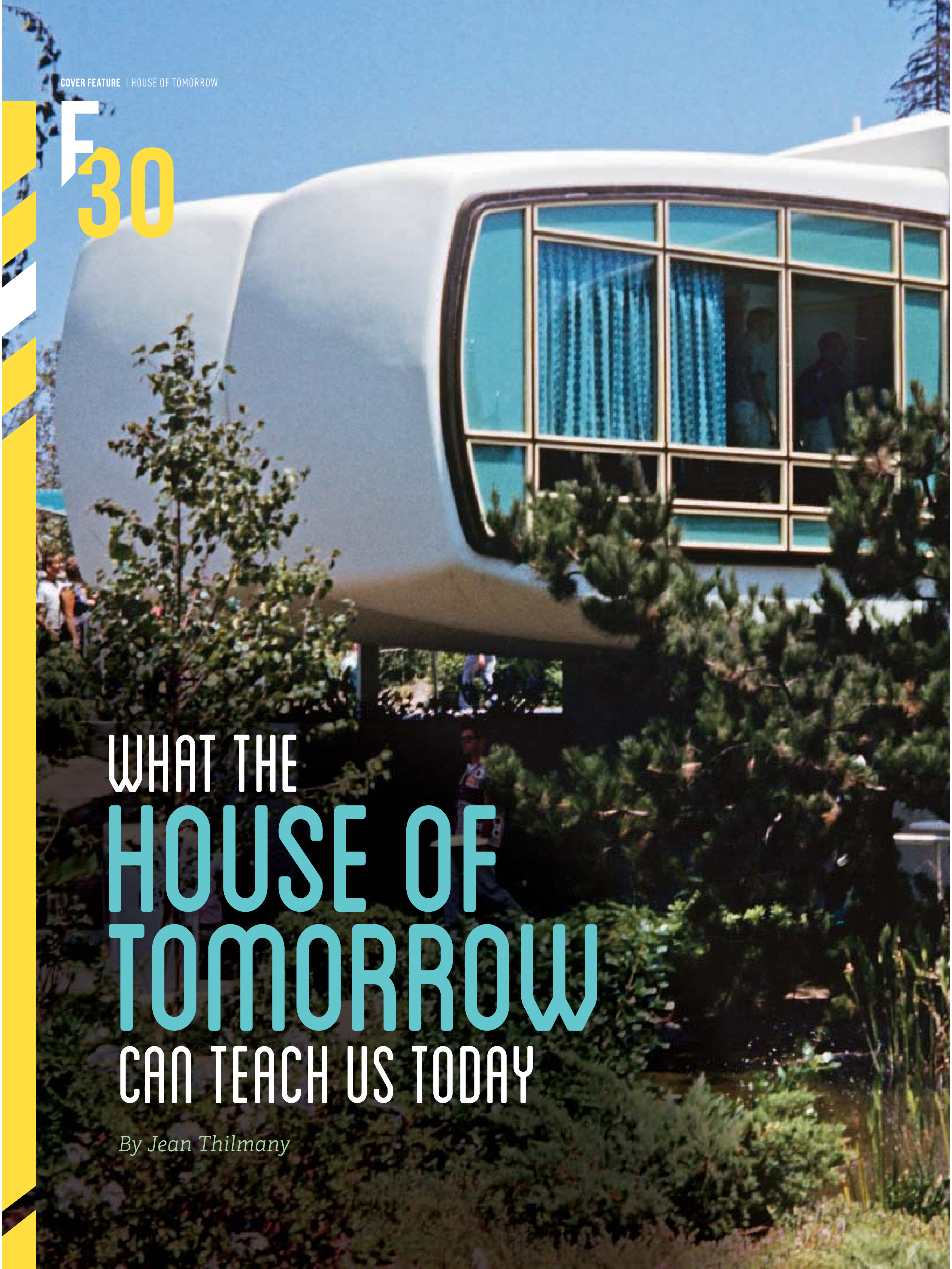
jobs.

For every $100 spent in independent stores,

$69 RETURNS

to the community. (If you spend that in a national chain, only $43 stays local.)

F30



WHAT THE HOUSE OF TOMORROW CAN TEACH US TODAY

By Jean Thilmany

WHAT WERE THEY THINKING? WHEN HOME DESIGNERS OF YESTERYEAR PREDICTED THE FUTURE, THEY TOLD US MOSTLY ABOUT THE TIMES IN WHICH THEY LIVED. AND SO IT GOES TODAY.

ONE WORD: PLASTIC.

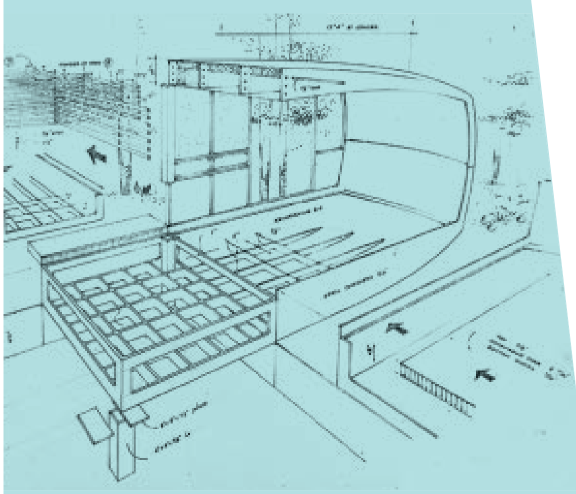
OK, a couple more: affordable, mass-produced.

Those were the adjectives that were expected to define late-20th century housing. By the middle 1980s Americans and Western Europeans were supposed to be living in white plastic Swiss crosses with windows lining the arms. Like pies on display, the houses were to be constructed on pedestals.

The team that designed the Monsanto House of the Future, a Disneyland attraction from 1957 to 1967, originally set out to create their vision for an affordable home for the families flocking into the housing market following World War II. Designed and engineered by Monsanto, Marvin Goody and Richard Hamilton of MIT, and

Image courtesy: Goody Clancy

The Monsanto House of the Future was built from plastic wings that were trucked to the site and fused to a concrete base. The idea was that this sort of house could be set up anywhere—and quickly.



Walt Disney Imagineering, the house was envisioned as something that could be quickly and inexpensively constructed on nearly any terrain and could withstand most any force of nature, said Gary Van Zante, architecture curator at the Massachusetts Institute of Technology Museum. That's not the home they finished with, and only in small part because they were working with the most popular material of their day—namely plastic—and with building techniques that hadn't yet caught up with that material, he said.

In 2010, Van Zante gave a presentation on the Monsanto House of the Future.

When it was completed, Disneyland visitors could tour the house of the future set in the far-off year 1986, complete with an imaginary family and futuristic household appliances such as microwave ovens.

We may snicker at the retro-future, but it's something we can't escape. Projections of the future have to represent what's actually happening in the days in which they're imagined. Many of their bells and features might not be functional in a future we can't predict, said David Forster Parker of Parker and Associates, a real-estate development and marketing consultant firm in Jacksonville, Fla. He's been building homes for 50 years and has also worked as a community planner and developer.

A look back at what designers predicted for the future of housing gives us insight into the society and the times in which they were working, and shows how they expected design, technology, and lifestyle to progress, Parker said. For instance, the end of World War II, the rise of the suburbs, the back-to-the-earth movement, and the rise of mass production have all been reflected in houses of the future.

Designers might have some foundational ideas that may go on to be developed; other great ideas unfortunately fall by the wayside on the way to the future, Parker said.

The vast majority of developers aren't looking to design the house of the future, which is why studying those who were offers unusual insights.

"Builders and developers often rely upon historical trends rather than working out innovations," Parker said. "They put small innovations in, but they don't want to change it too much for fear of losing their clientele, and we see improvements come in baby steps over years."

A case in point is the material of the Monsanto House of the Future.

"What designers were working with at the time was shaped by their idea of the future," Van Zante said. "Plastic was seen as the utopian material at that time though it wasn't exactly new then."

But the material was innovative for the designers of the time, who imagined the popularity of such a pliable substance would only grow, Van Zante said.

THE FACTORY LINE

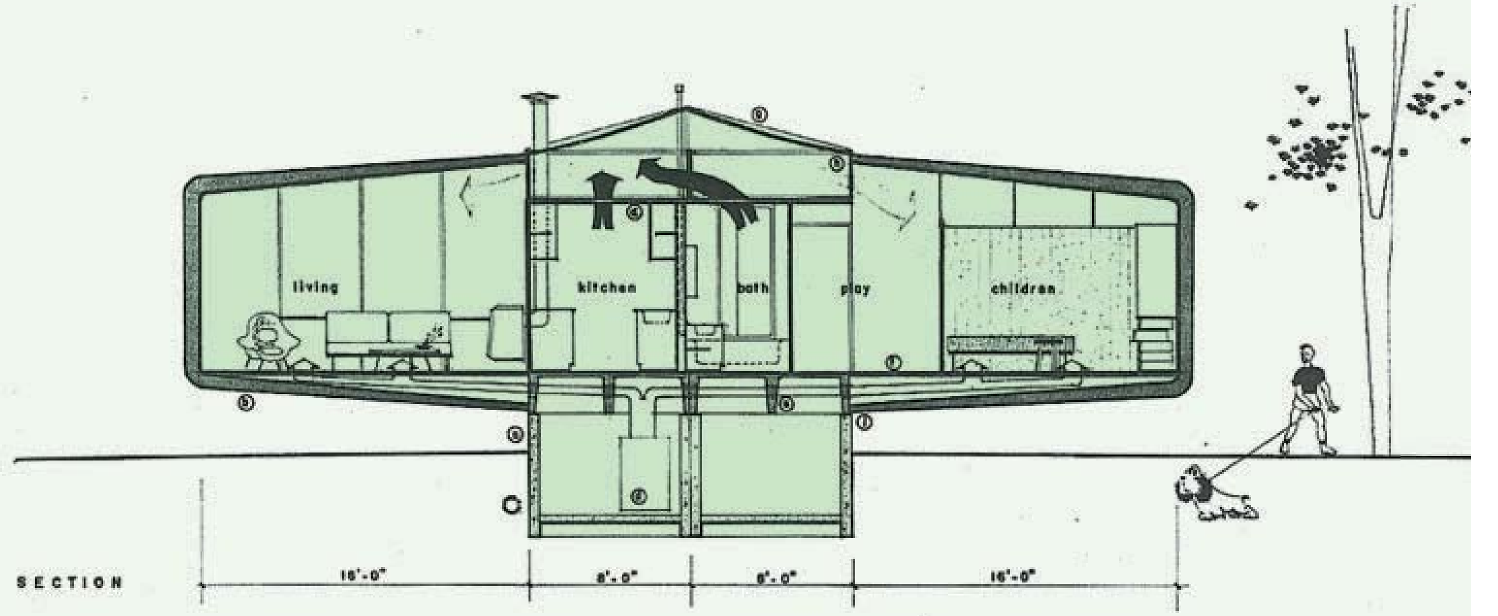
Before the housing boom of the early 1950s, before the rise of suburbia, the Chicago World's Fair of 1933 and 1934 (formally named A Century of Progress International Exposition) sought to build on the mass production capabilities that Henry Ford had helped pioneer with his automobiles. The fair committee sought to demonstrate that housing, too, could be produced on the factory line.

The Century of Progress fair committee produced a book outlining the requirements for its Homes of Tomorrow Exhibition. The exhibition showcased 12 model homes that featured contemporary designs. They were to include new materials and demonstrate techniques for prefabrication.

A major requirement of the 1933 fair committee was that homes' components be massed produced and affordable for the average American family, said historical architect Judy Collins, who keeps a copy of the Century of Progress book in her office.

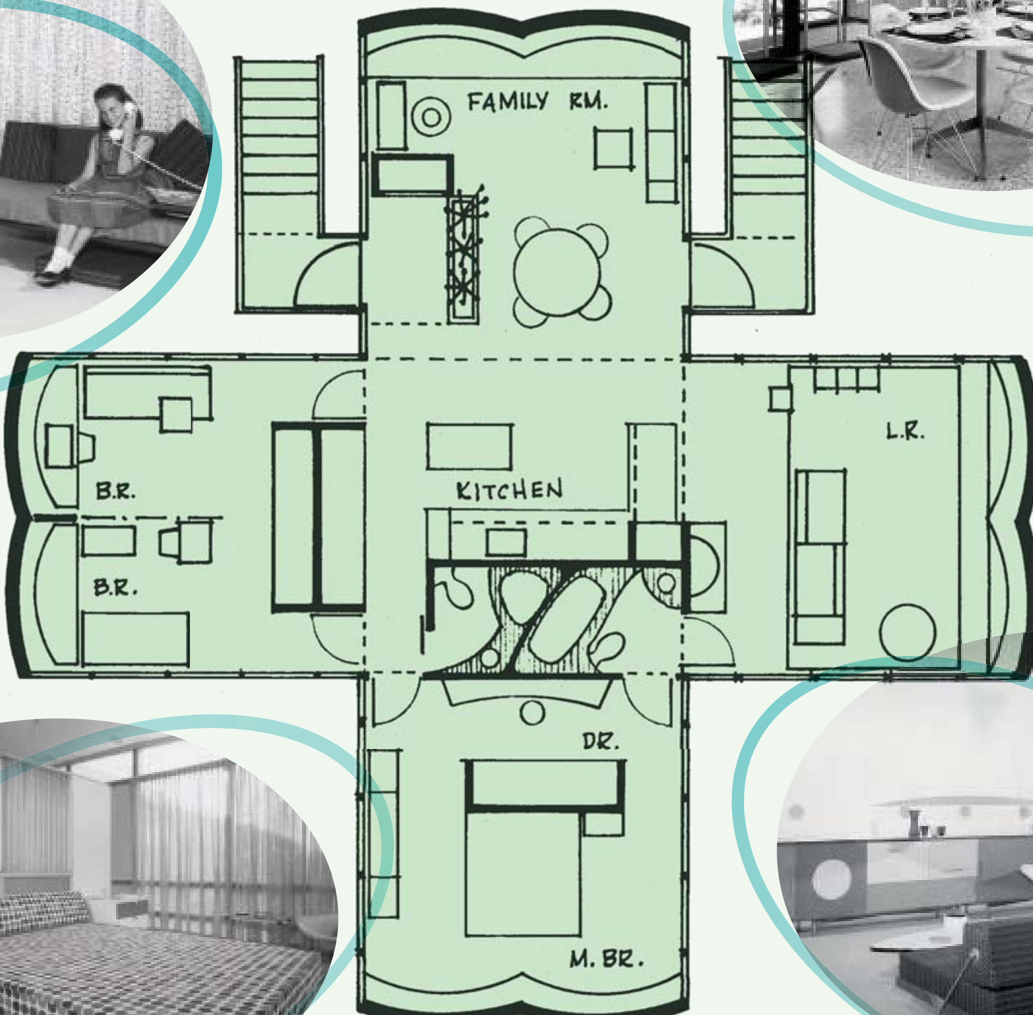
"This was still in the Depression, but the Exposition was highly influenced by the automobile industry," Collins said. "They really wanted the construction industry to become more industrial, more of a manufacturing process like for the automobile, which was coming into its own at that time. People were looking to the production line as way to produce construction materials. And things were being manufactured on a factory line, so why not houses to bring down their costs?"

After the exposition ended in 1934, Robert Bartlett purchased five of the homes—the Wieboldt-Rostone House, the House of Tomorrow, the Florida Tropical House, the Cypress Log Cabin, and the Armco-Ferro House—load-



The House of the Future was designed around a central core that housed the plumbing, heating, and ventilation systems. From the kitchen, living space radiated outward in 250-square-foot pods. The interior was furnished to reflect the ultramodern tastes of a family living in 1986.

Images on these pages courtesy: Goody Clancy



THE 1933 HOUSE OF TOMORROW ORIGINALLY INCLUDED ITS OWN AIRPLANE HANGAR

The Florida Tropical House (top) was flamingo pink and originally designed to withstand hurricanes. The Wieboldt-Rostone House (bottom) had to be re-clad after its experimental exterior rotted away.

Images courtesy: Indiana Dunes National Lakeshore

ed them on barges, and floated them across Lake Michigan to Beverly Shores, Ind.

That's where Collins comes in: she's a historical architect with the National Park Service in Chesterton, Ind., and she's working to help restore the five homes through a partnership of the NPS, a non-profit organization called Indiana Landmarks, and private individuals.

The houses failed to meet the affordability goal, however, because designers equipped the homes with more and more flourishes and bells and wishes. Of the five homes at the Beverly Shores site, only one was affordable for its time, the Armco-Ferro House, an enamel frameless steel house sponsored by the Ferro Enamel Corp. and the American Rolling Mill Co.

Many of the Century of Progress houses were made from a steel frame, a common material that hadn't often before been used for home construction, Collins said. But the Armco-Ferro House was designed very particularly to be mass-produced from steel, she said. Based a traditional four-square home, the house itself is composed of corrugated steel panels bolted together: the walls, the floors, the roof, all are corrugated steel.

The Wieboldt-Rostone House was framed in steel and clad with Rostone, an artificial experimental stone made from shale limestone alkali that never really caught on. Though other Rostone-clad homes weathered the years "just fine," Collins said, the original house was too close to steel mills and oil refineries. By 1950 it had deteriorated under too much acid rain "and has been sheathed over with another material," Collins said.

The House of Tomorrow, also now at Beverly Shores, was prohibitively expensive. But theoretically it could have been massed-produced: the home's columns were made from steel and the joints of steel and lightweight concrete. The house originally included its own airplane hangar and glass walls that offered views from every angle, a feature that so taxed the experimental air conditioning system that it soon failed.

"But the House of Tomorrow and the Armco-Ferro House are two of the best examples of how quickly homes made of pre-manufactured pieces could go up," Collins said.

The Florida Tropical House, also in Beverly Shores, has a wood frame covered with stucco, though original designs called for it to be constructed with poured concrete walls to withstand hurricanes.

"So that was really forward-thinking," Collins said.

WHEN PLASTIC WAS FANTASTIC

Prefabrication is not unusual today, Parker, the home builder and developer, said. Many companies make prefab, manufactured houses that can be cheaply and speedily built and even customized, within limits, to client specifications.

The Monsanto House of the Future had itself been intended as a quick-build, low-cost prefabricated structure for the surge of returning World War II veterans starting families and moving into single-family homes. A plastic house would nicely serve their needs; as a bonus, the house could be sited on any frontier the housing boom would open.

"After the war there was this enormous population and economic boom, and this housing boom that led to the need to deploy housing very quickly," Van Zante of MIT said. "So this house was prefabricated, compact modular, and entire subdivisions of them could be put up very quickly, unlike hammer and nail wooden or brick housing that would take weeks or months to build.

"The idea was that the base could be placed anywhere even on a hilly or rocky terrain and then the house attached to it," he said. "It was all about prefabrication; it could be shipped anywhere; it was also modular so it could be shipped on the back of an 18-wheeler."

"These plastic houses could be put up in an afternoon after the concrete core had been poured and dried," he added.

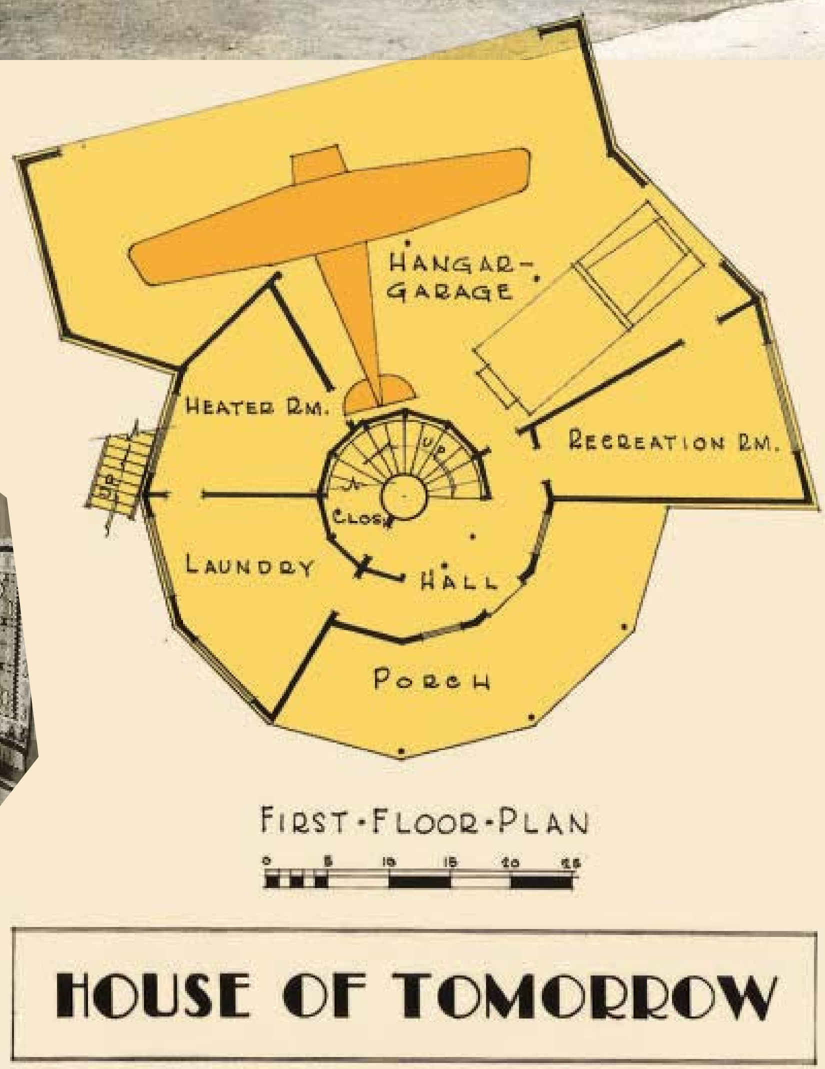
The house was crafted from eight wings of plastic fused "very imperfectly" to a base, Van Zante said. Imperfectly because the designers didn't know how to best fuse plastic to concrete, their material of choice for the home's base. The designers were working with both a new material—plastic—and a very traditional concrete, which they chose as the best method to secure the house to the ground.

"No one had ever built a plastic house before," Van Zante said. "They'd decided they needed a concrete foundation because they didn't know any other way to secure the house to the ground. They knew plastic wouldn't be dense enough to provide that kind of stability and that concrete could handle the moisture of the ground.

One reason designers chose to create a plastic house had everything to do with its sponsor.

"Monsanto had geared up over the years of the war to produce plastic for the war effort," Images courtesy: Century of Progress Records, 1927-1952, University of Illinois at Chicago Library

The House of Tomorrow at the Chicago Century of Progress Exhibition hinted at a future where airplanes would be common. The circular plan led to some odd-shape rooms, however, and the floor-to-ceiling windows led to overheating.



Images courtesy: Indiana Dunes National Lakeshore

The Armco-Ferro House featured corrugated steel panels that were bolted together. The kitchen, though, was conventional.

Van Zante said. "It was an essential material during the war, but when the war ended they had an unfulfilled production market; so they wanted to create a domestic market."

The plastic used for the house closely resembled fiberglass, so its designers turned to boat-building techniques to create the structure.

"The builders were working with what they knew, as always," Van Zante said. "Boats were the largest objects built out of plastic at that time. If this had been mass produced, the whole concept would have been developed over time and would have been innovated along with other concepts. But it just kind of stopped dead."

Though the house was "imperfectly fused" to its base, Van Zante is confident that had its design and material caught on, the fusing technique would have advanced with time.

"Because the house didn't go further, the idea of fusing it didn't either," he said. "Fusing plastic to concrete wasn't an ideal solution. They'd have had to develop it further."

Though plastic houses hadn't become the norm by 1986, the design of the Monsanto House of the Future was actually quite forward-thinking, Van Zante said. The concrete base, for example, acted as the home's central core through which all utility lines were run without the need to be threaded throughout each room.

The kitchen acted as the cultural hub of the home.

"The housewife of the future could command the house from the kitchen through electronic controls," Van Zante said. "The window shades could move and doors could open and be locked with these controls."

The command center anticipated today's mobile applications and household electronics that allow for much the same kind of control. The Internet of Things promises to link household appliances and much more to the Internet, giving them the capability to be programmed and controlled at the touch of a button.

As the Monsanto house was designed to include every innovation possible, it became expensive, well over the estimated budget. Too costly to be a viable mass-produced product, the idea of the house as a prototype was eventually abandoned, Van Zante said. The house functioned strictly as a Disney exhibition home.

THE WRECKING BALL BOUNCED OFF THE PLASTIC WALLS.

HOUSES OF OUR FUTURE

The Monsanto House of the Future closed in 1967 when Disneyland sought newer exhibits. According to the Walt Disney Company, the wrecking ball bounced off the plastic walls. The house had to be dismantled.

Its demise came well before the advent of the historical preservation movement. "I've had some of my students ask me if they recycled the pieces of the house," Van Zante said. "At the time, there weren't any environmental or conservation concerns."

Ironic, because today's housing buzzword is green: low-energy, sustainable, and tiny.

"Everyone wants green everything, but what is green? I challenge anyone to define it," Parker said. "There's no standardization over green. People started jumping on it, but it's expensive to do, and the consumer still wants a cheap house."

For his part, Parker expects the house of the future—meaning the houses built in 50 or so years—to pretty much resemble the homes of today. Externally, that is.

"We'll continue to see advances in housing, but like cars the changes will be mostly under the hood. The envelope will change much more slowly," he said, citing American's avoidance of radical styles of homes.

"You'll notice in new subdivisions that replication of very old styles like the Victorian and the Tudor are still very popular, and the current craze is for Tuscan architecture," he said. "A lot of builders are moving with that because it's safe to do."

Under the hood—or in this case, the roof—he expects to see continued advances in home electronics, so that the furnace and air conditioning really can be controlled by a touch of a button. He expects to see refrigerators that track the food inside and electronically alert the homeowner of soon-to-spoil produce or a lack of butter and milk.

Due to its expense, he doesn't expect solar energy to become popular "until we stop using coal" and public utilities fall from favor. But he does expect to see a movement to bury electrical wires that now run down streets and through backyards.

"Those are terrific changes but they'll happen so slowly you don't notice them," Parker said.

Green and solar and wireless. Those are the real key elements to the home of the future. But how far in the future is an open question, Parker said. **ME**

JEAN THILMANY is an associate editor of *Mechanical Engineering* magazine.

Images courtesy: Steve Fisher

Livin' the Dome Home Life

There's no home design more futuristic than the geodesic dome popularized by Buckminster Fuller. He hoped the domes—which could be constructed on site and placed on many types of terrain—could aid the postwar housing crisis.

The homes did see a wave of popularity, especially within the back-to-the-earth movement and were popularized by Lloyd Kahn, former shelter editor with the *Whole Earth Catalog*. In the late 1980s the homes were sold in kit form, ready to be erected by homeowners.

But the domes never caught on, for a number of reasons—many experienced by Steve Fisher, a marketing consultant in Los Angeles who recently purchased a 30-year-old geodesic dome home built from a kit in the Big Smoky Valley of Nevada. (See photos above and right.) When his wife suggested a dome as their retirement home he took to the Internet and found it.

He knew about the unique problems he'd face as a dome homeowner and they've pretty well all come to pass, Fisher said. First, the bank wouldn't give him a loan for the home because its resale value is practically nil. Few people want to live in a dome, it seems, and most don't want to live near one.

Same with buying homeowner's insurance. Fisher is now insured with Lloyd's of London.

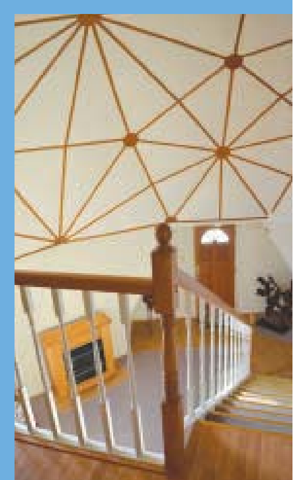
Every house has its nitpicky problems, but a dome's are unique, Fisher said.

"If you're talking about a house that's supposed to be cheap and efficient, this doesn't fit," he said. "People and hardware think rectangularly, all the venting out there is for right angles."

It goes without saying there are few right angles in a dome. "That's not the way the future was supposed to go," Fisher said.

Venting is an important consideration because his house is also prone to condensation buildup due to its high ceiling. The temperature upstairs can be 20 or so degrees warmer than downstairs.

Heating is another factor. Fisher heats with propane, which, due to the inclusion of water, raises humidity levels. The couple needs to keep the windows open, even in winter, or moisture condenses on the walls.



And then there's the roof. It can leak, which then ruins the acoustic tiles underneath. Fisher hopes to find roofers who can lay shingles on the many acoustic tiles that make up the dome's sides.

"But it can withstand 90 mile-per-hour winds," Fisher said. "It was designed to be built in the middle of nowhere by hippies. Those new terms like 'green' and 'sustainable'— isn't that what the hippies were all about?"

Despite those issues—and all homes have issues, Fisher said—he thinks the dome home is poised for a comeback.

"Nowadays the buzz is all 'tiny house' but a dome home is that same thing, being in tune with nature," he said.

MAXIMUM ZERO

Homes and office buildings that produce as much energy as they consume are becoming an affordable reality.

BY MARK CRAWFORD

Completely energy-sufficient households sound like something out of *Doomsday Preppers*—the kind of houses that have barrels of freeze-dried food in the cellar and hoards of gold stashed under the floorboards. But constructing highly energy-efficient dwellings that produce as much energy as they use is not a far-out idea. Traditional buildings consume about 40 percent of the total fossil fuel energy produced in the U.S. That makes striving toward energy self-sufficient buildings—what's known as zero net energy housing—a great way to cut greenhouse gas emissions and reduce dependence on fossil fuels.

These apartment units in Davis, Calif., are designed to use half the energy of units built to the California efficiency code. *Turn the page to see more.* *Photo: UC Davis ARM*

Today, builders aren't just striving toward the zero net energy goal, they're achieving it. Energy efficiency is being achieved through green-building techniques and high-efficiency appliances, HVAC, and lighting systems. On-site renewable energy (mostly solar) provides energy to run the home. Over time, energy consumption balances out energy production, resulting in a zero net energy bill. (Sometimes a home can have an energy surplus, which is usually sold back to the grid.)

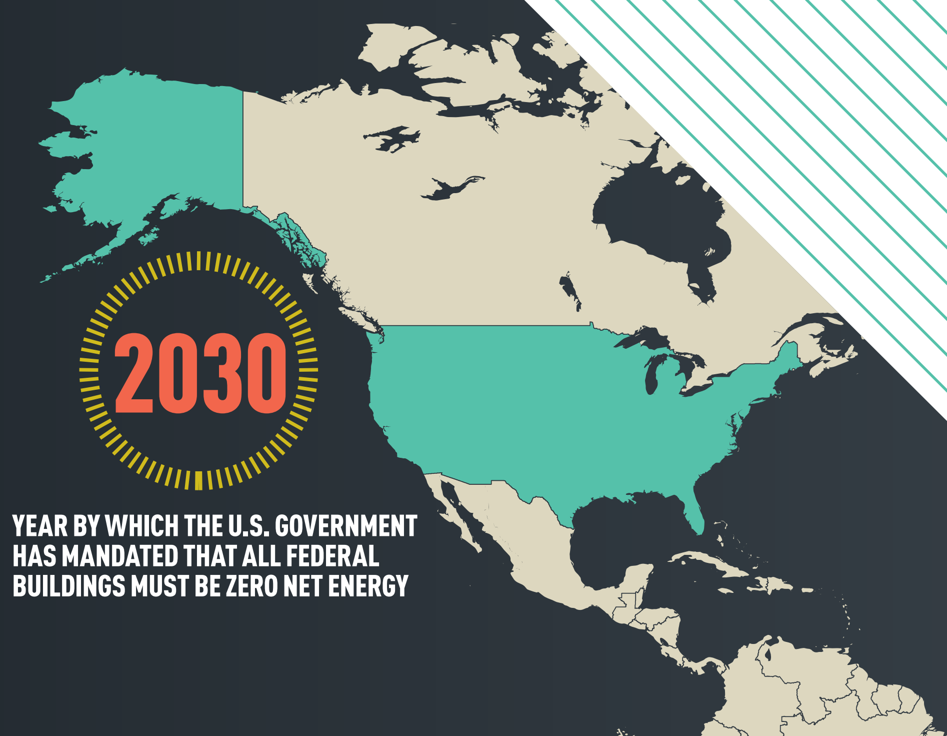
Even so, prospective home buyers are more likely to be concerned with kitchen countertops than the net energy balance of the building. That's because zero net energy homes are considered far too expensive for most Americans to build. But this, too, is starting to change. Thanks to new technologies, lower-cost manufacturing, and significant tax incentives, the out-of-pocket cost of building a zero net energy house is lower than ever. For example, in New York, home owners can receive tax credits of $20,000 or more for buying or building a zero net energy home.

The U.S. government is serious about zero net energy, too. It has mandated that federal buildings must be zero net energy by 2030. Federal incentives are also available for commercial and residential construction.

NET-ZERO COMMERCIAL CONSTRUCTION HAS

DOUBLED

SINCE 2008



Oak Ridge

About $150,000 worth of retrofits reduced a 7,000-square-foot building's energy usage by 40 percent. The operational energy needs for the national laboratory building were supplied by a 51 kW solar array.

Vivint and Garbett

This home in Utah was one of the first built in a cold climate to reach self-sustaining status. Its developers believe the design can be deployed all over the country. *Photo: The Zero Home*

NZERTF

This 2,700-square-foot suburban house in Maryland was built to test out many high-efficiency appliances and construction techniques. It also uses solar and geothermal heating systems. *Top photo: Beamie Young/NIST Bottom photo: A. Eustis/NIST*

50%

PERCENTAGE BY WHICH NEW SOLID-STATE LIGHTING TECHNOLOGY HAS THE POTENTIAL TO REDUCE U.S. LIGHTING ENERGY USAGE

Net-zero commercial construction has doubled since 2008. "Thanks to advances in structural insulation, energy-efficient appliances, new government incentives, and the falling price of solar, expensive green-building projects—like net zero—are now within reach," writes Lacey Johnson in the March 2012 *Scientific American*. "And they don't always require a commercial-scale budget."

The energy flow of a typical building involves tapping off-site energy sources—grid electricity and fuel delivered via pipe or truck—and using that to provide heat and power for various appliances. To achieve zero net energy consumption, a building must generally provide its own on-site power generation, be equipped with energy efficient appliances, and have a design that reduces the need for artificial heat and light.

That last part is relatively straightforward. There are many proven construction methods for building an energy-efficient shell, including the orientation of the home, air barrier systems, advanced insulation systems, window and door materials, daylighting, and sun control and shading.

Reducing energy consumption on the inside depends on ultra-efficient appliances, high-performance HVAC systems, geothermal heat pumps, and lighting controls. Impressive advances are occurring in the field of solid-state lighting technology, which has the potential to reduce U.S. lighting energy usage by nearly 50 percent. Department of Energy funding has been instrumental in supporting R&D for standard light-emitting diode and organic LED technologies.

Such approaches may greatly reduce a building's energy consumption, but it still needs energy to operate. The only way to achieve zero net energy is by using on-site energy-generating technologies. Solar is the most common, both for home heat and water heating. Some homes use wind turbines. Other alternatives for on-site, renewable energy production include burning biomass to create energy for certain parts of the home, or for hot water. When deciding on the energy system, it is important to consider availability of the energy source, reliability, system maintenance, and life-cycle costs over time.

Zero net energy homes still need to be connected to the electric grid for those times when their on-site systems cannot meet required energy loads. In some states, excess energy that is produced can be sent to the electric grid and credited to the owner's electric bill. When a home is truly zero net energy, the only bill from the utility company is a monthly charge for being connected to the grid.

Several building projects in recent years have achieved (or come tantalizingly close to) zero net energy. One of the first government buildings to reach zero net energy status is a 7,000-square-foot office building at Oak Ridge National Laboratory in Tennessee. About $150,000 was spent on retrofits in 2009 and 2010, which reduced the building's energy usage by 40 percent. Its operational energy needs were supplied by a 51 kW solar array.

The lab also implemented software to shut down computers and other electronic equipment at night. "It's surprising how much energy computers use," said Norman Durfee, senior project manager at Oak Ridge National Laboratory. "Because our measures

THE COST DIFFERENCE BETWEEN A REGULAR HOME AND NIST'S RESIDENTIAL TEST FACILITY

$160,000

UC-Davis West Village

This is one of the largest planned zero net energy communities in the country. In 2014, Honda opened its new zero net energy home here; it generates enough excess energy to power an electric vehicle. *Photos: UC Davis ARM*

5-10%

ADDITIONAL OUT-OF-POCKET COST OF A NET-ZERO HOME WHEN FACTORING IN STATE AND FEDERAL INCENTIVES AND THE LATEST TECHNOLOGIES, CUTTING THE TIME TO RECOUP INVESTMENT TO AS LITTLE AT 10 YEARS

with powering off computers were so successful, this has now been implemented across all of Oak Ridge National Laboratory."

Another government agency, the National Institute of Standards and Technology, in 2012 opened a new laboratory which goes by the snazzy acronym, "NZERTF," short for the Net-Zero Energy Residential Test Facility. NZERTF is a 2,700-square-foot, four-bedroom home in suburban Maryland built using energy-efficient construction and tricked out with energy-efficient appliances, solar photovoltaic systems, solar water heating, and geothermal heat pumps. The goal was to demonstrate that a typical residential home can meet zero-net standards.

Results thus far have been successful. The test facility generated a surplus 491 kilowatt-hours of energy in its first year of operation.

But for zero net energy buildings to have an impact, they will have to be lived in. Construction companies and non-profit organizations are working to develop the technology and experience to build energy-efficient housing.

Last year, for instance, the solar-energy technology company Vivint partnered with Garbett Homes to take on one of the biggest challenges for net-zero housing: creating designs that work in cold climates. The house that Vivint and Garbett built in Herriman, Utah, attained a Home Energy Rating System score of zero, indicating that the home is completely self-sustaining. The HERS Index, established by the Residential Energy Services Network, is the industry standard for measuring a home's energy efficiency.

The companies maintain this is the first zero net energy home design that is highly replicable and scalable, and the starting price of $350,000 isn't much different from other high-end houses. Impressively, though, Herriman is in the same climate zone as northern Idaho or parts of upstate New York. The project also demonstrates how important solar energy is for achieving zero net energy. Vivint's solar energy system dropped the HERS score by 23 points.

UC-Davis West Village at the University of California-Davis is one of the largest planned zero net energy communities in the country. Opened in 2011, West Village is home to the university's research efforts on energy efficiency and sustainability. In 2014 Honda opened its new zero net energy home on the campus. The home generates enough excess energy to power a Honda Fit EV for daily commuting.

LED lighting produces 40 to 100 lumens per watt, which is five times more energy efficient than traditional incandescent bulbs. Such super-efficient lighting is used throughout the homes in West Village. But the homes also feature a circadian rhythm-friendly lighting system that mimics natural shifts in daylight that occur throughout the day. That feature enables occupants to select lighting scenes that complement their own circadian rhythms, and better support night vision and overall wellness.

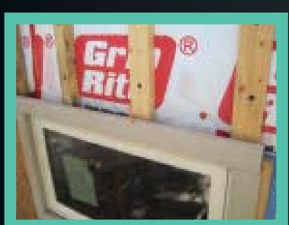
Perhaps the most impressive zero net energy accomplishment comes from Minneapolis. Twin Cities Habitat for Humanity and its partners, including University of Minnesota's School of Architecture and Design and Center for Sustainable Research, built an affordable, net zero energy house in 2013. Habitat for Humanity says it's the first net-zero home built by an affordable housing developer.

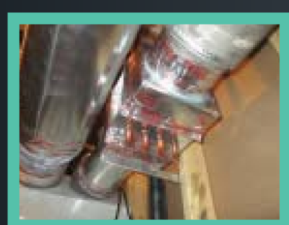
Twin Cities Habitat Net Zero House

Designed to show that super-efficient dwellings could be built for lower-income families, the house features triple-pane casement windows (below left), heat exchangers (center), and extra insulation (right). *Photos: Twin Cities Habitat*

$2,200

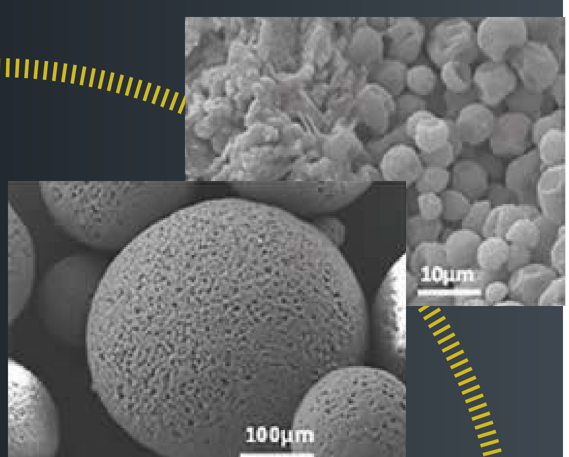
AMOUNT A FAMILY OWNING A HABITAT FOR HUMANITY NET-ZERO HOME CAN SAVE PER YEAR IN UTILITY COSTS





15-20%

IMPROVEMENT IN ENERGY EFFICIENCY OF UCLA'S INNOVATIVE CONCRETE



Phase-Change Materials

Researchers at UCLA are mixing microscopic wax-like beads into concrete to better absorb heat by day and release it at night. The result is a 15 to 20 percent improvement in energy efficiency. *Images: UCLA*

"What is most exciting about this achievement is that the home, which is based on Habitat for Humanity's relatively modest home designs, shows that a net zero energy home is not just a possibility for the wealthy," said Chad Dipman, project manager for Twin Cities Habitat for Humanity. "It also highlights the fact that net zero energy homes are especially suited for lower-income families. Ideally, the homeowner will not have to pay any utility bills at all. And, since the home is connected to the energy grid, any extra electricity it produces can be sold back to the system."

Habitat for Humanity's Minneapolis home scored a four on the HERS scale. "A typical new home built to Minnesota's energy code, which is stricter than most other states, receives a HERS rating of 62," Dipman said. "The Twin Cities Habitat Net Zero house reduces carbon emissions by 16.7 tons per year, sulfuric oxide emissions by 50.6 pounds per year, and nitrogen oxide emissions by 40.3 pounds per year, compared to the typical new Minnesota home."

Key energy-efficiency elements in the home include solar thermal panels, two air-to-air heat exchangers, improved insulation, triple-pane casement windows throughout the house, and a special coating on south-facing windows to collect energy in the winter.

"The low-income family that owns the net-zero home will save about $2,200 per year in utility costs, compared to a home built to Minnesota energy code standards," Dipman said. "This amount is tremendously significant for a Habitat family, whose average income is less than $35,000 for a family of five."

That sort of demonstrable savings has led to growing support—from nonprofits like Habitat for Humanity to the construction industry to the federal government—to build zero net energy buildings. The Department of Energy, for instance, has been extremely supportive of zero net energy residential and commercial buildings. One of its top priorities is to help zero net energy homes become an affordable reality by 2020 (and commercial buildings by 2025). Government agencies, national laboratories, universities, and the private sector are working hard—often in partnership with one another—to advance zero net energy-related research.

For example, a UCLA research team is studying new materials and technologies for zero net energy buildings. One of their projects involves mixing capsules of phase-change materials similar to paraffin wax, 10 to 100 micrometers in size, into concrete that is poured for wall panels. The capsules absorb heat during the day as the wax melts at a constant temperature. At night, as the building cools, the capsules release energy as the wax solidifies. The phase-change ability allows building materials to passively absorb and release heat for maximum efficiency. The materials help a building's heating and cooling systems do their jobs, but without the need for fuel. So far results show a 15 to 20 percent improvement in energy efficiency.

Ultimately, cost will be the driving factor in the widespread acceptance of zero net energy construction. The cost difference between a regular home and NIST's residential test facility is about $160,000. It would take a family 28 years to earn back the extra cost of this net zero energy home through energy savings alone.

Part of the research effort involves understanding which efficiency technologies produce the most proverbial bang for the buck. Energy modeling can help determine which green elements are most cost-effective and energy-efficient for a given site. State and federal incentives, when combined with energy-saving building methods and the latest heating and cooling technologies, can reduce the total out-of-pocket cost of a net zero energy home to as little as 5 to 10 percent more than a new conventional home. That cuts the time to recouping the investment to as little as 10 years.

The Habitat for Humanity house, in particular, shows how affordable zero net energy homes can be—especially for lower-income homeowners. "With our standard design as a basis, this project shows that a net-zero home can be built for just over $200,000," Dipman said. "Commercial developers could also replicate our model and scale it up to meet—or create—middle-class consumer demand. Such a movement would have a huge environmental impact." ME

MARK CRAWFORD is a geologist and independent writer based in Madison, Wis.

130 million

UNITS OF HOUSING STOCK, MOST OF WHICH HAVE BEEN IN EXISTENCE SINCE THE 1970S

A Net Zero Retrofit

ENERGY EFFICIENT HOUSING DOESN'T HAVE TO BE BUILT FROM SCRATCH. PURDUE UNIVERSITY HAS PARTNERED WITH WHIRLPOOL CORP. ON A THREE-YEAR PROJECT TO CONVERT AN EXISTING HOME IN WEST LAFAYETTE, IND., INTO A NET ZERO ENERGY STRUCTURE.

Called the ReNEWW house (Retrofitted Net Zero Energy, Water, and Waste), it will be retrofitted with energy- and water-saving features and equipped with solar panels to produce electricity and hot water.

"So much of the net zero energy discussion now focuses on new buildings," said Eckhard Groll, a professor of mechanical engineering and director of Purdue's Office of Professional Practice. "But most homes are existing structures."

The housing stock in the United States has more than 130 million units, most of which have been in existence since the 1970s. Even if every new house was a zero net energy building—an impossibility—the effect of that effort would be blunted by millions of inefficient houses that still have decades of productive life left in them.

The ReNEWW house was built in the 1920s.

Whirlpool engineers will come to Purdue as graduate students and live in the house for two semesters as part of the Whirlpool Engineering Rotational Leadership Development (WERLD) program. They will take long-distance courses through Purdue's engineering professional education program while they collect baseline energy and water consumption data that the company can use to develop next-generation, ultra-efficient appliances.

"The ReNEWW house will allow Whirlpool Corporation to leverage the world-class resources at Purdue University, in conjunction with our WERLD program, to accelerate the development of the next-generation system of innovative home appliances that offer even more performance without compromise," said Ronald Voglewede, global sustainability lead for Whirlpool.

Doctoral student Stephen Caskey (left, top) confers with Purdue professor Eckhard Groll inside a house in West Lafayette, Ind. The house, which was built in the 1920s, is being renovated to become a zero net energy building. Caskey uses an infrared camera (inset) to look for drafts. *Photos: Mark Simons, Purdue*

Three Mile Island Nuclear Power Plant »

Unit 2 of the Three Mile Island power plant in Pennsylvania (below, left) suffered a partial meltdown and fire in 1979. The fire cause is attributed to water hammer, which caused compression and ignition of flammable gases. Unit 1 (right) has continued operations.

FROM WATER HAMMER

It can be hard to get even scientifically minded people to reexamine their conclusions; change is hard to hold on to.

I have been working toward acceptance of a new theory of mine concerning accidental combustion in nuclear facility and oil industry pipelines. The theory has safety implications for any pipeline where explosive gases can form in liquid filled systems, and is consistent with pipeline accidents in nuclear power plants, such as Three Mile Island. I suggest that this theory is certainly worthy of further study.

THE SPARK THAT IGNITED THREE MILE ISLAND BURST FROM A SAFETY VALVE.

TO IGNITION

BY ROBERT A. LEISHEAR

I wrote to the U.S. Nuclear Regulatory Commission and suggested that the theory had direct application to the hydrogen burn that followed a nuclear reactor meltdown in Unit 2 at Three Mile Island. The agency thanked me and politely said I was mistaken. They also sent me a report published under the designation GEND-INF-023, "Analysis of the Three Mile Island Unit 2 Hydrogen Burn." It was prepared for the Department of Energy by J.O. Henrie and A.K. Postma of the Electric Power Research Institute.

Studying this document convinced me that the chain of events proved my theory that accidental combustion in a pipeline caused a dangerous fire at Three Mile Island. The facts presented in the report support conclusions that water hammer and trapped gases in a pipeline ignited the hydrogen burn at TMI-2. In fact, different responses by reactor operators could have even resulted in an explosion at Three Mile Island.

The partial meltdown at TMI-2 began at about 4:00 a.m. on March 28, 1979. According to the Nuclear Regulatory Commission, a series of mechanical failures, design flaws, and human errors resulted in a loss of coolant to the reactor.

TMI-2 was one of two pressurized water reactors at Three Mile Island. In pressurized water reactors, the controlled nuclear reaction among the fuel rods heats water, which is pressurized to more than 2,300 pounds per square inch so that it does not boil.

The pressurized water circulates in a closed loop called the primary cooling system. The primary system transfers heat to the secondary system, another closed loop of circulating water, which converts water to steam to run the turbines.

A third system of circulating water cools the steam in the secondary system as it exits the turbines and condenses it to water, which is recycled to boil again. The third system is open to cooling towers and takes water from the river. At no point do the three systems share water with each other.

A meltdown may be defined as extreme overheating of fuel rods in a nuclear reactor core. In the case of TMI-2, cooling water flowed out of the reactor core through a valve, referred to as the pilot-operated relief valve, which was stuck in the open position. As the reactor core was uncovered, its shield of water boiled away, the zirconium cladding of the fuel rods ruptured, and fuel pellets wrapped in the cladding melted. Half the core melted at temperatures above 4,200 °F during the early stages of the accident, but an uncontrolled nuclear reaction or criticality accident did not occur.

During the meltdown, the primary reaction to form hydrogen occurred when zirconium cladding reacted with steam to form 126,000 cubic feet of hydrogen. At this time, there was not enough oxygen present to burn the hydrogen in the reactor, since four percent oxygen is required to maintain a flame in hydrogen, and free oxygen does not form in the zirconium-steam reaction.

The only reaction that formed oxygen for ignition inside the reactor was that due to radiolysis. During radiolysis, radioactivity separates water into oxygen and hydrogen molecules. There may, or may not, have been a minimal amount of oxygen in the reactor during the meltdown, but there were no reported indications of major fire or explosion in the reactor at that time.

The steam bubbling from the molten reactor core and the newly formed hydrogen increased the reactor system pressure. Due to the pressure increase, steam and most of the hydrogen were then vented from the reactor into the reactor building through a safety valve, which was distinct from the stuck valve that initiated the meltdown. Hydrogen and air then mixed in the building to create flammable conditions.

Later that morning, operators forced water into the reactor core, which cooled, stopping the meltdown and the formation of hydrogen from the zirconium. In less than three hours, the meltdown was under control even though operators were unaware that a meltdown was in progress.

A fire was waiting to happen. Air in the unoccupied reactor building had thoroughly mixed with 703 pounds of hydrogen released from the reactor for approximately seven hours after the meltdown was brought under control. All that was required was a flame to start the fire.

Henrie and Postma's report detailed the complex chain of events that resulted in the release and subsequent burning of hydrogen in the reactor building. Nearly ten hours after the accident started, a hydrogen fire occurred without explosion in the reactor containment building. The report did not, however, identify an ignition or spark source for the fire.

My ignition theory states that the sudden compression of trapped flammable gases due to fluid transients, or water hammer, in pipelines may heat the gases sufficiently to autoignite them, similar to the combustion of fuel with air compressed in a diesel engine. In other words, slugs of liquid squeeze an oxygenated combustible gas until it gets hot enough to burn or explode. I outlined the theory in a paper, "A Hydrogen Ignition Mechanism for Explosions in Nuclear Facility Piping Systems," published by the ASME *Journal of Pressure Vessel Technology* in 2013 (135(5), 054501).

TO VALIDATE MY THEORY SEVERAL CONDITIONS NEEDED TO BE PRESENT, AND THOSE CONDITIONS WERE, IN FACT, PRESENT AT THE TIME OF THE BURN.

1. Hydrogen and oxygen needed to be present in the piping. Henrie and Postma acknowledged that the radioactive breakdown of water, or radiolysis, occurred during the accident. Once the zirconium-hydrogen reactions stopped during meltdown, and the hydrogen was released to the reactor building, the only continuing source of hydrogen in the piping was radiolysis. Hydrogen and oxygen formed as the melted fuel pellets radioactively decomposed water in contact with the exposed reactor fuel. When radiolysis occurs, sufficient oxygen is formed to support a fire or explosion in the presence of an ignition source.

2. Water hammer had to occur in the piping. Flowing steam and water were simultaneously present in the primary system at the time of ignition. Conditions were right for water hammer. Condensate-induced water hammer occurs when water and steam flow together in piping systems. Steam vapor bubbles, or steam voids, collapse to induce sudden pressures of thousands of pounds per square inch as shock waves resonate the piping system. Water hammer behavior is detailed in my book, *Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, published by ASME Press.

3. Piping near the relief valve should increase in temperature as the hydrogen and oxygen in the piping burns or explodes. Henrie and Postma acknowledged this temperature increase.

4. The ignition source of the fire had to occur at the safety valve in the reactor building. Henrie and Postma stated that the fire started near the safety valve at the time that the safety valve opened.

In short, water hammer started a fire or explosion in the primary system piping by compressing hydrogen and oxygen. The piping near the safety valve increased in temperature immediately prior to the hydrogen burn, which is consistent with an explosion or fire in the piping. Increasing pressures then opened the safety valve to start the fire in the reactor building.

Approximately seven hours after the meltdown was brought under control, the safety valve opened at 13:49, and a flame front fired from the reactor piping into the reactor building. That is, a flame shot from the safety valve into the building filled with hydrogen and air. The resulting 1,400 °F fire was detected by pressure increases at 13:50; one minute after the safety valve opened. In other words, the safety valve opening was nearly coincident to the time that the burn started.

All of the reported facts are consistent with the new ignition theory. More than 35 years after the accident, the cause of the Three Mile Island fire has an explanation.

"WATER HAMMER IN PRIMARY SYSTEM PIPING IGNITED HYDROGEN AND OXYGEN. THE SAFETY VALVE THEN OPENED AND STARTED THE FIRE IN THE REACTOR BUILDING."

Hydrogen and Oxygen From Steam »

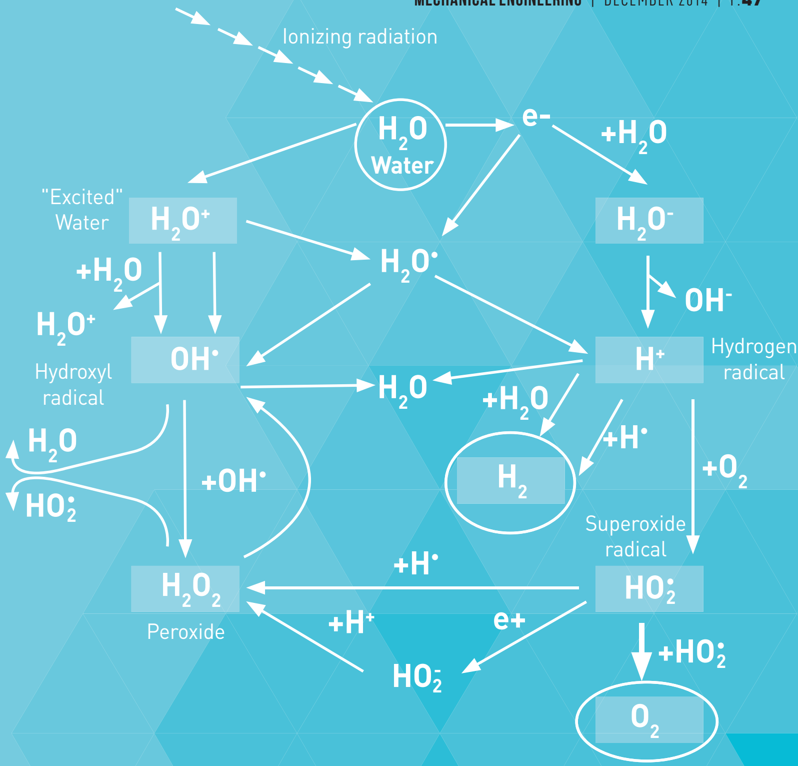
The oxidation of zirconium with steam was a principal source of the hydrogen that burned at Three Mile Island. According to an international Atomic Energy Agency document, IAEA-TECDECDOC-1661, the primary reaction to create 85 to 90 percent of the hydrogen during a meltdown is expressed by:

$$Zr + 2H_2O \rightarrow ZrO_2 + 2\,H_2 + \Delta H,$$

where ΔH is the energy released during the chemical reaction.

The remaining 10 to 15 percent of hydrogen may be caused by oxidation of steel in the core. The IAEA study was rather uncertain on this point.

Radiolysis is considered to be a minor initiator of hydrogen during and after pressurized water reactor meltdowns. However, radiolysis is the only identified initiator of free oxygen inside the reactor. The reactions during radiolysis are rather complex, but are shown at right. Essentially, water plus radiation yields hydrogen plus oxygen.



A complex series of reactions produces the end result of radiation splitting water into hydrogen and oxygen.

Why is further research required? The NRC documented extensive actions to improve reactor safety after the Three Mile Island accident, but this new ignition theory has yet to be fully evaluated with respect to off-normal reactor operations in the U.S. and abroad. Several nuclear reactor fires and explosions warrant consideration.

This fire-and-explosion theory is consistent with past piping explosions at nuclear reactors in Brunsbuettel, Germany, and Hamaoka, Japan, where eight-inch diameter steel pipes shredded like paper firecrackers. When my theory was first published, the causes of German piping explosions were unknown, but later reports concluded that water hammer probably caused the explosions. The Japanese piping was removed from service.

With respect to Three Mile Island, there was no explosion in the containment building during the accident, since 99.4 percent of the hydrogen had already burned. Only half of the reactor core was affected by the meltdown. Slower reaction times by operators could have destroyed the entire core and more than doubled the hydrogen in the reactor building. This additional hydrogen may have been sufficient to cause an explosion rather than a fire. Following the TMI-2 accident, unburned hydrogen was safely vented from the reactor building to the atmosphere by reactor operators. The hydrogen burn was contained in the reactor building.

Hydrogen burns were not so well contained, however, at Fukushima Daiichi in Japan. Several hydrogen explosions accompanied meltdown caused by a tsunami that damaged nuclear reactors. During this reactor accident, radioactive clouds blasted into the air from hydrogen explosions that devastated nuclear reactor buildings.

Mild winds then dispersed the radioactive contamination across the surrounding Japanese countryside, where 300,000 residents were evacuated. Some accident details of these Japanese explosions are available from the Tokyo Electric Power Co. (*Fukushima Nuclear Accident Analysis Report*, 2012), and the conditions to apply this new ignition and combustion theory to these explosions were present. Specifically, for two of the reactors, at the time of explosions sea water was abruptly added to reactor cores experiencing meltdown accidents. That is, water hammer was potentially applied to hydrogen in the pipelines to ignite flames, which in turn could have entered the reactor buildings to initiate explosions of hydrogen. If the sea water had been added at a slower rate, perhaps the explosions could have been prevented.

The Japanese report neglected the ignition source of the explosions. Neither the Tokyo Electric Power Co., the International Atomic Energy Agency, nor the Japanese Atomic Energy Agency answered correspondence with respect to this nuclear safety and environmental concern.

Nuclear reactor accidents deserve further investigation, since reactor fires and explosions were ignited by sources that were reported to be unknown. This new theory confirms a source of ignition.

If the causes of reactor explosions and fires were unknown for decades, the implications of this new theory are certainly not understood. Reactor explosions can be stopped to improve nuclear reactor safety, prevent deaths, and avoid environmental disasters. **ME**

ROBERT A. LEISHEAR, an ASME Fellow, is a fellow engineer at Savannah River National Laboratory, and a member of the ASME B31.3 Process Piping Design Committee. His book, *Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, was published by ASME Press in 2013.

GLOBAL Gas Turbine NEWS
Volume 53, No. 8 • December, 2014

In this issue

go.asme.org/IGTI
Email: igti@asme.org

ASME 2014 Gas Turbine India Conference
New Delhi, India
India Habitat Centre
December 15 – 17, 2014

It is not too late to register and join over 300 gas turbine professionals for the ASME 2014 Gas Turbine India Conference being held in New Delhi, India from December 16 - 17, 2014 at the India Habitat Center. The 2-day conference will include panel discussions, student posters and scholar lectures. An exhibit will also be held during the 2-day conference. Visit the Gas Turbine India Web site to plan your visit (http://www.asmeconferences.org/GTIndia2014). Plan to attend one of the Monday, December 15 workshops and stay for the Tuesday Keynote Address and the technical sessions and exhibit through Wednesday.

The venue, the India Habitat Centre (IHC) has been conceived as an ideal physical environment with a range of facilities that would maximize the effectiveness of the individuals and institutions, in the holistic support of the habitat. The principal resolve of the Centre - "to restore at every level - environmental and ecological - a balanced, harmonious and improved way of life," is reflected in its concept and design. Spread over nine acres in the heart of New Delhi, IHC has a built up area of approximately one million square feet. It incorporates innovative new technologies in building management systems, conference systems, communication and energy conservation, creating probably the most intelligent building in the country.

...Continued on next page

Keynote

Professor Nicholas A. Cumpsty
"Jet Propulsion: How, Why and Whither"
Tuesday, December 16th
9:00 – 10:00 AM

Nick Cumpsty studied Mechanical Engineering at Imperial College London. He conducted his postgradute research at the University of Cambridge, Department of Engineering, where he was awarded a Ph.D. for a dissertation entitled "The Calculation of Three-Dimensional Turbulent Boundary Layers". He has been Professor of Aerothermal Technology in the University of Cambridge and is a visiting professor in the Massachusetts Institute of Technology, in the Department of Aeronautics and Astronautics. Prof. Cumpsty was a Senior Noise Engineer in Rolls-Royce from 1969-72 and then from 2000-5 Chief Technologist of Rolls-Royce. On retiring from Rolls-Royce he returned to the Department of Mechanical Engineering in Imperial College as a professor and served as Head of Department until retiring again. He is now Emeritus Professor and Distinguished Research Fellow.

Prof. Cumpsty has published 68 papers in International journals, 2 books, Chapters in 3 other books, 15 conference publications and 1 patent in UK & USA in his illustrious career.

Pre-Conference Workshops

Gas Turbine Aerothermodynamics and Performance Calculations
December 15, 2014 — 8:00 am – 6:30 pm

This interactive workshop provides review and reinforcement of relevant thermodynamic and aerodynamic concepts as applied to gas turbine engines, and introduces performance calculation methods of both aircraft engine and power generation gas turbines. The workshop emphasizes fundamentals which will be helpful for the practicing engineer but is not designed to review industrial practices which are usually proprietary. The acquired knowledge, including the review of illustrative examples, will enhance participants' ability to excel in various assignments in gas turbine design, development, education, and application. The workshop material has been evaluated by the Department of Mechanical and Aerospace Engineering of North Carolina State University. After completing the course the participants should be able to apply aerothermodynamic concepts to the analysis of gas turbine engines; analyze turbomachinery velocity diagrams and relate those to thermodynamic parameters; appreciate the usefulness of the degree of reaction and the radial equilibrium equation; comprehend the discipline of operability and combustor characteristics; analyze cycle analysis problems on integrating the component performances to get the overall engine performance. The illustrative examples on the integration of the component performances to obtain the overall performance will facilitate comprehension of compressor/turbine matching; accounting for turbine cooling flows; the method of sizing critical flow path areas at the design point; method of satisfying conservation laws to achieve cycle balance at off-design; technique of the multivariable solver used in cycle models; making models match test data; and the analysis of various engine cycles in the power generation field including hybrid cycles. ***Special Notation: A laptop is recommended for individual reviewing of the CD in class. Earn 9 Professional Development Hours (PDH's) and receive a certificate of completion!***

Instructor:
Syed J. Khalid, Parametric Solutions Inc.

Hot Gas Path Cooling for Gas Turbine Engines

Air from the compressor is used for cooling the combustor/turbine in order to maintain the metal temperatures within their design limits of 1500 to 1700 deg F or 820 to 930 deg C depending on the alloys utilized, while the gas flowing through the turbine may be as high as 2500 deg F or 1370 deg C. The requirement for cooling the turbine limits the ultimate thermal efficiency of the gas turbine and technologies are being developed in the areas of materials including ceramics and enhanced cooling effectiveness in order to minimize the cooling air requirement. With more advanced materials and cooling technologies, increases in turbine inlet temperature are possible in order to increase the thermal efficiency of the cycle. Attendees will gain a comprehensive insight of turbine cooling technologies, matured and under development, including various design considerations and rules of thumb for analyzing cooling needs and benefits. ***Earn 7 Professional Development Hours (PDH's) and receive a certificate of completion!***

Instructor:
Srinath V. Ekkad, Ph.D., ASME Fellow

A Primer on Cogeneration/CHP Technologies

Attendees will learn the basics of Cogeneration/CHP (Combined Heat and Power) technologies including various practical considerations and rules of thumb relating to the key topics listed below on technologies currently used and under development for enhanced performance. This workshop also covers non-gas turbine based and hybrid cogeneration/CHP systems. Cogeneration/CHP technologies are gaining renewed attention globally as a means of effective utilization of available energy resources. It is projected that globally more than 300,000 MWe of Cogeneration/CHP power will be added by the year 2020. ***Earn 7 Professional Development Hours (PDH's) and receive a certificate of completion!***

Instructors:
Rakesh Bhargava, Ph.D., ASME Fellow
Hemant Gajjar, B.E. (Mechanical), ASME Member, IEI Fellow

Workshop for Creating and Teaching Effective Engineering Courses

(The CDIO Initiative) *By Invitation Only | Limited space

This workshop is designed to provide professors and teachers with the resources and skills they need to improve their abilities to design course curriculum, teach students and assess how much of what was taught was actually learned. It addresses the fundamental question of "What should engineers know and be able to do when they graduate"? The material culminates in describing the CDIO Initiative, which educates students on how to Conceive, Design, Implement (build) and Operate complex, value-added engineering products, processes and systems in a modern, team-based, global environment thus producing students who are 'ready to engineer' when they graduate.

Instructor:
David C. Wisler, Ph.D.
US National Academy of Engineering | GE Aviation, retired
CDIO Engineering Education Initiative

Conference Leadership:

Conference Chair
Prof. P.B. Sharma

Technical Program Chair
Mr. Hemant Gajjar
STEAG Energy Services (India) Pvt Ltd.
Noida, India

Review Chair
Prof. Subrata Sarkar
Indian Institute of Technology | Kanpur, India

2014-2015 STUDENT ADVISORY COMMITTEE LEADERSHIP

John McClintic, Chair
Kathryn L. Kirsch, Vice Chair
Reid Berdanier, Past Chair
Sulfikerali Noor Mohamed, Secretary

New Student Poster Session at the ASME Turbo Expo 2015

Following a successful inaugural Poster Session at Turbo Expo 2014, the Student Advisory Committee is once again sponsoring a student poster session at ASME Turbo Expo, this year in Montreal, Canada. Student posters will be on display on the main exposition floor.

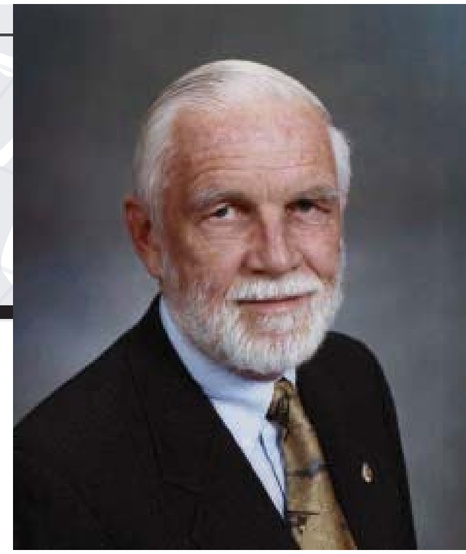
This poster session is intended to give students opportunities to present their work outside of the paper sessions. **Therefore, poster content cannot be work that is in an ASME Turbo Expo Paper.** Students interested in participating in the contest are required to submit an abstract to the ASME Turbo Expo Web site by **December 31, 2014**.

Abstract: 200-400 words
Poster size: 44"x36" or ISO/DIN A0

Undergraduate and graduate/PhD students are invited to participate by submitting a poster for display in the ASME Turbo Expo 2015 Exhibit Hall. All posters will be reviewed and approved through an abstract submission process. USD Cash prizes will be awarded for First Prize: $500, Runner-Up: $300 and People's Choice: $200.

Feel free to contact the Student Advisory Committee at sac.igti@gmail.com with any questions regarding the 2015 Turbo Expo conference or the Student Poster Session.

As the Turbine Turns



Plasma Actuator Tip Flow Control

by Lee S. Langston, *Professor Emeritus, Mechanical Engineering, University of Connecticut*

Axial flow turbomachinery tip leakage, be it at the tip of a rotating blade or at the root of a cantilevered stator represents an insidious source of aerodynamic loss in gas turbines, decreasing component efficiencies in both compressors and turbines.

I wrote about tip clearance and its control in an earlier article [1]. Tightening tip clearances and keeping them under control is a constant worry for OEMs and operators. Two critical parameters for tip leakage flows are the airfoil loading (local pressure difference between pressure and suction surfaces) and the actual tip clearance (either expressed as a percentage of span or chord). Loading is set by the designer and tip clearance is the stepchild to be controlled.

Tip clearance effects are especially critical in gas turbine high pressure compressors, where they are a large source of aerodynamic loss and stall inducing blockage. According to Saddoughi, et al [2], due to low aspect ratio blading and mechanical limitations on the actual magnitude of achievable clearances, new high compressor designs are forced to accept tip gaps from 1% to 4% (based on span). This has a significant impact in reducing high compressor efficiency and stall margins, in these very low aspect ratio blade passages.

In our June 16-20, 2014 TURBO EXPO in Dusseldorf, Aspi Wadia of GE Aviation, a co-author of [2], presented promising results from an experimental evaluation of the impact of high compressor tip clearance with and without plasma actuator flow control. The evaluation was run on the Law/Wennerstrom single-stage transonic compressor rig at Wright Patterson AFB in Ohio.

The plasma actuators were placed on the compressor's casing inner wall upstream of the rotor leading edge. The compressor performance was mapped from part-speed to high speed at three clearances with axial and skewed configurations of the plasma actuators at six different actuator frequency levels. The authors report a maximum stall margin improvement of 4%, with the large clearance configuration benefiting the most. They attribute the improvement by plasma actuators to a reduction in unsteadiness of the tip clearance vortex under near stall conditions. No impact was seen in compressor steady state performance. One can speculate, that had the actuators been placed on the casing inner wall directly in line with the rotor blade tips, perhaps the steady state performance also would have been improved, by reducing tip clearance flows.

This GE study represents the first open literature report of plasma actuators actually used on gas turbine blading at representative engine flow conditions. Past studies have dealt with wind tunnel tests on flat plates and plane cascades, usually with subsonic flows at lower Reynolds numbers.

Just what is a plasma actuator? There are a number of versions, but the most popular is the dielectric barrier discharge (DBD) plasma actuator. The DBD version was used in the GE study [2] reported on in Dusseldorf by Wadia, and is shown in sketch of Fig. 1.

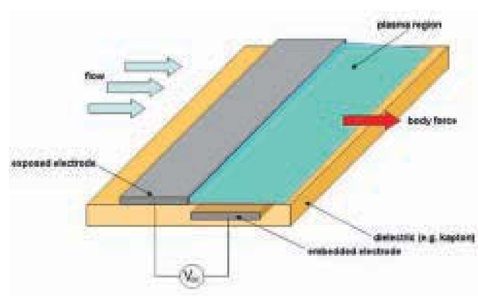


Figure 1 Dielectric Barrier Discharge Plasma Actuator

Following an explanation given by Kotsonis, et al [3], DBD is based on the ionization of air using an ac voltage between two electrodes, as shown in Fig. 1. The electrodes are separated by a dielectric barrier layer (e.g., a Kapton polyimide film) which prohibits arc formation, but allows accumulation of ionized gas in the vicinity of the exposed electrode end.

As the Turbine Turns...

The ionized gas is acted upon by a Lorentz force (the body force in Fig. 1), and will cause it to flow concurrently away from the edge of the exposed electrode. The exact mechanisms of interaction between weakly ionized gas and neutral air are still under study [3], but the collisional processes between them are responsible for the momentum transfer causing the plasma actuator flow.

Ideally, DBDs would be mounted on a compressor (or turbine) casing inner wall circumferentially and axially in the blade path. The induced Lorentz forces then oppose the pressure gradient forces which cause tip leakage. It is important to point out that the resultant Lorentz force is a function of both DBD applied voltage and the ac frequency, thus allowing two ways to control tip leakage. Given the flexible and superior response time of modern electronics, it should be possible to adjust DBD operation in response to transient flow phenomena associated with blade passing frequency.

In the Dusseldorf discussion on the GE paper [2], Wadia reported that the electronics associated with DBD are continuously being improved and miniaturized. Voltages needed are being reduced, and there is an unexplored area involving the great operational flexibility offered by frequency control. Readers should keep eyes open for future developments in this potentially important area of tip leakage control.

References

1. Langston, Lee S., 2013, "Blade Tips - Clearance and It's Control", *Global Gas Turbine News,* August, pp. 64,69.
2. Saddoughi, S., Bennett, G., Boespflug, M., Puterbaugh, S.L., and Wadia, A.R., 2014, "Experimental Investigation of Tip Clearance Flow in a Transonic Compressor with and without Plasma Actuators", GT2014-25294, Proc. ASME Turbo Expo 2014, June 16-20, Dusseldorf, Germany, pp. 1-14.
3. Kotsonis, M., Ghaemi, S., and Veldhuis, L., and Scarano, F., 2011, "Measurement of the Body Force Field of Plasma Actuators", *J. Phys. D: Appl. Phys.*, vol. 44, 045204, pp. 1-11.

UPCOMING STUDENT OPPORTUNITIES

Young Engineer Travel Award

Nomination deadline for Turbo Expo 2015 - March 1, 2015.

The **ASME IGTI Young Engineer Travel Award** is intended for young engineers at companies, in government service, or engineering undergraduate or graduate students in the gas turbine or related fields to obtain travel funding to attend ASME Turbo Expo to present a paper which they have authored or co-authored. The purpose is to provide travel funding to those who cannot attend the conference without this assistance.

For 2015, ASME IGTI will provide Young Engineer Travel Award winners with:

- One Complimentary ASME Turbo Expo Technical Conference Registration
- Complimentary hotel accommodations (Sunday to Friday). Up to $1,000 towards approved travel expenses

The nominee must have completed the research to be presented at the Turbo Expo while seeking a degree at a university. At the time which the application for the travel award is made, the applicant may be a student, post-doc, or practicing engineer. If the applicant is a post-doc or practicing engineer, he/she must be within two years of having completed his/her degree at the time the paper is presented at Turbo Expo.

The application is located at: *http://www.asmeconferences.org/TE2015/TravelAward.cfm*

60th ASME Turbo Expo: Building on Our Heritage

Join over 3000, of your colleagues and industry leaders at the Palais des Congrès de Montréal, June 15-19, 2015, in Montréal, Canada for the 60th Anniversary celebration of ASME Turbo Expo!

The 2015 keynote theme is Building on Our Heritage. The 2015 Keynote and Awards Program will take place on Monday, June 15 at the Palais des Congrès de Montréal. Additional details will be announced in the February issue of the GGTN.

CONFERENCE

Now in its 60th year, ASME TURBO EXPO is recognized as the must attend event for turbomachinery professionals. ASME Turbo Expo includes technical sessions, tutorials, panel discussions, trade show exhibits, committee meetings, career development and unrivaled networking opportunities. Take the lead and plan to attend ASME Turbo Expo where you will find benefits for all the turbine industry segments; design, manufacturing, research and development, education, operations, repair and maintenance.

Following a successful inaugural Poster Session at Turbo Expo 2014, the Student Advisory Committee is once again sponsoring a student poster contest at ASME Turbo Expo. Student posters will be on display on the main exposition floor. This poster session is intended to give students opportunities to present their work outside of the paper sessions. Therefore, poster content cannot be work that is in an ASME Turbo Expo Paper. Students interested in participating in the contest are required to submit an abstract to the ASME Turbo Expo Web site (turboexpo.org) by December 31, 2014.

Every international visitor should check with his or her local consulate regarding visa and entry regulations for Canada. Please do this well in advance of the conference. If you require a letter of invitation to Turbo Expo as a part of a visa application, please plan on requesting the letter of invitation during completion of your online registration. Registration will be available in late Winter.

EXPOSITION AND SPONSORSHIP

When you exhibit at Turbo Expo, you will be among other key industry players. Exhibiting at Turbo Expo will maximize your ROI by placing your company in front of a focused target market, enabling you to generate high-quality leads to achieve your marketing objectives. Space is still available to join the leaders in the turbomachinery industry on the show floor.

New this year, recognizing the 60th Anniversary, attendees are invited to visit the Show Museum, showcasing the history of ASME International Gas Turbine Institute.

The exhibit hall will feature the Museum and be open during Exposition hours for all registered attendees.

Brand-enhancing sponsorship packages are available! Packages are designed around your particular corporate goals and are an extremely effective way for your company to really stand out from the crowd – before, during and after the Show.

Contact ASME IGTI via email at igtiexpo@asme.org now to make the most of your marketing dollars.

WELCOME TO MONTREAL

An international destination of choice, Montréal is easily accessed by land, water and air. Downtown is a mere 20 minutes from the Pierre-Elliott Trudeau International Airport, which handles some 600 flights daily. Public transit is not only affordable, it's also a great way to get around the city. Quick, safe and clean, the metro connects downtown to major tourism attractions, as well as to numerous bus stops and train stations.

Plan your trip now. Register for the Conference and Exposition and secure your hotel room at one of the Conference Hotels online at www.turboexpo.org.

CALENDAR OF EVENTS

December 15-17, 2014
ASME Gas Turbine India Conference
India Habitat Centre | New Delhi, India
http://www.asmeconferences.org/GTIndia2014/index.cfm
The 2-day conference (December 16-17) will give you the unique opportunity to interact with experts in the gas turbine industry, as well as find out the latest methods and cutting-edge technology that can improve how gas turbines operate in the future. The Pre-Conference workshops are being held December 15.

June 15-19, 2015
ASME Turbo Expo 2015 | Palais des Congrès de Montréal, Montréal, Canada
Celebrating its 60th year, ASME Turbo Expo is recognized as the must-attend event for turbomachinery professionals. The technical conference has a well-earned reputation for bringing together the best and brightest experts from around the world to share the latest in turbine technology, research, development, and application. Turbo Expo offers unrivaled networking opportunities with a dedicated and diverse trade show floor. The 3-day exhibition attracts the industry's leading professionals and key decision makers, whose innovation and expertise are helping to shape the future of the turbomachinery industry and will feature a Student Poster Session.

November 15-20, 2015
International Gas Turbine Congress 2015
Toranomon Hills | Tokyo, Japan
http://www.gtsj.org/english/igtc/IGTC2015/index.html
Come by and visit ASME in our booth at this event.

October 7-9, 2015
Organic Rankine Cycle Conference 2015
Brussels, Belgium
The Seminar on ORC Power Systems (ASME ORC) has reached its 3rd edition and it is bound to build on the large success of the Delft (2011) and Rotterdam (2013) events, attended by almost 400 participants. This unique forum provides an exciting opportunity to learn about and discuss the latest advances in research & development, application and demonstration, and a variety of topics related to this emerging technology for the conversion of renewable thermal energy sources, including waste heat recovery. The seminar features presentations by prominent research groups, leading ORC companies and expert users at the forefront of the application of the technology. Themes include turbomachinery, displacement expanders, system optimization, applications, simulation and design tools, operational experience, prototypes, components, and working fluids. Academics, industry practitioners, professionals, and government officials working in the energy technology field are encouraged to participate to update themselves with respect to the latest progress of science and technology and commercial developments. Sponsoring companies will showcase their achievements, and a lively poster session will complement the oral presentations.

Save the Date!
June 13-17, 2016
ASME Turbo Expo 2016
COEX Convention and Exhibition Center
Seoul, South Korea

A VIEW FROM THE CHAIR

By Dr. Seung Jin Song, Chair, ASME IGTI Board

Welcome back to the Global Gas Turbine News (GGTN), the quarterly newsletter of the ASME International Gas Turbine Institute (IGTI). In this issue, I would like to update you on our coming events and continuing efforts for student support and globalization.

The preparations for the 60th Turbo Expo, to be held in Montreal on June 15-19, 2015, are progressing smoothly. The theme of Turbo Expo 2015 has been selected to be "Building on Our Heritage". To celebrate IGTI's distinguished heritage, the IGTI Board has decided to provide complimentary DVD's, containing all of the Turbo Expo papers beginning in 1956, to the registrants of Turbo Expo 2015! Also at Turbo Expo 2015, the 60th Anniversary Museum will display IGTI's "historical materials". Furthermore, an expanded exhibition will even include a helicopter.

For making all of this possible, I would like to thank the authors, staff, reviewers, and organizers - the Session Organizers, Vanguard Chairs, and Point Contacts. Special thanks are due to the Turbo Expo Executive Committee Members. Edward Hoskin, the Executive Conference Chair, and Geoff Sheard, the Conference Chair, are overseeing the overall organization efforts. Hany Moustapha, the Chair of the Local Liaison Committee, is actively engaged in every aspect of onsite preparation, and Damian Vogt, the Technical Program Chair, is ensuring timely organization. Tim Lieuwen, the Review Chair, and Vice Review Chairs John Chew, Anestis Kalfas, and Jaroslaw Szwedowicz are monitoring the monumental review process. Dave Pincince, the Exhibitor Representative, is promoting the exhibition side of Turbo Expo. Finally, I would like to extend sincere thanks to all of our sponsors, especially to our Platinum Sponsors – GE, Pratt & Whitney, and Rolls Royce.

Recently, IGTI has expanded its geographical and technical scope via Gas Turbine (GT) India and Organic Rankine Cycle (ORC) conferences. Since its inaugural conference in 2012, GT India continues to grow, and this year's meeting will take place December 15-17, 2014, in New Delhi, India. Due to its success, GT India 2014 has been expanded to a 3-day format from the previous 2-day format and will feature Professor Nick Cumpsty as the Keynote Speaker. ORC 2015 Conference is scheduled to take place in Belgium in October, 2015. ORC is an emerging area with strong academic and industrial interests, and IGTI will continue to support this event, as it did in 2013.

Attracting young talent and globalization are two of the main objectives of the IGTI . To promote interest in turbomachinery among students, IGTI offers Student Scholarships. To help young engineers travel to Turbo Expo, IGTI funds Young Engineer Travel Awards. At Turbo Expo, students run the Student Committee and organize the Student Poster Session. IGTI will continue to explore ways (e.g. promote research collaboration) to strengthen support for students and young engineers.

IGTI is already global. Out of the 1279 papers of the Turbo Expo 2014, 50% were from Europe, 24% from North America, and 23% from Asia. Also, IGTI is already well represented in India. Nevertheless, IGTI will continue to seek opportunities in any region with interest in turbomachinery. Currently, talks are ongoing to explore possibilities of organizing a user-oriented meeting in South America.

Within ASME, IGTI is now one of several constituent groups of the Energy Conversion Segment (ECS) which is headed by Karen Thole, the past Chair of IGTI. Other members in the ECS leadership group are Eduardo Barrientos, Rich Dennis, Ralph Hill, Tim Lieuwen, Vinod Philip, George Saxon, and Laura Schaefer. In this environment, the IGTI Board is now exploring ways to continue serving the IGTI community and to expand the activities of IGTI through collaboration with other Groups of ECS.

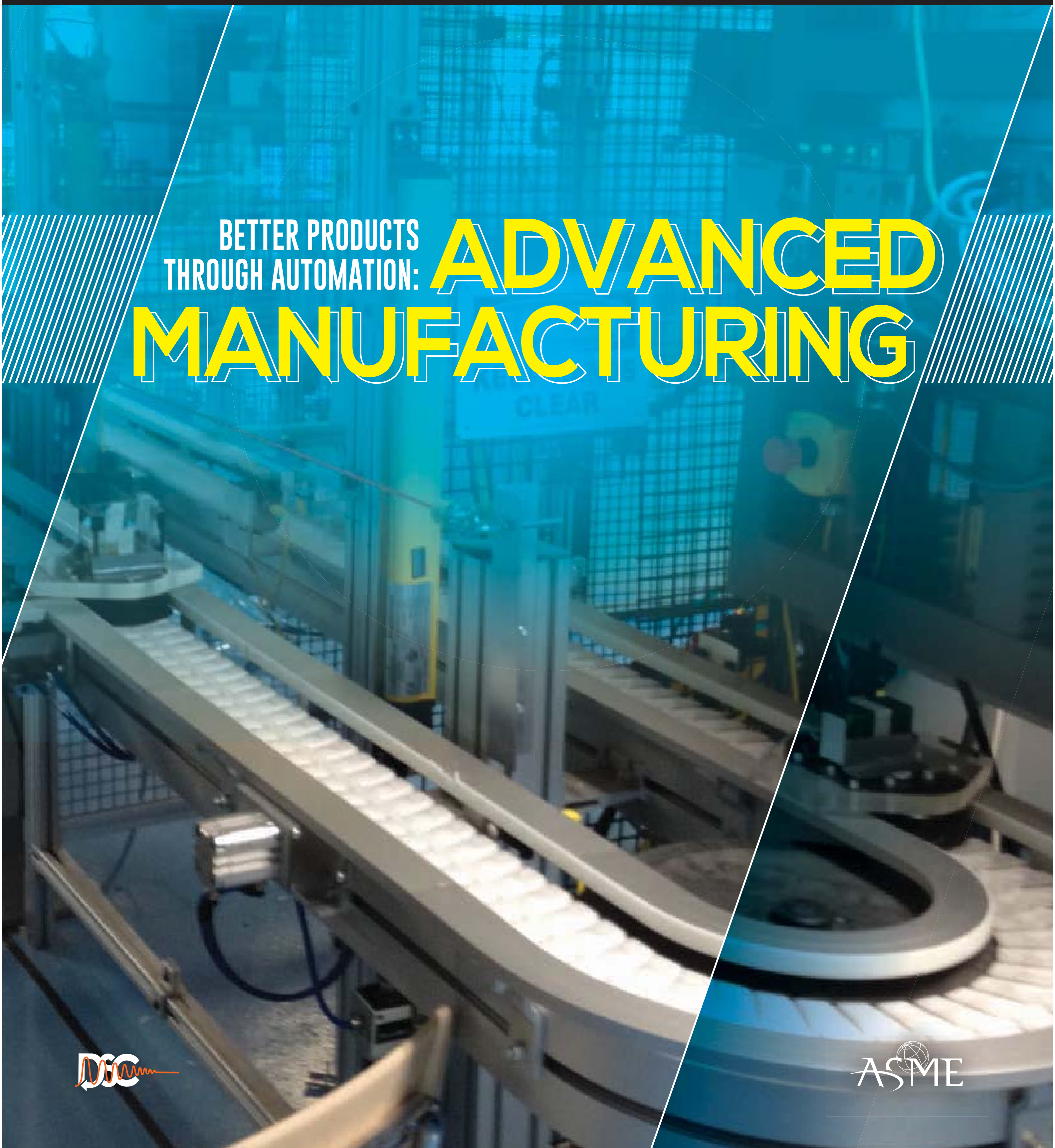
In closing, I would like to thank you for your interest in IGTI and to wish all of you a happy holiday season and all the best in 2015.

A forum for emerging systems and control technologies.

DYNAMIC SYSTEMS & CONTROL

DECEMBER 2014 VOL. 2 NO. 4

BETTER PRODUCTS THROUGH AUTOMATION: ADVANCED MANUFACTURING



SUBMIT ARTICLE IDEAS TO:

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SUBMIT DSCD NEWS ITEMS TO:

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Future issues of *Dynamic Systems & Control Magazine* will include the following themes:

March 2015
Dynamics and Control of Offshore Drilling

Advanced Manufacturing Systems

Manufacturing is essential to a healthy national economy. This issue of ASME *Dynamic Systems and Control (DSC) Magazine* focuses on control systems in advanced manufacturing, including cyber security of industrial controllers, additive manufacturing and logic controllers. As usual, you will also find news of recent and upcoming activities of the ASME Dynamic Systems and Control Division (DSCD).

Keith Stouffer and Rick Candell, from the National Institute of Standards and Technology, describe a testbed they are developing to evaluate the performance of industrial control systems that have been designed to meet cyber security standards.

Joe Beaman, long time member and former Chair of DSCD, helped make additive manufacturing possible by developing and commercializing the selective laser sintering process. He and Felipe Lopez describe the increasingly important role of manufacturing process control for small lot manufacturing, such as 3 D printing and vacuum arc remelting.

Dawn Tilbury, a recent Chair of DSCD, introduces programmable logic controllers (PLCs), which control and coordinate the thousands of machines, conveyors, etc. in a typical manufacturing plant. She describes how PLCs work and are programmed, and how they can be designed for reconfiguration, so that as consumer needs change the plant can be changed to make the products they want.

With this issue *DSC Magazine* has successfully completed two years of publication, and was well received by the membership. Consequently, the DSCD leadership has decided to continue with publication. I have fulfilled my commitment to launch this new publication, but I am pleased to report that publication will now continue under the Editorship of Peter Meckl from Purdue University who has already guest edited two previous issues of *DSC Magazine*. You can now send your comments, as well as suggestions for future issues, directly to him at **meckl@purdue.edu**.

A. Galip Ulsoy
Editor of DSC Magazine

2014 American Control Conference: Report and Awards

The 2014 American Control Conference was held June 4-6 in Portland, Oregon, under the leadership of General Chair **Dawn Tilbury** and Program Chair **Gary Balas**. More than 1200 registrants enjoyed the technical and social programs. The conference was held at the Hilton Portland and Executive Tower Hotel in downtown Portland, one of the most walking- and biking-friendly cities in the US. The opening reception at the hotel featured a "beer tasting" including several of Portland's famous micro-brews. The closing reception was held off-site at the World Forestry Center, a short ride from the Hilton via public transportation. Participants viewed exhibits about forests both in the Pacific Northwest and around the globe, while enjoying food and drinks under sunny skies.

Professor **Keith Glover** of Cambridge University gave the plenary talk on Wednesday morning, discussing the symbiotic relationship between theory and practise. Thursday and Friday morning each featured two semi-plenary speakers. University of Michigan Professor **Anna Stefanopoulou** presented the control of powertrain systems at the high efficiency limit, including internal combustion engines as well as batteries and fuel cells. Professor **Vijay Gupta** of the University of Notre Dame talked about recent results and challenges in the control of cyber-physical systems. University of California Santa Barbara Professor **Bassam Bamieh** discussed new directions in networked and distributed parameter systems. Dr. **Juan de Bedout** of General Electric presented a vision for a merging of controls and big data over the industrial internet, enabling controls to shape the business landscape.

Industry participation included 8 Gold and 13 Silver Sponsors, four of which hosted lunchtime special sessions describing their products or introducing opportunities at their companies. Many of the sponsors also had booths in the exhibit hall, enabling them to interact with the attendees on an informal basis during the conference. Several evening special sessions featured industry engagement, including sessions on industry job-hunting, connected and automated vehicles, the power grid, venture-capital based start-ups, and complex electrical systems.

Four finalists for the Best Student Paper competition presented their papers on Wednesday; the winner was announced during the AACC Awards Ceremony on Thursday just before the conference banquet. All finalists for the student best paper award received full travel support to attend the ACC. In addition, 96 students received partial travel support, thanks to the generosity of the AACC, ASME, and IEEE. Special sessions on job-hunting (one for academia and another for industry) were well-attended by the students. ■

CONTRIBUTED BY DAWN TILBURY, ACC 2014 GENERAL CHAIR

Upcoming Conferences

53rd IEEE Conference on Decision and Control will be held December 15-17, 2014 in Los Angeles, California.
http://control.disp.uniroma2.it/CDC2014/

12th IFAC Workshop on Time Delay Systems will be held June 28-30, 2015, at the University of Michigan, Ann Arbor, MI, USA.
http://me.engin.umich.edu/dirifac/

14th European Control Conference 2015 will take place in Linz, Austria July 15-17, 2015.
http://www.ecc15.at/

NEWS CONTENTS EDITED BY RIFAT SIPAHI

Left to Right: General Chair **Dawn Tilbury** (University of Michigan) congratulates student best paper finalists **Armin Zare** (University of Minnesota), **Richard P. Mason** (winner, University of Oxford), **Mehdi Maasoumy** (University of California, Berkeley), and **Yuchun Li** (University of Arizona) for their outstanding work.

From left to right: **Glenn Y. Masada** (President-Elect, American Automatic Control Council AACC), **B. Wayne Bequette** (Secretary, AACC), **Richard P. Mason** (Student Best Paper Award), **Davood B. Pourkargar** (O. Hugo Schuck Best Paper Award in Application, with **Antonios Armaou**), **Konstantinos Gatsi** (O. Hugo Schuck Best Paper Award in Theory, with **Alejandro Ribeiro** and **George J. Pappas**, not pictured), **Hamsa Balakrishnan** (Donald P. Eckman Award), **Roger W. Brockett** (John R. Ragazzini Education Award), **Linda Bushnell** (Treasurer, AACC), **Tariq Samad** (President of AACC), **R. Russell Rhinehart** (Past-President of AACC). **Dimitri Bertsekas** (Richard E. Bellman Control Heritage Award) is not pictured.

MEASURING IMPACT OF CYBERSECURITY ON THE PERFORMANCE OF INDUSTRIAL CONTROL SYSTEMS

BY KEITH STOUFFER AND RICK CANDELL, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Industrial control systems (ICS) are everywhere in our engineered world. They regulate temperature, lighting and access in our buildings; they provide fuel efficiency and safety while reducing emissions in our cars; they synchronize and regulate every aspect of production in our manufacturing plants; they monitor patients in our hospitals. In many cases the reliable and secure operation of such systems is essential, and they must be designed to be secure against hackers and terrorists. The National Institute of Standards and Technology (NIST) is developing a cybersecurity testbed for ICS. The goal of the testbed is to measure the performance of ICS when instrumented with cybersecurity countermeasures in accordance with practices prescribed by national and international standards and guidelines. Examples of such standards and guidelines include the ISA/IEC 62443 *Industrial Automation and Control Systems (IACS) Security* series of standards and NIST SP800-82, *Guide to Industrial Control Systems (ICS) Security.* The testbed will cover multiple types of ICS scenarios. Each scenario is intended to cover one or more aspects of industrial control.

ICS OVERVIEW

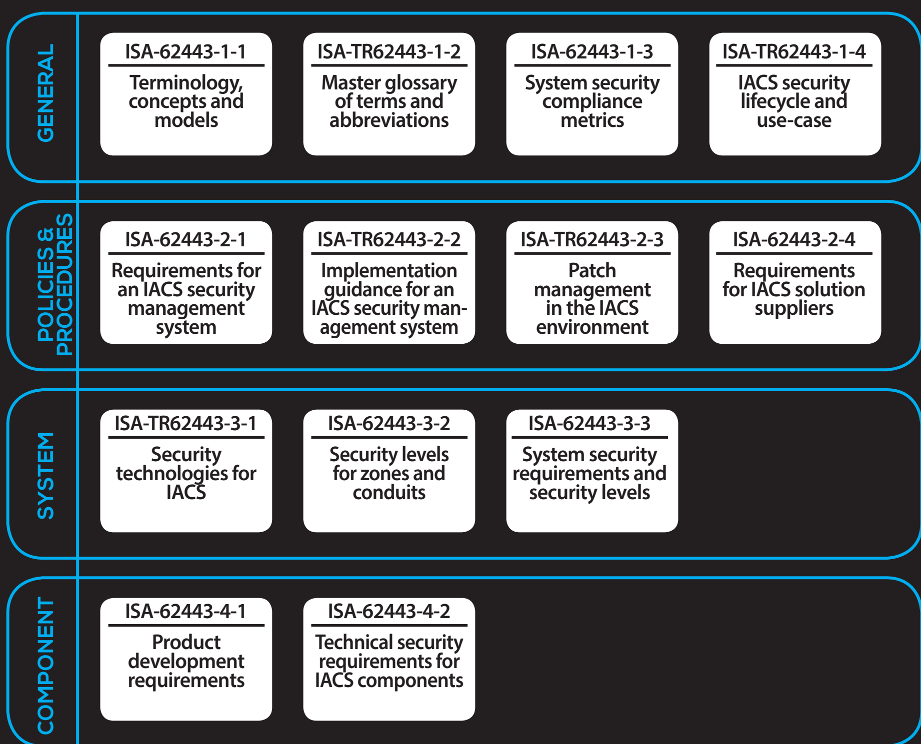
ICS is a general term that encompasses several types of control systems, including supervisory control and data acquisition (SCADA) systems, distributed control systems (DCS), and other control system configurations such as Programmable Logic Controllers (PLC) often found in the industrial sectors and in critical infrastructures, such as industrial plants, water treatment facilities, power generation and distribution systems. An ICS consists of combinations of control components (e.g., electrical, mechanical, hydraulic, pneumatic) that act together to achieve an industrial objective (e.g., manufacturing, transportation of matter or energy) [1]. These types of networks are often composed of numerous interconnected devices with centralized or decentralized control depending on the application.

Modern requirements of modularity, decentralization, ease of maintenance, and lower operational costs have driven designers of ICS toward the adoption of Internet protocol (IP) routable data communications protocols traditionally found in home and office environments. With this change, ICS cybersecurity has become increasingly important. Traditional information technology (IT) security policies focus primarily on confidentiality with availability typically being the lowest security priority. In contrast, ICS, especially those considered critical infrastructure, must maintain a high level of system availability, data integrity and operational resilience for many reasons including economic, environmental, human safety, and national security. For many processes, it would be unacceptable to degrade ICS performance for the sake of security. A risk analysis is required for each system to make such a determination. Security countermeasures must be implemented in a way that maintains system integrity during normal operation as well as during a cyber-attack [3]. ICS security may include elements of resilient physical design (redundancy and physical adaptability) in addition to information security, to maintain acceptable system availability. Such requirements are determined by a process of careful risk analysis and system engineering [1]. The ICS cybersecurity testbed will serve as a test platform to provide guidance to the ICS community on implementing an ICS security program based on sound measurement science and standards.

TESTBED GOALS

The primary goal of the testbed is to measure the performance of ICS when instrumented with cybersecurity countermeasures in accordance with practices prescribed by national and international standards and guidelines. The results of this research will allow NIST to provide guidance to the ICS community on best practices for effectively implementing cybersecurity standards and guidelines without negatively impacting ICS performance. The testbed will be used to demonstrate the application of ICS cybersecurity standards such as the ISA/IEC 62443 [2] series, shown in Fig. 1, and NIST SP 800-82 [1], to networked control systems, and measure the change in performance, if any, after applying security countermeasures. Some research areas of interest for the testbed include: perimeter network security; host-based security; user and device authentication; packet integrity and authentication; encryption; zone-based security; field bus (non-routable) protocol security; and robust/ fault tolerant control.

FIGURE 1. ISA/IEC 62443 Series of Standards



The secondary objective of the testbed is to measure the performance of ICS when under cyber-attack and secured with standards and guidelines as written. Resiliency will be a central research focus for systems under attack. Penetration testing will be conducted during the latter years of the ICS security research project; however, that timeline can be accelerated depending on the level of industry demand for penetration research. The results of this research will be fed back into the standards developing organizations for potential revision of the standards to address identified vulnerabilities, if any.

TESTBED DESIGN

The ICS cybersecurity testbed will be designed to demonstrate application of security countermeasures to a variety of processes such as control of a chemical plant, dynamic assembly using robots, additive manufacturing, and supervision and control of large distributed networks such as intelligent transportation systems. Each scenario is intended to cover one or more aspects of industrial design. The Tennessee Eastman scenario defined by Downs and Vogel [4] is intended to cover continuous process control. A collaborative robotic assembly scenario is intended to cover rapid and dynamic discrete manufacturing. An additive manufacturing scenario is intended to cover advanced manufacturing processes, and an intelligent transportation scenario is intended to cover large distributed networks for industrial systems such as railways and pipelines involving SCADA systems.

While it is not practical to construct an entire industrial operation such as chemical process control within the laboratory, simulation and emulation will be leveraged where appropriate with hardware-in-the-loop (HIL) components simulating real-world interfaces between the sensors and actuators and the controller.

MEASUREMENT APPROACH

A measurement enclave will be constructed within the testbed to capture network traffic, retain system log messages, and manipulate traffic. Traffic manipulation will be used for man-in-the-middle attacks, traffic shaping, and local and wide area network modeling.

The testbed is designed to support three measurement approaches. The first measurement approach will be to introduce communication link uncertainty between sensors and controllers. ICS process performance will be measured and correlated with varying degrees of channel degradation. This approach will provide a technology-independent view of how processes are impacted by certain channel models indicative of security countermeasures.

The second approach will be to demonstrate the process for developing a risk model and applying cybersecurity countermeasures in accordance with ISA/IEC 62443 and NIST SP 800-82. This approach will demonstrate how to apply the standards with multiple levels of security to industrial processes. For each scenario (i.e., process and security level), the performance of the system will be measured with and without the security countermeasures in place to provide a comparison of performance of a system instrumented with security but not undergoing attack.

For the third approach, the performance of the system will be measured while under cyber-attack. For each process undergoing evaluation, test scenarios will entail multiple levels of security.

FIGURE 2. Collaborative Robotic Assembly Scenario in NIST ICS Cybersecurity Testbed

INDUSTRIAL SCENARIOS

In December 2013, NIST sponsored a 2-day roadmapping workshop on measuring the impact of cybersecurity on ICS performance. At this workshop, attendees from industry, academia, and government were asked to participate in defining the priorities of the testbed. In particular, the protocols identified for inclusion in the testbed were primarily IP-routable protocols. Non-routable protocols were indicated to be of lesser importance. For inclusiveness, the ICS cybersecurity testbed will include both types of protocols.

Chemical Process Control

The Tennessee Eastman (TE) model was chosen for the chemical process control scenario for several reasons. First, the TE model is a well-known plant model used in control systems research and the dynamics of the plant process are well-understood. Second, the process must be controlled; otherwise perturbations will drive the system into an unstable state. By being open-loop unstable, the TE process model represents a real-world scenario in which a cyber-attack could pose a risk to human safety, environmental safety, and economic viability. Third, the process is complex, highly non-linear, and has many degrees of freedom by which to control and perturb the dynamics of the process. And finally, numerous simulations of the TE process have been developed and reusable code is readily available. The University of Washington Simulink controller model by Ricker [5] was chosen for its multi-loop control

ABOUT THE AUTHORS

Keith Stouffer has been with the Engineering Lab at NIST for 25 years focusing on ICS security since 2000. Mr. Stouffer is the lead author of NIST Special Publication 800-82, Guide to Industrial Control Systems Security, which provides guidance on how to secure ICS while addressing their unique performance, reliability and safety requirements. Mr. Stouffer has also provided input to the ISA/IEC 62443 and NERC CIP security standards. During his career, he has received Gold and Bronze Medals from the Department of Commerce and the Gov30 Security Award. Mr. Stouffer holds a Master's degree in Computer Science from Johns Hopkins University and a Bachelor's degree in Mechanical Engineering from the University of Maryland.

Rick Candell has twenty years of experience in telecommunications with emphasis on tactical radio and satellite-based tracking systems. Mr. Candell spent twelve years developing, testing, and deploying secure wireless technologies for the US Army. He was an important contributor in developing cost-saving technologies for the US Army fleet tracking system. He holds patents related to successive interference cancellation and transmission burst detection. Mr. Candell recently joined the NIST Engineering Laboratory where he is applying his wireless networking and information security knowledge to industrial control systems. Mr. Candell holds an MSEE degree from the University of Memphis.

Keith Stouffer and Rick Candell

architecture making distributed control architectures viable. The TE process will be controlled by real ICS hardware and software.

Other chemical processes being considered for the simulator include a dynamic model of a benchmark manufacturing process used to produce vinyl acetate (VAC) monomer [6]. The process shares many performance metrics and security vulnerabilities with the TE process while highlighting some key differences that warrant investigation from a cybersecurity perspective. The VAC process model is significantly larger in terms of interacting modules and dynamic states. The VAC process features 246 states, 26 manipulated variables, and 23 polled measurements, as opposed to 50 states, 12 manipulated variables, and 22 polled measurements for the TE process. The process is controlled using a multiloop Single Input Single Output architecture, which lends itself to more granular evaluation of targeted control system vulnerabilities. The process features multiple vapor phase reactions with much faster dynamics requiring a 1 second sampling interval, while the sampling interval for the TE process is 40 seconds. The faster sampling interval makes the system especially sensitive to delays in communication and loss of synchronization across independent control loops.

Collaborative Robotic Assembly

The collaborative robotic assembly scenario, shown in Fig. 2, will be used to demonstrate cybersecurity application in a discrete state process with fast dynamics and high data throughput demands using a combination of a deterministic real-time protocol and an Ethernet-based IP protocol. The collaborative robotic assembly system will demonstrate the impacts of cybersecurity on a system with embedded control and dynamic planning. The collaborative robotics scenario will be constructed as multiple local area networks with EtherCAT serving as a real-time conduit between sensors, controllers, robots, and a safety system.

A safety system will be constructed to measure performance of ICS safety systems when instrumented with cybersecurity countermeasures. The safety system will include a safety PLC, an emergency stop button, a solid state relay, and a light curtain sensor. The safety PLC will be networked to the main robot controller using the real-time EtherCAT bus as well as the non-real-time Ethernet interfaces.

Additive Manufacturing

The additive manufacturing scenario is intended to cover advanced manufacturing processes. Additive manufacturing is rapidly evolving from just a prototyping tool to a production method for functional parts. The ability to produce small quantities efficiently makes it particularly attractive. Information about materials, finish, and other physical attributes are all contained in the digital production (print) file, which makes this file a critical piece of intellectual property to protect. The testbed currently contains a networked extrusion type 3D printer for cybersecurity testing.

Intelligent Transportation

The intelligent transportation scenario is intended to cover large distributed networks for industrial systems such as SCADA systems. The specific system to be simulated has not yet been selected, but candidate systems include railway and an intelligent transportation system for a large metropolitan area. Cybersecurity for single-hop and multi-hop wireless architectures will be explored within this scenario.

CONCLUSION

Control systems are embedded in essentially all engineered systems, such as our cars, homes, offices, industrial plants, and in critical infrastructures such as power plants, water treatment plants, and transportation systems. To ensure the security of industrial control systems (ICS), particularly for critical infrastructures, standards are being developed to ensure ICS cybersecurity. The NIST ICS cybersecurity testbed will be constructed to facilitate the measurement of industrial process performance for systems instrumented with cybersecurity technologies. This testbed will allow for validation of existing security standards and guidelines and will allow researchers to provide valuable feedback to the community on methods, practices, and pitfalls when applying a cybersecurity program to an ICS. Additional work will be required to identify new use cases and pertinent performance metrics. The testbed will provide an opportunity for collaboration between government, research institutions, and industry partners. Interested parties are encouraged to contact the authors directly to discuss opportunities for collaboration. ■

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3 Eric Knapp, *Industrial Network Security Securing Critical Infrastructure for Smart Grid, SCADA, and Other Industrial Control Systems.* Waltham, MA: Syngress, 2011.

4 J.J. Downs and E.F. Vogel, "A Plant-Wide Industrial Process Control Problem," *Computers and Chemical Engineering*, vol. 17, no. 3, pp. 245-255, 1993.

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EMERGING NEXUS OF CYBER, MODELING, AND ESTIMATION IN ADVANCED MANUFACTURING: VACUUM ARC REMELTING TO 3D PRINTING

BY JOSEPH BEAMAN AND FELIPE LOPEZ, UNIVERSITY OF TEXAS AT AUSTIN

There have been tremendous advances in three important technical areas in the last decade: computing capability, physics-based modeling, and estimation methods. Although these advances are known in the research community, they have not been deployed to any great extent in the manufacturing industry. It has become increasingly clear that manufacturing is of fundamental importance to the vitality of the US economy. Small lot or small volume manufacturing, often of high value products, offers a unique opportunity to open up fundamentally new businesses for manufacturers. One of the major challenges in small lot manufacturing is the cost of qualifying and certifying that the product meets its design specifications. This is substantially the function of manufacturing process control. Contemporary process control is statistics based and is most effective for large volume manufacturing. Such process control is often not effective if the conditions or the product changes, such as occurs in small lots.

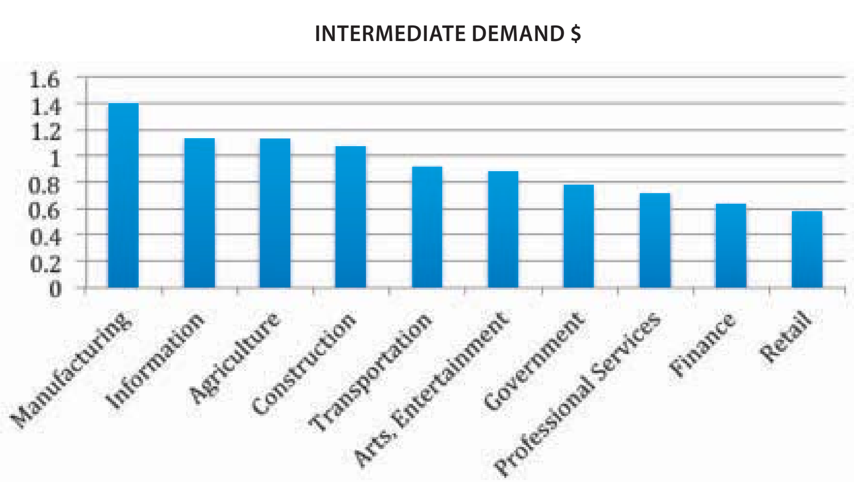
This article will describe opportunities for exploiting these three technical areas for advanced manufacturing in small lots. Two illustrative applications will be highlighted:

1. Application in a new emerging manufacturing process – 3D Printing or Additive Manufacturing.

2. Application in a mature manufacturing process – Vacuum Arc Remelting for super alloy production.

In particular, Cyber Enabled Manufacturing Systems (CeMs) for small lot manufacturing that incorporates a model of the process directly into the control algorithm is presented and discussed. The model enables the manufacturing monitoring and control algorithm to accommodate changing conditions without extensive additional experiments. Objectives of the CeMs system are rational setting of manufacturing tolerances, real time prediction of manufacturing defects, real time control of process to eliminate defects, and real time monitoring and control for small lot manufacturing. These goals are achieved through high fidelity, physics based models including models of faults/defects, uncertainty quantification, reduced order models that run in real time, measurement, real time prediction, real time computer architecture, real time control with inverse solutions, and automating the CeMs process for generic manufacturing processes. The development of such accurate control algorithms and their application to manufacturing processes can provide a competitive edge.

FIGURE 1: Intermediate demand necessary to produce $1.00 of a sector demand [2]



IMPORTANCE OF MANUFACTURING

Manufacturing is of fundamental importance to the vitality of the United States economy and national security. Besides the obvious large quantity of products that are manufactured and the higher-than-average paid jobs created today, the manufacturing sector is a key element in creating new innovations that become the new businesses of the future.

> *Manufacturing provides many of the jobs and drives many of the businesses of today. Yet its role in providing jobs and providing the businesses of tomorrow is even more important. The manufacturing sector accounts for about 72% of all private sector R&D spending and employs 60% of U.S. industry's R&D workforce. As a result, the manufacturing sector develops and produces many of the technologies that advance the competitiveness and growth of the entire economy, including much of the service sector.[1]*

Manufacturing also contributes greatly to economic growth. Manufacturing has a larger multiplier on growth than any other sector as can be seen in the chart in Fig. 1 in which $1 of demand in manufacturing results $1.41 of supporting demand in the economy.

ADVANCED MANUFACTURING

Control systems have always played an important role in manufacturing, but this article is about a unique and timely opportunity for the control community in advanced manufacturing. Advanced manufacturing is not a well-defined term, but there are generally two categories: (1) new manufacturing processes and (2) the use of technology to improve existing manufacturing processes in time, cost, and yield. The opportunities for the control community in these two categories are somewhat different. New manufacturing processes are often associated with start-up ventures which may not have resources or time to use modern estimation and control technology. However, a new manufacturing process usually does not have established

ART TO PART

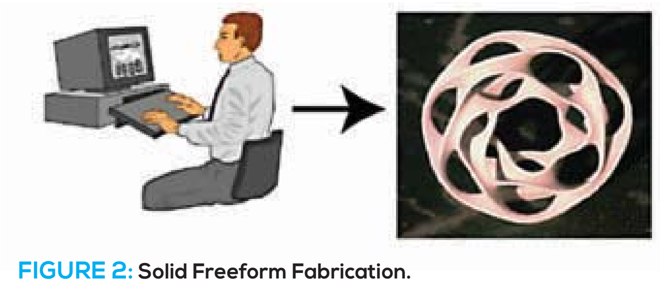


FIGURE 2: Solid Freeform Fabrication.

certification procedures, so technology can be more easily incorporated into the process. For existing processes there may be readily available resources for new technology, but the cost of changing established certification procedures of an existing process may be high. This article focuses on areas for both new processes and existing processes that have the potential to overcome these barriers to implementation.

3D PRINTING: A NEW MANUFACTURING PROCESS

The term 3D Printing is often used to describe a number of new manufacturing processes. One of these processes, Selective Laser Sintering (SLS), was co-developed at the University of Texas by the first author of this article in the mid 1980's. The name that we used to describe the 3D Printing technology is Solid Freeform Fabrication. We defined Solid Freeform Fabrication as the ability to fabricate complex solid objects from a computer model of an object without part-specific tooling or human intervention. Essentially, this is an art-to-part process in which a designer sits at a computer design station and hits hard copy or print to make the 3D part, see Fig. 2.

The problem that Solid Freeform Fabrication is trying to solve is how to make one of something quickly without part-specific tooling or human intervention. A conceptual solution to this problem is voxel manufacturing in which a voxel is a volume element of matter. The concept is to deliver two types of voxels: structural voxels and support voxels (see Fig. 3). As implied by their names, structural voxels have strength while support voxels only need to supply temporary support to the part and are eventually removed.

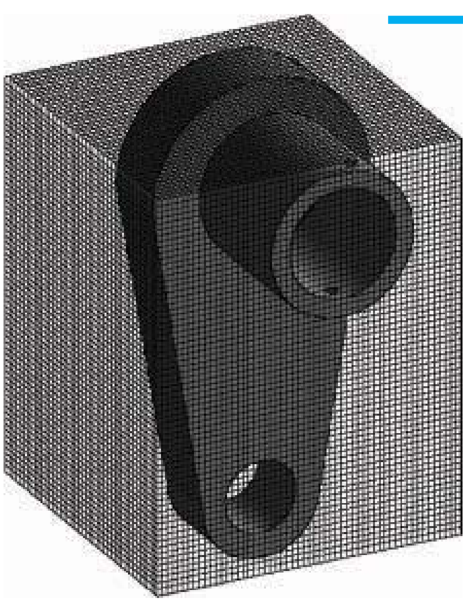


FIGURE 3: Voxel manufacturing with structural and support voxels

The SLS process, is shown as a schematic in Fig. 4: laser beam energy is applied to the top surface of a powder bed in the pattern of a cross-section of a part to be made. The position of the beam can be very precisely controlled with a set of galvanometer driven mirrors. Wherever the beam hits the powdered material, the powder melts (this is not sintering but melting) and subsequently solidifies into structural material. Scan speed and beam power are set in order to have a regular melt penetration depth. In this embodiment, the powder is delivered to the part cylinder from two piston-driven powder cartridges by a counter-rotating roller that delivers and levels the powder in layers. The object is built in the part-build cylinder vertically in repetitive layers that are bound together by the melt penetration. A controlled piston in the part-build cylinder determines the layer depth. Throughout the entire process the part is fully supported by the un-melted powder.

The SLS process and other similar Solid Freeform Fabrication processes were made possible by three enabling technologies that matured in the 1980's.

1. Solid modeling was commercialized. Solid models can represent three-dimensional parts easily in a computer and on a monitor. A solid model is required for necessary Solid Freeform Fabrication sub-processes such as slicing the solid into layers.

2. Lasers became available at reasonable prices. Lasers deliver the energy required to solidify the object and can deliver this power in a precise way in order to make geometrically accurate parts.

3. The personal computer was commercialized. The geometric and precision power operations in Solid Freeform Fabrication require a level of computing power that became available in the personal computer.

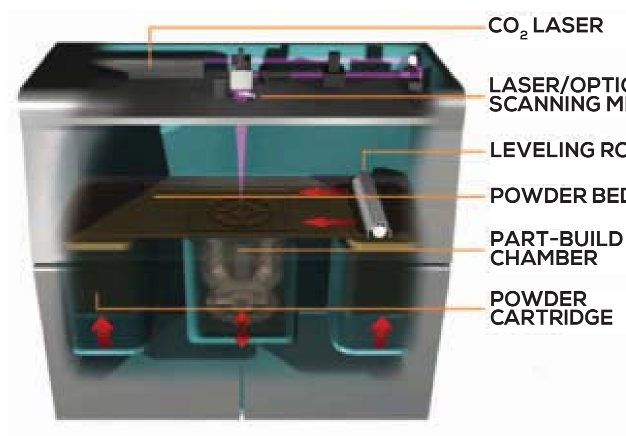


FIGURE 4: Schematic of SLS Process

As expected the process control for these first systems was very crude and, somewhat surprisingly, the process control remains fairly crude today. SLS is a thermal manufacturing process and for polymer SLS the process chamber is equipped with a part-build surface heater and powder cartridge surface heater. A single point infrared temperature sensor pointed at the part-build surface controls the part-build heater, and two single point infrared sensors pointed at the powder cartridge surface control the two powder cartridge heaters. One of the primary control issues in polymer SLS is the temperature distribution across the part-build surface.

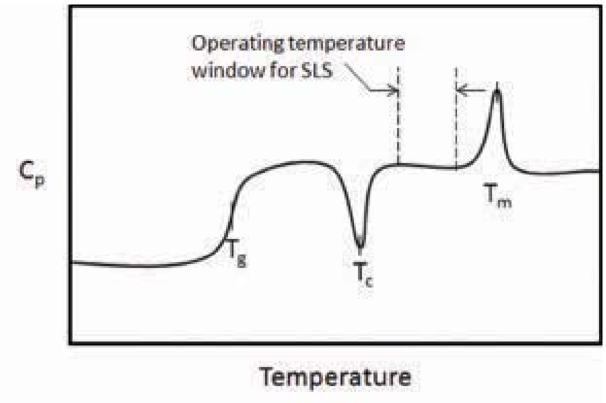


FIGURE 5: Typical DSC of for a Semi-Crystalline Polymer (Courtesy Harvest Technologies)

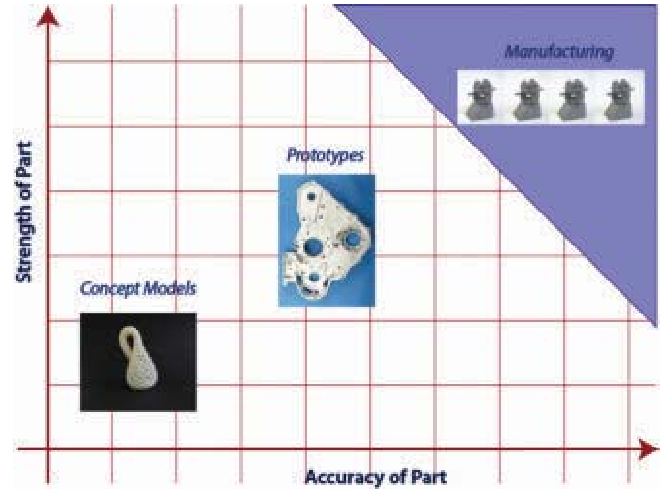


FIGURE 6: Markets in Solid Freeform Fabrication

Polymers that build the best parts in SLS machines are typically semi-crystalline. The relatively sharp melting point of semi-crystalline polymers yields parts that have sharp edges and thus accurate parts. Differential Scanning Calorimetry (DSC) captures the important thermal properties of the polymer. A representative DSC plot is shown in Fig. 5. In this figure, T_m is the melt temperature and T_c is the recrystallization temperature. The operating temperature of the part-build surface has to be below the melt temperature to avoid melting the entire part-build surface and above the recrystallization temperature to prevent part distortion. The state-of-the-art of process control in commercial machines consists of calibrating multi-zone heaters to achieve a relatively uniform temperature field across the part-build surface and then using the single point infrared temperature sensor to keep this surface point in the operating temperature window. Of course this method does not measure the entire part build surface, which can vary substantially from the controlled surface point. This variation can result from both residual laser heat as well as convective cooling, which is different from part to part since the essence of the process is to make different parts.

The current process control in Additive Manufacturing machines is coarse because SLS technology initially grew out of a commercial need for rapid prototyping. This market has a different requirement for process and quality control from traditional manufacturing. As shown in Fig. 6 concept models require relatively low accuracy and low strength. Increasingly inexpensive machines, with little or no process control, are serving this concept model market. At the other end of the spectrum is true manufacturing that requires relatively high accuracy and strength. This is the emerging market for Additive Manufacturing, which is presently being served by machines that were designed for the rapid prototyping market. Prototypes are primarily used for initial form, fit and function but do not typically have to last a long time. Also variation between prototype parts can be tolerated more than in a part for production.

True Additive Manufacturing has grown slowly over the last decade and has been embraced by the aerospace industry. There are many polymer parts on existing aerospace systems that have been manufactured by Additive Manufacturing. These are for the most part non-structural parts such as ducting. These parts are made without part-specific tooling and due to the geometric complexity available in Additive Manufacturing can be almost any shape. This leads to a great reduction of part count and cost. Maybe even more importantly, the cost to make one part is roughly the same cost to make any number of parts. Most manufacturing processes have a great reduction in price as the volume goes up. This feature of Additive Manufacturing can enable a new business model for manufactured parts called the long tail [3]; a strategy that states that *selling a large number of unique items is more profitable that selling a few popular items in large numbers*.

Another aspect of Additive Manufacturing is the process can run mostly without human intervention. This leads to a business model of regional manufacturing in which it is economic to manufacture locally rather than in low wage countries. For this and other reasons, there is a great deal of excitement about the potential of Additive Manufacturing in the business community. But, none of this potential is possible, if Additive Manufacturing does not have adequate process control. Although the economic production of Additive Manufacturing can be greater than 10,000 parts [4], it is for the most part a small-lot process. Contemporary process control is statistics based and is most effective for large volume manufacturing. Such process control is often not effective if the conditions or the product changes, such as occurs in small lots. Although not unique to Additive Manufacturing, small lot manufacturing process control is critical to its success in manufacturing. In the following section, we describe a methodology for achieving this control not only for Additive Manufacturing, but also for other small-lot manufacturing processes.

SMALL LOT PROCESS CONTROL

Statistics based quality control techniques, often used in the manufacturing industry, are not easily extendable to small-lot manufacturing. Extensive testing is required for the determination of error bars that quantify admissible deviations from optimal operating conditions, which are not well defined in small lot manufacturing or when each product has unique specifications.

Although not extensively used in manufacturing practice, model-based techniques, which are used more regularly in the chemical processing industry, can provide distinct advantages for small lots. Due to the predictive nature of models, model-based methods can substantially reduce or possibly eliminate extensive testing. These techniques combine knowledge of the process with in-process measurements to adjust to characteristics of each product to ensure they are free of defects.

There are simplifications that are intrinsic to traditional model-based approaches. For example, it is assumed that measurements, communication, and data processing are tasks that are performed instantaneously, which often ignore the internal dynamics of these elements. The reality of a CeMs process control system is different, as computational models, sensors and actuators, and computing units become part of a network that has interaction with the physical manufacturing process. The CeMs approach that we are advocating seeks to incorporate all computational components and the physical plant in a unified control system.

CeMs is a derivative of a generic cyber-physical system consisting of embedded and distributed sensors, actuators, and computational units that are networked to effectively gather and process information while being coupled with the control system for immediate response. The advantages of this approach are evident. For example, optimization of computation and communication enables the adoption of methods that were considered too slow for closed-loop operation. The study of CeMs is a multidisciplinary task that involves the study of manufacturing processes, computational models, characterization of defects, distributed sensors, communication, fast processing of measurements, and control algorithms. This novel area is designed to enable collaboration between process engineers, control engineers, and computer scientists.

PHYSICS-BASED MODELS

Incorporation of high-fidelity physics-based models in a process controller would have been difficult a decade ago. Tremendous advances in modeling have occurred in recent years. Commercial modeling packages have resulted in a large reduction in time required to develop these models. In the chemical process industry, these modeling tools are now used to study the effect of varying parameters on the quality of the obtained products, enabling open-loop optimization. In the case of small lots, the effect of unmodeled disturbances that affect the product quality cannot be neglected. It becomes necessary for computational models to adjust to varying operating conditions, which can be done by coupling them to the plant and updating them in real time. This approach results in increased information of the varying process dynamics in the manufacturing process and it enables the observation of phenomena that cannot be measured physically. If a computational model is used for sensing it must return information quickly enough for it to be used by the controller, making the acceleration of these models a necessity.

The complexity of high-fidelity models can prevent their application in the design of process estimators and controllers, necessitating reduced-order models to decrease the state dimension. The challenge is to do so in a way that is faithful to the outputs over the input parameter space. In linear models, balance and truncate, singular perturbation approximations, and Hankel norm approximations are used to reduce the order of state-space realizations; but these methods are not easily extendable to nonlinear models [5]. In such scenarios, reduced order models are typically constructed with snapshots generated from training points that sample input parameter space [6]. Thus, the reduced model can be rapidly evaluated within a control loop or while sampling probabilistic parameter spaces. One challenge has been to ensure that the reduced order models remain faithful to the outputs of interest over a wide range of inputs.

ESTIMATION

Anomalies in manufacturing are difficult to detect and correct in a timely manner. They are usually described by parameters that are not measured directly, or have to be inferred from noisy observations, making accurate state and parameter estimation necessary.

Materials processing used in manufacturing involves processes governed by transport equations: fluid mechanics, heat transfer, and mass transfer [7]. These equations are well known but are controlled by state-dependent coefficients that make them highly nonlinear. Nonlinear estimation is still considered challenging, as optimal solutions available for linear Gaussian scenarios are not extendable when nonlinearities appear. Nonlinear estimators

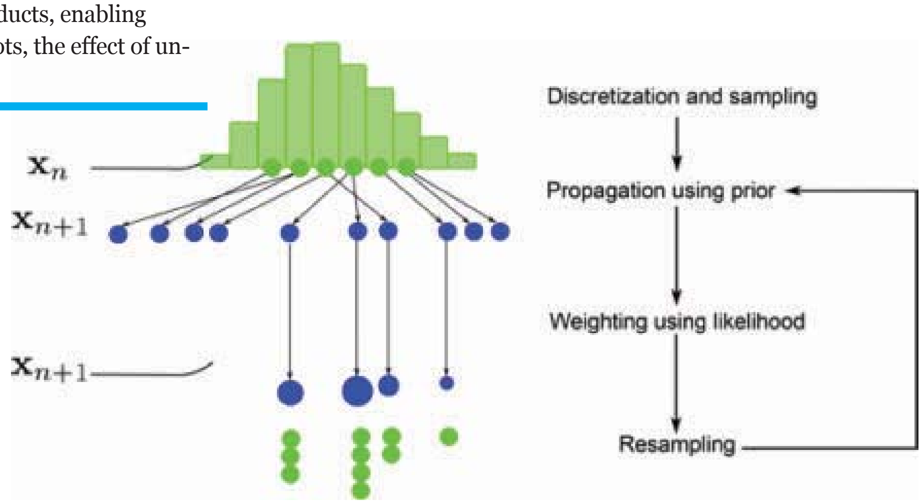


FIGURE 7. Particle filter, the most common Sequential Monte Carlo estimator.

available in the literature can be classified in three groups: (1) extensions to the classic Kalman filter, such as the extended and unscented Kalman filters; (2) moving horizon estimators, common in the model predictive control literature; and (3) Sequential Monte Carlo methods.

Sequential Monte Carlo methods are commonly presented as the most promising alternative because of their flexibility [8]. In these methods, a continuous probability density function is approximated by a discrete probability measure, where the support is defined by the finite number of particles and the shape of the distribution is defined by the weights on the particles. The particles and their weights are updated when a new set of measurements becomes available. Two of the most common Sequential Monte Carlo estimators, the particle filter and the auxiliary particle filter (see Fig. 7), are often used in a wide variety of applications, such as computer vision, finance, robotics, etc. Until recently the biggest impediment for the adoption of Monte Carlo techniques in online estimation applications has been their computational cost.

COMPUTER ARCHITECTURES AND NETWORKS

A computational architecture that can meet the real-time constraints of the manufacturing process and Monte Carlo methods is essential to the success of the CeMs approach. One way to accelerate computations is to implement them in a computational unit with an optimal architecture. For example, Sequential Monte Carlo methods are parallel by nature, and their performance is improved by orders of magnitude when moved from a CPU to a more appropriate unit, such as graphics processing units (GPUs) [9]. Similar approaches can be followed to accelerate the physics-based model, if necessary [10].

VACUUM ARC REMELTING

One of the manufacturing processes currently being studied with this methodology is Vacuum Arc Remelting (VAR). Similar to Additive Manufacturing, VAR is a small lot, high value manufacturing process. VAR is used in the superalloy industry for the production of expensive rotor-grade materials. Production is performed in a discrete manner, and each production run takes an entire day or longer, which drives manufacturers to search for alternative approaches that will ensure a higher yield in order to reduce manufacturing costs.

In contrast to Additive Manufacturing, VAR is a mature manufacturing process, which has been around since the 1950s, and it has a stable economic base of machines. It is used to homogenize and remove volatile components when producing segregation-sensitive superalloys. In industry, it is common to use VAR to improve the quality of ingots obtained with vacuum induction melting (VIM), electroslag remelting (ESR), compacting metal sponge, or other primary techniques. In this process, a metal electrode is suspended in a water-cooled copper crucible, where a vacuum is set. Direct current is used to melt the electrode, which falls to the bottom of the crucible and solidifies into an ingot. The CeMs strategy is currently under development for VAR.

Despite the method's many advantages, VAR ingots can be prone to segregation defects caused by un-dissolved material fall-in (white spots), convection instabilities (freckles) and perturbations in the melt pool (tree rings) [11]. Prevention of such defects can be attained by following desired melting and solidification conditions. It is known that the tendency for freckles decreases when melting with shallower liquid pools, as the tendency for buoyancy-driven flows decreases. On the other hand, it is important that the liquid pool is deep enough to dissolve any fall-in material that might become a solidification precursor. Prevention of freckles and white spots can be thought of as a balancing act that requires having a liquid pool that is deep enough to prevent white spots while being shallow enough to prevent freckles [12].

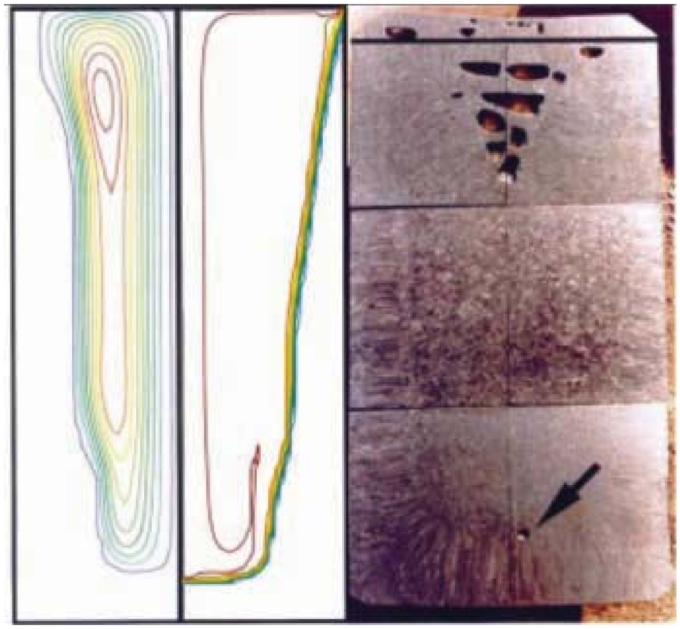


FIGURE 8. Favorable comparison between predicted temperature field and marked solidification front [14].

A major impediment for accurate prevention of such defects is that no measurements are available from the solidification front. However, one can use a finite volume model in parallel with the furnace, updating it to account for time-varying control inputs and process parameters, to gather predictions of the otherwise unobservable solidification front. As shown in Fig. 8 this methodology was implemented in a laboratory-scale experiment showing that the predicted liquid pool depths compared favorably to those measured manually [13].

A computational model, which was used for process optimization and post-mortem analysis in the 1990s, is now able to return real-time predictions of solidification conditions. The incorporation of a computational model in a network of sensors enhanced the capabilities of the controller, but it was still based on a linear model accurate only when operating near nominal conditions. Highly-transient behavior is observed in VAR in the beginning of the process (start-up) and in the end (hot-top). Control in these conditions is difficult, and it is common practice to discard these parts of the ingot since segregation defects are common. Superalloys producers are interested in enhancing their control capabilities to prevent defects in these highly-transient regions too, and that requires the application of nonlinear estimation and control techniques.

VAR is a relatively slow process, and therefore a good candidate to start testing these time-critical techniques as it is not as restrictive as other fast processes such as Additive Manufacturing. A typical VAR experiment takes an entire day, and has a sampling time on the order of seconds (2 seconds for small ingots and 5 seconds for production ones). Research was dedicated to the selection of an appropriate controller that was not only accurate but that also could be accelerated with a proper choice of computer architecture.

The stochastic model that describes the VAR process is defined by what in Bayesian estimation is known as a diffuse-prior peaked-likelihood problem, which means that the evolution equation for the state is much more uncertain than the observation equation. This is due to the disturbances in the system, such as the unknown current distribution in the electric arc, inhomogeneity of the metal electrode, varying helium pressure in the cooling system, and end effects at the beginning and end of the melt. Some measurements, on the other hand, are quite precise, such as those for tracking the position and the mass of the moving electrode; but there are also some others that are extremely noisy, such as electrode gap.

Application of Sequential Monte Carlo techniques can be inefficient in peaked-likelihood scenarios, because a large number of the particles proposed based on prior knowledge will end up in regions of the state space with a small likelihood based on the observed measurement and will disappear when resampling. An alternative approach that takes the current measurement into account when exploring the state space was found to be more efficient. The auxiliary particle filter resulted in a decrease in the number of particles required for acceptable accuracy by 87.5%.

Although the auxiliary particle filters resulted in a huge reduction in computational cost, the required number of particles was still high due to the high dimensionality of the system, and it was necessary to accelerate the estimator

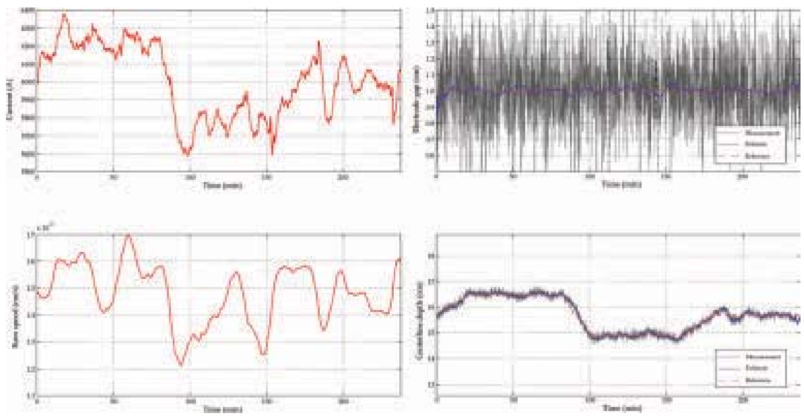


FIGURE 9. GeForce GTX TITAN, used in the acceleration of parallel estimation and control algorithms.

to meet the constraints of the control system. As shown in Fig. 9 NVIDIA's GeForce GTX TITAN, powered by GK110 and based on CUDA (Computer Unified Device Architecture), was used for a faster implementation [15]. The implementation of the algorithm on the GPU resulted in estimates obtained in milliseconds even when millions of particles were used, proving fast enough not only for this remelting application but also for other manufacturing processes with faster dynamics.

A similar approach can be taken to accelerate a constrained optimization problem for process control. A finite-horizon constrained optimization problem, such as model predictive control, can be expressed in the form of a sequential estimation problem [16]. Once in the form of an estimation problem, it too can be accelerated using parallel architectures. An example of nonlinear model predictive control where estimation and control are performed using Sequential Monte Carlo methods in shown in Fig. 10.

To date the research in CeMs for VAR has focused on development of models (both high-fidelity for defect prediction and reduced-order for estimation and control), estimation and control algorithms that can be accelerated, and computer architectures. The next steps in the project involve the design of a test bed where a proper study of the network will be included to improve the robustness of the system. These efforts are expected to ensure repeatability of quality standards that are necessary to complete current quality control techniques used in the superalloy industry.

ADDITIVE MANUFACTURING CEMS PROCESS CONTROL

CeMs for SLS is currently under development. The SLS process like the VAR process is a primarily a thermal process, but it involves at least two distinct thermal regions. First, there is a microscopic region of the laser

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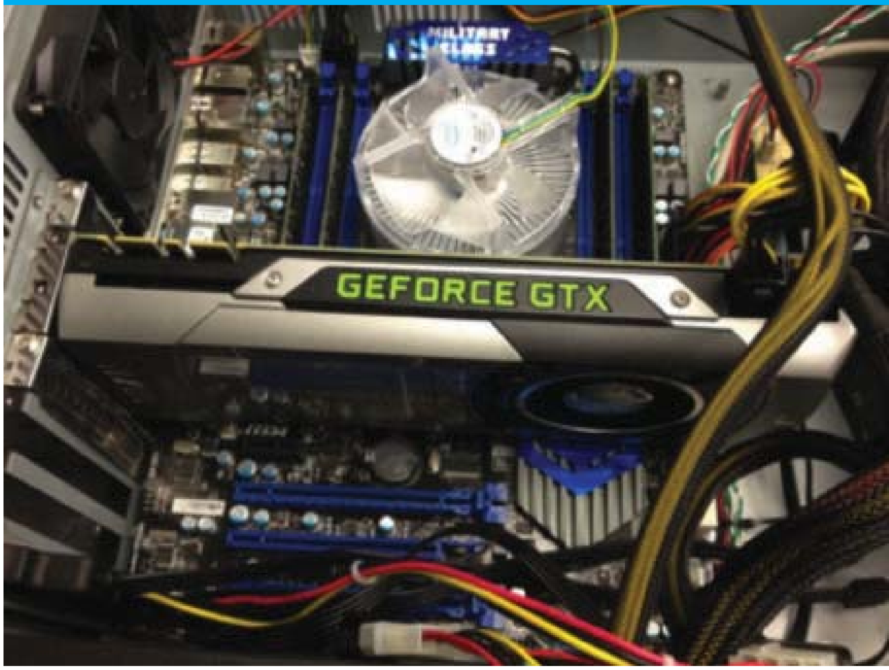

FIGURE 10. **Auxiliary particle filter-model predictive control for the VAR process showing accurate control of the process even when the reference liquid pool depth is changed.**

material interaction, which includes rapid melting and solidification. If this microscopic thermal region is poorly controlled, the bonding between layers can be degraded leading to part failure. This region is much faster than the dynamics of the VAR process and requires even faster methods than those used in VAR. Second there is a macroscopic region of the entire build chamber including the part bed. It is well known that the entire time-temperature history of a part can affect its properties. This region has a very slow change in time and is on the order of the VAR process (an SLS run might take 24 hours). For this reason, two separate models that feed into each other are being developed.

One distinct advantage the SLS process has over the VAR process is the ability to change the process. This is possible because it is an emerging process and the Additive Manufacturing community is just starting to understand how to control this process. We are developing our control on a laboratory SLS machine that we have custom built. For example, this machine has an IR camera that can image the entire part-build surface and additional temperature sensors that profile the entire build chamber. This would be difficult to do in an established commercial machine and process. This system has available thermal measurement of every single layer. The system also has the capability to measure the microscopic region of melting by a sensor that looks down the laser mirrors.

Even with all of these sensors, the CeMs method for process control for SLS will be essentially the same as VAR. It will include multi-physics computational models, modern (nonlinear) estimation methods and measurement, and high performance computational units.

SUMMARY & FUTURE OUTLOOK

There is great opportunity for the control community to have a major impact on advanced manufacturing. This includes increasing the performance of mature manufacturing processes such as VAR or developing the critical control of emerging manufacturing processes like 3D printing. This opportunity is especially timely because of a nexus of multi-physics simulation software, modern estimation methods, and real time computer architecture and hardware. ■

ACKNOWLEDGMENTS

The authors are pleased to acknowledge support for the research described here from ONR, NSF, and AFRL.

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RECONFIGURABLE LOGIC CONTROL FOR MANUFACTURING SYSTEMS

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1 WHAT IS A LOGIC CONTROLLER

High-volume discrete manufacturing systems can produce upwards of hundreds of thousands of parts per year. With a single line, that translates into several parts being produced every minute. The total process is broken down into operations that can each be performed at a station – the part must arrive at the station, be fixed, processed, and released within the cycle time. A typical part will go through hundreds of stations from the beginning of the line to the end. At each station, a continuous controller such as a CNC (computer numerical controller) ensures that the part is processed correctly, for example maintaining the feeds and speeds on a machine tool. The logic control coordinates all of the different machines, together with the material handling systems (e.g., conveyors, gantries, or robots) and interfaces with the human operator. A high-level view of a manufacturing system is shown in Figure 1, with raw materials arriving and processed materials (finished parts) leaving. The logic controller sends inputs to the machines based on the values of the sensors and the operator commands.

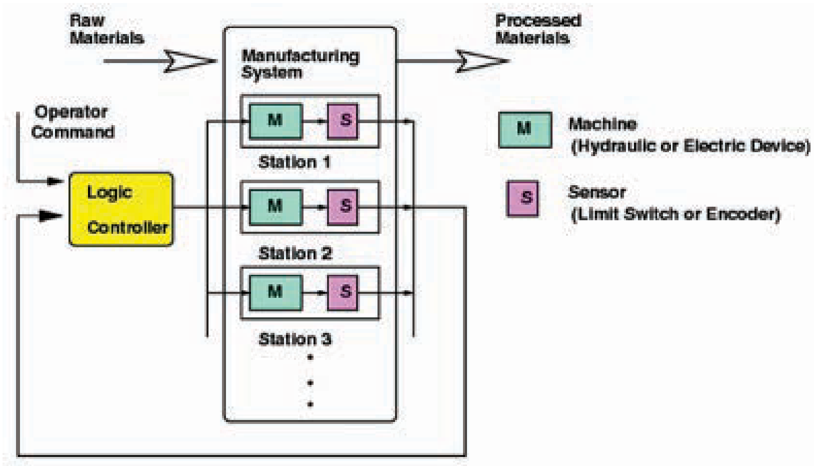


FIGURE 1: The logic controller sends commands to the machines based on the sensor feedback and operator input

In a typical discrete manufacturing plant, there are dozens of PLCs (programmable logic controllers). Each PLC coordinates the stations and material handling within a physical region of the plant. It may interface to an RFID (radio-frequency identification) system that keeps track of which part is where, and what processes each part has gone through. The RFID tag may also be used to track quality inspections of the parts. It is not uncommon for a single PLC to be associated with several thousand I/O (input-output) points – these discrete I/O are mostly binary (on/off) sensors and actuators, and can include limit switches, proximity sensors, flow sensors, hydraulic valves, and motors. Although continuous controllers are used to control the speed of motors, logic controllers often interface with these motor controllers to turn them on or off, and to set the reference speeds, etc.

Logic control can be thought of as a rule-base, a set of "if-then" statements. "If the proximity sensor indicates a part has arrived, and the RFID tag indicates it is part type 2, then tell the gantry to move the part into machine 3." Each of these statements is quite simple; the complexity arises when there are thousands of statements, and possibly conflicting rules.

In the automatic mode, the logic controller keeps the system operating automatically. As long as parts are entering the system, and there are no errors, the logic controller keeps the parts moving between the machines via the material handling systems. The logic controller is also responsible for detecting and handling errors, and interfacing with the operator to help the system recover from these errors. The complexity associated with the error-handling modes of a logic controller is considerable. Logic controllers also interface with the safety system in a plant. For example, when a safety gate is open, certain operations are prohibited, but others may be necessary for troubleshooting.

The operator interacts with the logic controller through an HMI (human-machine interface). There are often buttons to push (either manually or via a touchscreen), to start or stop the system as a whole, or to step through a manual mode of operation. The manual mode is useful for debugging, when the operator wants the system to go one step at a time, instead of automatically. In the manual mode, the operator must push a button for each operation to occur – in effect, it adds an additional "and" condition to each logical statement.

2 LANGUAGES FOR LOGIC CONTROL

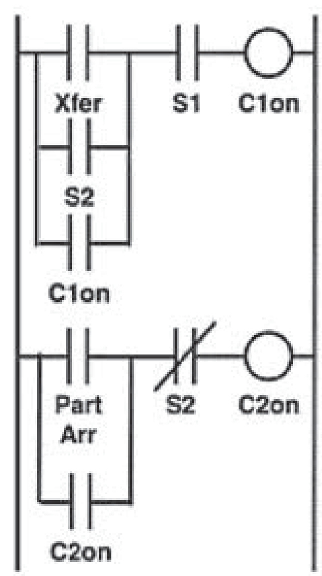
Logic controllers can be written in many different languages. Most logic controllers implemented on PLCs are written in one of the standard languages from the IEC (International Electrotechnical Commission). More formal languages for logic controllers have also been considered to enable verification of certain logical properties.

2.1 INDUSTRY STANDARDS: IEC 61131 AND 61499

The IEC 61131-3 standard brings together the most common programming languages into a single standard, and defines data types, variables, and how programs are written and executed on PLCs [1]. In the US, Ladder Diagram (also called Ladder Logic) is a popular logic control language. This language is based on the previous practice of hard-wiring the logic to control manufacturing systems using electro-mechanical relays. It can be understood by electricians, and if an output is not enabled, it is very easy to find the correct rung in the ladder and see which inputs are prohibiting the output. For example, in Figure 2, Output C1 is on if either Xfer or S2 are true, and S1 is true. Note that after C1 turns on, it is 'latched' so that Xfer and S2 can turn off, and C1 remains on (S1 must remain on).

The other four programming languages are also widely used. SFC (Sequential Function Chart) is similar to a flow chart, with steps that define

FIGURE 2: Ladder Logic



the actions and transitions that define decision points. It is based on Petri nets which will be discussed below. Structured Text is a textual language, using if-then-else rules to encode logic. Instruction List is a low-level textual language, similar to assembly language. Function Block Diagram (FBD) encapsulates the logic in a function block, with well-defined inputs and outputs.

Many PLC programming environments support more than one language, and even mixing of multiple languages in one program. For example, any of the other languages can be encapsulated in a function block.

The distributed control standard IEC 61499 is based on function blocks [2]. Each function block has two types of inputs (events and data), an execution control chart (ECC), and a set of algorithms written in one of the 61131 languages. Input events can trigger a change of state of the ECC, execution of one or more of the algorithms, and generation of output events and/or data. Function blocks can be combined by connecting the outputs of one to the input of another in a network arrangement.

2.2 FORMAL METHODS

In recent years, many academic groups have considered the problem of developing logic controllers that can be verified as correct, according to some specification. The formalism of Discrete Event Systems (DES) is used, in which the system evolution is defined according to the occurrence of instantaneous discrete events. Examples of such events include the push of a button by the operator, the tripping of a limit switch, or the turning on of a machine. These events occur at discrete moments in time, instead of over some time interval, and can either be inputs or outputs. Sometimes the events are classified as controllable or uncontrollable, where actuators are controllable and disturbances and sensors are uncontrollable (from the point of view of the control designer).

The most general way to describe a

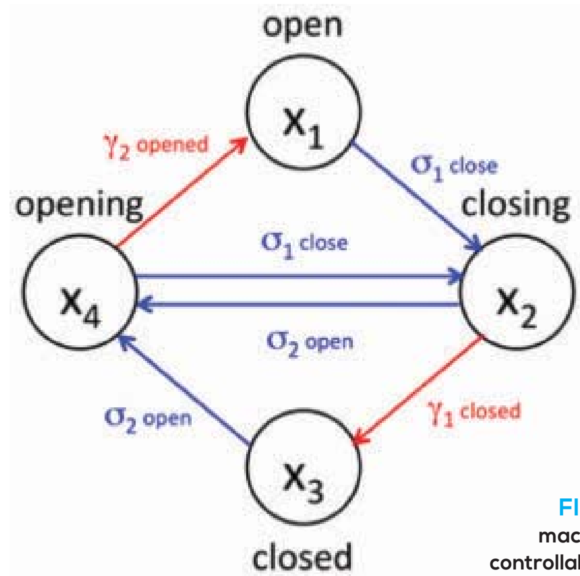


FIGURE 3: A simple finite state machine with 4 states (in black), 2 controllable events (blue) representing outputs and 2 uncontrollable events (red) representing inputs.

discrete event system is through its *language*, which is the set of strings (ordered sets of events) that the system can generate. Although general, languages are typically made up of infinite sets and can be difficult to work with. The two most commonly used DES approaches for logic control development are Finite State Machines (FSM) and Petri nets.

A finite state machine is a quintuple, $S = \{X, \Sigma, \alpha, x_0, X_m\}$ where X is a finite set of discrete states, Σ is the set of discrete events, $\alpha: X \times \Sigma \rightarrow X$ is the transition function. $\alpha(x_1,\sigma_1)=x_2$ indicates that if the system is in state x_1 and event σ_1 occurs, then the system will transition to state x_2. Note that the transition function is rarely complete: not every event can occur in every state of the system. x_o is the initial state of the system, and X_m is a set of marked states. A simple finite state machine representing a clamp is shown in Figure 3. The states $X=\{x_1,x_2,x_3,x_4\}$ are shown in black, and indicate whether the clamp is open, closing, closed, or opening. The events σ_1,σ_2 in blue are used to command the clamp to close or open, and the events γ_1,γ_2 in red represent limit switches that indicate whether the clamp has closed or opened completely. The transition function α is indicated in Table 1.

TABLE 1: The state transition function α for the finite state machine in Figure 3.

α	σ_1	σ_2	γ_1	γ_2
x_1	x_2	—	—	—
x_2	—	x_4	x_3	—
x_3	—	x_4	—	—
x_4	x_2	—	—	x_1

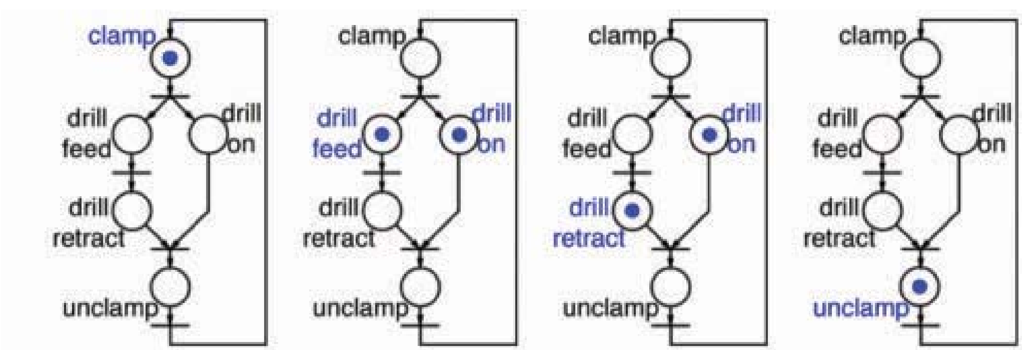
At a low level, finite state machines are relatively simple and easy to understand, as shown above. Multiple FSM can be combined through parallel composition. The combined set of states is the cross-product of the states in each individual FSM, and the set of events is the union of the sets of events. Taking the combination of three FSM each with 4 states and 4 events leads to a new FSM with $4^3=64$ states and 12 events. This exponential increase in the number of states leads to the "state explosion" property for large systems. Techniques have been developed to reduce the number of states, but in general, large combined systems can quickly become unwieldy.

A Petri net is represented as a bipartate graph, with two types of nodes: *places* (circles) and *transitions* (bars). Nodes are connected by arcs, which can have weights (in ordinary Petri nets, all of the weights are equal to one). The *marking* of a Petri net assigns a non-negative integer to each place, indicated by a number of tokens (dots) shown in the circle. A transition leaving a place is *enabled* if there are at least as many tokens in the place as the weighting of the arc. When the transition *fires*, the number of tokens indicated by the weight are removed from the input place and added to the output place.

A firing sequence of an ordinary Petri net is shown in Figure 4. Here, the places model operations, with the active operation indicated by a token. Transitions model events, which transition the system from one operation state to another. Note that this Petri net exhibits both concurrency (with two operations happening simultaneously) and synchronization (since unclamp will not start until both drill on and drill retract have finished).

Petri nets can be used as analysis tools for event-based systems that are concurrent, synchronized and distributed. They can be used to verify three key properties of a discrete-event system: Liveness (avoidance of deadlock), safeness (no request of ongoing operations), and reversibility (ability to return to the initial state). Safe Petri nets can be directly translated into SFC, one of the IEC 61131-3 languages for logic control, as discussed in Section 2.1.

FIGURE 4: Evolution of a simple Petri net



3 DEVELOPING LOGIC CONTROLLERS

A logic control programmer typically starts from the mechanical definition of the system and the tasks that must be performed. In current industry practice, it is uncommon for a formal specification (written in a mathematical language) to be used. Many logic control programmers have only a high-school degree plus significant on-the-job experience [3]. Much of the programming work that is done is based on experience, and most programs are based on a previously-written program for a similar system. Some proprietary company standards exist from which pre-defined logic blocks can be put together to create a logic program.

3.1 SUPERVISORY CONTROL THEORY

Supervisory control theory is a formal method based on finite state machines that can be used for control [4, 5]. The events in an FSM are divided into controllable and uncontrollable events. The key idea is that the controller *disables* controllable events that could lead the system into an undesirable state (uncontrollable events cannot be disabled). Techniques exist to design supervisors that are optimal in the sense that they are maximally permissive – they do not unnecessarily restrict the behavior of the system while guaranteeing that it does not enter any undesirable states.

The application of supervisory control theory requires a detailed behavior-based model of the manufacturing system, as well as a formal model of the desired behavior (expressed as an FSM), which typically does not exist in current practice. Creating such models can be time-consuming, and require significant effort. In addition, since the supervisory control theory only disables events, it is not directly adapted to implementable logic control that must send commands to turn on motors, etc. Additional constructs such as forced events have been added to apply supervisory control theory to logic control for manufacturing systems.

Computational complexity also becomes an issue with large-scale systems. If sufficient formal models exist for a manufacturing system, modular and hierarchical approaches can be applied to develop supervisors that satisfy the specification and are guaranteed to be correct by construction. In one approach, the global system is decomposed into modules and interfaces are introduced between the modules to restrict interaction. These interfaces allow global properties to be verified by local analysis – each module only needs to be composed with its neighbor [6].

Andersson et al. use supervisory control theory to develop cell-level controllers [7]. To avoid the state explosion problem, they use a hierarchical approach, where the interactions between components are specified by the *coordination of operations*, and the low-level control (within a component) is specified by the *execution of operation*. Supervisory control theory is applied to define a supervisor over the coordination of operations, and after this has been accomplished, an extraction algorithm is applied to result in an easy-to-read control format that can be implemented on a PLC. The method has been applied to a manufacturing cell at Volvo in Sweden.

3.2 MODULAR FINITE STATE MACHINES

Modular finite state machines (MFSMs) are a low-level logic control language built on the concept of FSM [8]. In contrast to standard FSMs, which are just defined by a set of events, each module of an MFSM has a set of input events and output events, called *triggers* and *responses*. Triggers come from the environment, cause a change in state, and then responses are sent. The responses can go to another module (becoming a trigger), causing another state change and response, and so on, until the final responses are sent to the environment. With the modular nature, the logic can execute across several modules, and a single trigger can generate multiple responses.

MFSMs were designed to be verifiable from an input-output point of view. They rely on the idea of *assume-guarantee*. Each connection point of an MFSM has a set of trigger and response events, and a specific language that it generates. If the logic within the module is consistent with all of the interfaces, then the composed system can be verified in a modular fashion, avoiding the state-explosion property.

A sample of a single MFSM module is shown in Figure 5. The module starts in the initial state (Idle), indicated by the bold oval. The only trigger that is defined to occur in this state is rise (signifying a button press that causes a voltage to increase), coming from interface U.1. When this trigger event occurs, the MFSM transitions to the Working state, and the start response is sent out through the interface U.2. There are two different ways that the MFSM can transition back to Idle — either the binary signal on U.1 can fall (in which case a stop response is issued through U.2), or a done trigger can be received through U.2.

MFSMs can also be written in an Event-Condition-Action (ECA) formalism [9], inspired by work in active databases. All of the triggers from the environment come into a Main module, which has only one persistent state (Idle). Peripheral modules keep track of the state of the system. Depending on the trigger and the current state, responses are generated to the environment and the internal state is updated. A simple ECA-MFSM is shown in Figure 6. The environment consists of the button, the light, and the robot. When the button is pressed (2.rise), the logic checks the state of the robot. If the robot is already working, nothing happens. If the state of the robot is currently idle, the light is turned on and the robot is commanded to start. When the robot signals that it is finished (4.done), then the button is turned off and the robot state is updated to indicate it is now idle. The logic control tracking the state of the physical system is quite common (here, the logic tracks the state of the robot, idle or working), and can add significantly to the complexity of the logic control.

3.3 MODEL-BASED DESIGN

Henry et al. have developed a method to design logic controllers for automated manufacturing systems using the concept of operations [10]. This approach requires a detailed formal model of the system to be controlled, expressed in a formal language. Operations have conditions, effects, and constraints, and have associated resources and products. For example, an operation might consist of extending a

FIGURE 5: A single module of an MFSM, with two interconnections – one to the environment (a binary signal that can rise or fall) and the other to another module.

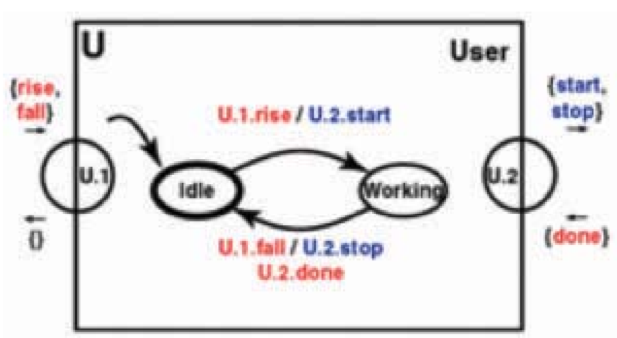
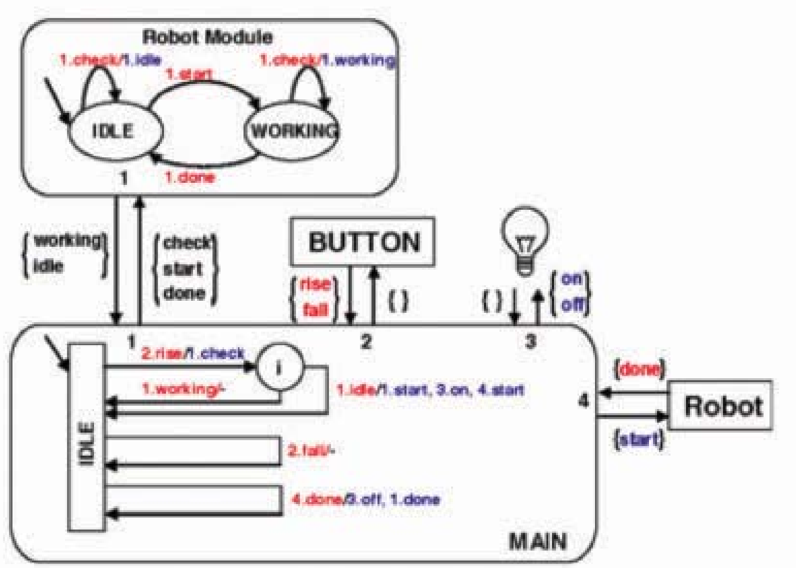


FIGURE 6: A simple logic controller written as an ECA-MFSM



cylinder, using the resource of the cylinder and a product that is moved from one location to another through the action of extension. A very detailed model of this operation is used to capture all of the conditions and constraints that must be satisfied for it to occur. However, once all of these models are available, a controller can be constructed by concatenating these operations using a graph search.

Valente et al. have proposed a holistic approach to logic control design, starting with an analysis of the production system and policies at a conceptual level [11]. A model is developed for each module of the system, including its interaction with other modules, as well as its capability for reconfiguration, using finite state machines. These models are then translated into executable control code, and evaluated for robustness through hardware-in-the-loop and software-in-the-loop simulation. The approach has been applied to a shoe manufacturing process in Italy.

4 VALIDATION AND TESTING OF LOGIC CONTROLLERS

As discussed above, some methods for developing logic controllers can be formally verified. Some approaches can check the code for internal correctness. If a model of the system and environment is available, the performance of the controller when connected to the environment can be verified. Since formal models are not always available, extensive testing of the controller is often required. Re-use of existing code from previous projects can reduce the amount of testing required.

4.1 ANOMALY DETECTION

Even well-written logic controllers often have some bugs, and detecting these can be challenging, especially when the bugs are intermittent and do not trigger a fault, but rather just cause incorrect behavior. We developed a method for detecting these *anomalies* – out-of-the-ordinary behavior of a logic controller that doesn't cause a fault [12]. A high-level view is shown in Figure 7. Our method requires observing the entire stream of events (inputs and outputs) coming through a system, and uses this event stream to build a model.

The key idea is that the anomaly detection system does not interfere with the normal operation of the plant. It only observes events that are sent between controllers, sensors, and actuators. It uses these streams of events to automatically build Petri net models of the synchronous system operation. The only information that is required to build these models is information about what are the shared resources in the system (and their capacities), and which events acquire and release these shared resources. From this information, and two sets of event streams that are labeled as normal and anomalous, the method automatically builds a set of Petri net models that capture the system operation. Since it may be impossible to know exactly the plant model just from the observed behavior, we use a set of models that capture some aspects of the behavior. Based on how well a new stream of data can be accepted by this set of Petri net models, it is classified as either normal or anomalous.

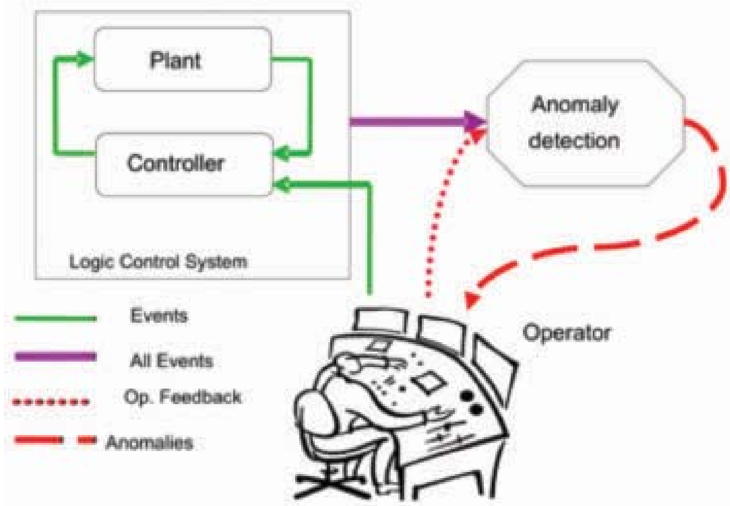


FIGURE 7: Detecting anomalies through observation of event streams

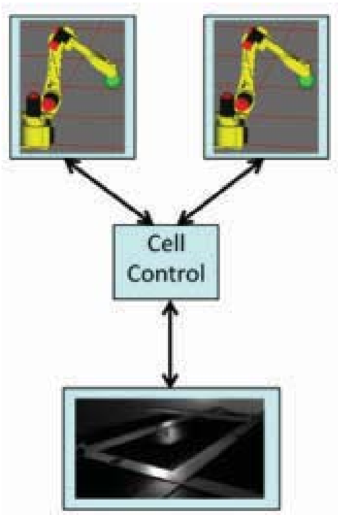
The method was applied to manufacturing process at an engine manufacturer [13]. In a system with two gantries feeding six machine tools, occasionally one of the gantries picked up a new part, at least one machine was available to process it, but the gantry waited for an unknown reason. Eventually the part was delivered to a machine, but

TESTBED: RFT

MUCH OF THE RESEARCH DESCRIBED IN THIS ARTICLE has been inspired by and implemented on the Reconfigurable Factory Testbed (RFT). This testbed was constructed as part of the Engineering Research Center for Reconfigurable Manufacturing Systems at the University of Michigan, and has been extended and expanded over the years as the research evolved.

The current testbed includes three industrial-scale robots (two Fanuc and one ABB) and four Denford CNC milling machines, connected by a conveyor system [16, 17]. Parts go through the system on pallets, are read by RFID tags, and are put into and out of the machines by the robots. The robots can also do some assembly (pick and place).

Figure 10 shows a schematic of the testbed. Recently, in a partnership with Rockwell Automation, the existing physical testbed has been retrofitted with a single network (Ethernet I/P) replacing a plethora of networks (DeviceNet, Profibus, Bluetooth, WISA, etc.), and a single system-level controller and HMI (ControlLogix) replacing a hierarchy of several research-grade cell- and system-level controllers. ■



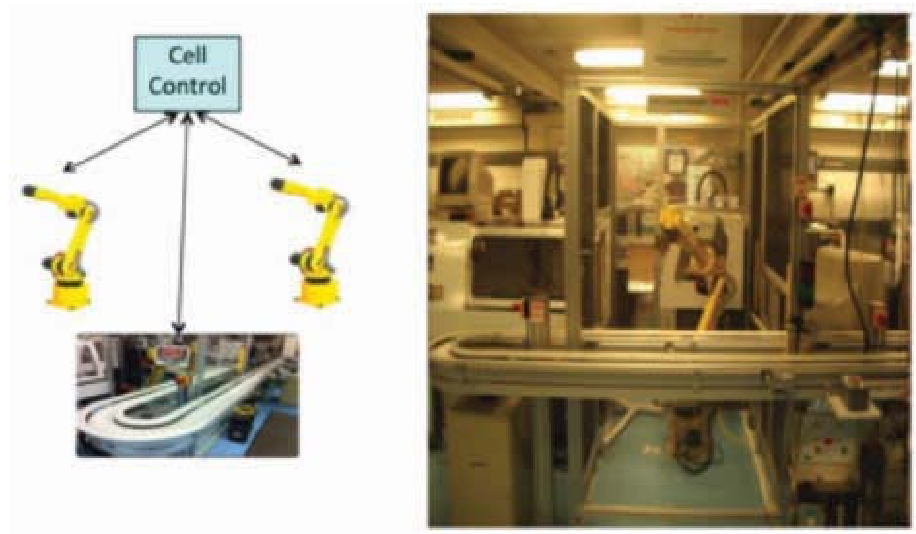


FIGURE 8: (Left) Schematic of a hardwired simulation, where the robot simulations are supplied by the vendor (Fanuc), the conveyor simulation is built using an open-source software, and the controllers and networks are in their final, physical form.

FIGURE 9: (Right) The physical system, with two Fanuc robots and a conveyor, and a Cell Controller.

productivity was being lost. We used data recorded from almost 1000 parts, including more than 40,000 messages from the six PLCs (each with up to 40 words of data). From these raw PLC logs, events were extracted for each gantry and events were extracted for each gantry and CNC to build the formal models. The anomaly detection system was able to identify the specific sequence of events that led to the lost production, enabling the PLC programs to be revised to eliminate this condition.

4.2 HYBRID PROCESS SIMULATION

To facilitate product launch with shorter times and lower costs, We have developed the concept of *hybrid process simulation (HPS)* [14]. HPS is a formalized methodology for applying the Hardware in the Loop (HIL) approach with multiple real and simulated components. HIL combines simulated and actual machines, leveraging the strengths of simulation (for well-known processes) while also reducing the drawbacks that come from potentially large inaccuracies in simulation models (for less-well known processes). Simulation enables better decision making in planning and more accurate performance analysis in the early development stages. System and component simulation models, however, do not always exist, and even with a model, a highly complex control system cannot be fully validated until it is tested against the actual system.

Integration of simulation is more accurate, since it includes the same components that will be used in the final process. Testing with real components makes inaccurate and unavailable models less of an issue and reduces process setup time, thereby reducing the overall cost of deployment. The HPS approach starts with a pure simulation model, and then progresses to a "hard-wired" simulation model – in which all of the machines, robots, material handling devices are simulated, but all of the controllers, networks, and databases are real. See Figure 8. The physical parts of the system are then replaced one at a time, allowing for incremental validation of the cell controllers and system-wide performance, until the entire system is realized in its final, physical form, as shown in Figure 9.

5 CONCLUSIONS AND FUTURE DIRECTIONS

There remains a lot of opportunity for research in the area of reconfigurable logic control for manufacturing systems. Many logic programs are still written as they were decades ago; progress is slow in this area. Although manufacturing is a high-volume enterprise, the manufacturing systems themselves are low-volume — a large company

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Dawn M. Tilbury received the B.S. degree in Electrical Engineering from the University of Minnesota in 1989, and the M.S. and Ph.D. degrees in Electrical Engineering and Computer Sciences from the University of California, Berkeley, in 1992 and 1994, respectively. In 1995, she joined the Mechanical Engineering Department at the University of Michigan, Ann Arbor, where she is currently Professor, with a joint appointment as Professor of EECS, and is currently the Associate Dean for Research in the College of Engineering. Her research interests include distributed control of mechanical systems with network communication, logic control of manufacturing systems, reliability of ground robotics, and dynamic systems modeling of physiological systems. She was elected Fellow of the IEEE in 2008 and Fellow of the ASME in 2012, and is a Life Member of SWE.

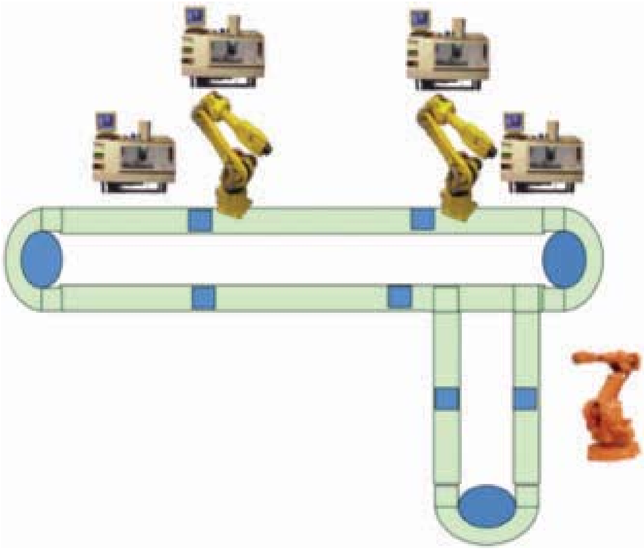

FIGURE 10: Testbed at University of Michigan, including robots, machines, conveyor.

may only build or reconfigure a handful of plants in any given year, and systems can run continuously for a decade or longer. Thus, the legacy issues are significant, and can be a barrier to large-scale changes.

On the other hand, the rapid advancement of computing and networking technologies is enabling more data to be gathered, stored, and analyzed. It is possible for all of the machines in a manufacturing plant to be connected to the Internet of Things (IoT) [15], with their production data stored either in a local database or in a cloud system. This opens up new avenues for on-line decision making based on real-time data coming from the system. However, it also introduces significant cybersecurity challenges that will need to be addressed for successful deployment. Traditionally, security in a manufacturing plant was handled through physical separation and access gates with badge identification. Connecting the manufacturing plant to the internet results in multiple opportunities for improving performance through better data analytics, as well as myriad challenges for safety, security and privacy. ■

ACKNOWLEDGMENTS

I was introduced to the challenging problems in logic control for large-scale manufacturing systems through the NSF Engineering Research Center for Reconfigurable Manufacturing Systems, directed by Prof. Yoram Koren, and co-directed by Prof. Galip Ulsoy. Thanks are due to the many students who worked on these research problems with me over the years, including Lindsay Allen, Emanuel Almeida, Eric Endsley, William Harrison, Rick Hill, Seungjoo Lee, Mory Lucas, and Euisu Park. We had excellent relationships with our industry partners at Ford, GM, Lamb Technicon, Rockwell, Siemens, and many others.

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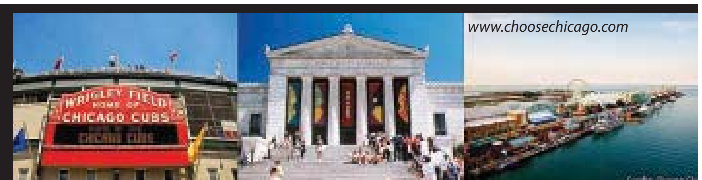

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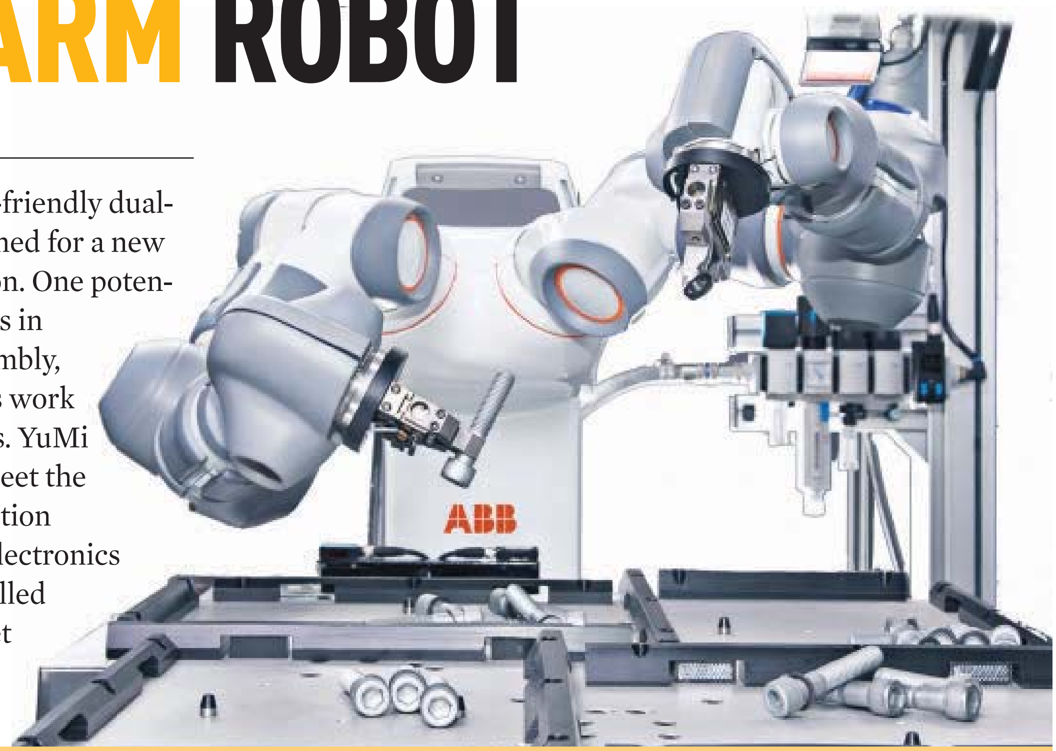

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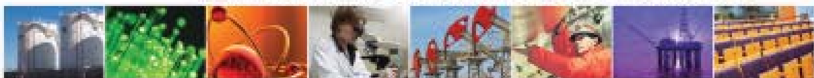

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PD583	Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance **ASME CODE COURSE**	2-3 Mar
PD190	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications **ASME CODE COURSE**	2-4 Mar
PD268	Fracture Mechanics Approach to Life Predictions	2-4 Mar
PD349	Design and Applications of Centrifugal Pumps	2-4 Mar
PD370	B31.8 Gas Transmission and Distribution Piping Systems **ASME CODE COURSE**	2-4 Mar
PD683	Probabilistic Structural Analysis, Design and Reliability-Risk Assessment	2-4 Mar
PD394	Seismic Design and Retrofit of Equipment and Piping	2-5 Mar
PD603	Geometric Dimensioning and Tolerancing Combo Course **SAVE UP TO $380!**	2-5 Mar
PD657	HVAC Systems and Chiller Performance Combo Course **SAVE UP TO $475!**	2-5 Mar
PD013	B31.1 Power Piping Code **ASME CODE COURSE**	2-6 Mar
PD432	Turbo Machinery Dynamics: Design and Operation	2-6 Mar
PD027	Heating, Ventilating and Air-Conditioning Systems: Sizing and Design	3-5 Mar
PD561	Geometric Tolerancing Advanced Applications with Stacks and Analysis **Top Seller**	4-5 Mar
PD606	NQA-1 Requirements for Computer Software Used in Nuclear Facilities **ASME CODE COURSE**	5-6 Mar
PD706	Inline Inspections for Pipelines **NEW!**	5-6 Mar

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MARCH 2015 – LAS VEGAS, NEVADA USA

PD475	The New Engineering Manager: Moving from Technical Professional to Manager	16-17 Mar
PD531	Leadership and Organizational Management	16-17 Mar
PD539	Bolted Joints and Gasket Behavior	16-17 Mar
PD077	Failure Prevention, Repair and Life Extension of Piping, Vessels and Tanks ASME CODE COURSE	16-18 Mar
PD395	API 579-1/ASME FFS-1 Fitness-for-Service	16-18 Mar
PD618	Root Cause Analysis Fundamentals	16-18 Mar
PD633	Overview of Nuclear Codes and Standards for Nuclear Power Plants ASME CODE COURSE	16-18 Mar
PD685	The New Engineering Manager: Moving from Technical Professional to Manager and Strategic Thinking Combo Course SAVE UP TO $465!	16-18 Mar
PD702	Process Safety and Risk Management for Mechanical Engineers NEW!	16-18 Mar
PD720	Layout of Process Piping Systems NEW!	16-18 Mar
PD014	ASME B31.3 Process Piping Design ASME CODE COURSE Top Seller	16-19 Mar
PD184	BPV Code, Section III, Division 1: Rules for Construction of Nuclear Facility Components ASME CODE COURSE	16-19 Mar
PD632	Design in Codes, Standards and Regulations for Nuclear Power Plant Construction ASME CODE COURSE	16-19 Mar
PD192	BPV Code, Section XI: Inservice Inspection of Nuclear Power Plant Components ASME CODE COURSE	16-20 Mar
PD581	B31.3 Process Piping Design, Materials, Fabrication, Examination and Testing Combo Course ASME CODE COURSE SAVE UP TO $575!	16-20 Mar
PD601	Bolting Combo Course SAVE UP TO $1,260!	16-20 Mar
PD686	Layout of Process Piping Systems and Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems Combo Course NEW! SAVE UP TO $635!	16-20 Mar
PD386	Design of Bolted Flange Joints	18 Mar
PD676	Strategic Thinking	18 Mar
PD631	Manufacturing, Fabrication and Examination Responsibilities in Codes,Standards and Regulations for Nuclear Power Plant Construction ASME CODE COURSE	18-20 Mar
PD115	The Gas Turbine: Principles and Applications	19-20 Mar
PD575	Comprehensive Negotiating Strategies®: Engineers and Technical Professionals	19-20 Mar
PD577	Bolted Joint Assembly Principles Per PCC-1-2013 ASME CODE COURSE	19-20 Mar
PD591	Developing Conflict Resolution Best Practices	19-20 Mar
PD634	Comparison of Global Quality Assurance and Management System Standards Used for Nuclear Application ASME CODE COURSE	19-20 Mar
PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems NEW!	19-20 Mar
PD457	B31.3 Process Piping Materials Fabrication, Examination and Testing ASME CODE COURSE Top Seller	20 Mar

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MARCH 2015 – COPENHAGEN, DENMARK

PD391	ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME CODE COURSE	23-24 Mar
PD634	Comparison of Global Quality Assurance and Management System Standards Used for Nuclear Application ASME CODE COURSE	23-24 Mar
PD146	Flow Induced Vibration with Applications to Failure Analysis	23-25 Mar
PD389	Nondestructive Examination - Applying ASME Code Requirements (BPV Code, Section V) ASME CODE COURSE	23-25 Mar
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME CODE COURSE Top Seller	23-25 Mar
PD645	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME CODE COURSE	23-25 Mar
PD616	API 579 /ASME FFS-1 Fitness-for-Service Evaluation	23-26 Mar
PD642	ASME B31.1 Power Piping Code ASME CODE COURSE	23-26 Mar
PD679	Selection of Pumps and Valves for Optimum System Performance NEW!	23-26 Mar

CONTINUED, MARCH 2015 – COPENHAGEN, DENMARK

PD716	BPV Code, Section 1: Power Boilers ASME CODE COURSE	23-26 Mar
PD443	BPV Code, Section VIII, Division 1 Combo Course ASME CODE COURSE SAVE UP TO €800!	23-27 Mar
PD635	ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications ASME CODE COURSE	25-27 Mar
PD441	Inspections, Repairs and Alterations of Pressure Equipment ASME CODE COURSE Top Seller	26-27 Mar

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MARCH-APRIL 2015 – ORLANDO, FLORIDA USA

PD100	Introduction to Elevators and Escalators	30-31 Mar
PD313	Fundamentals of Fastening Systems	30-31 Mar
PD456	Tools and Methods of Finite Element Analysis	30-31 Mar
PD389	Nondestructive Examination - Applying ASME Code Requirements (BPV Code, Section V) ASME CODE COURSE	30 Mar - 1 Apr
PD506	Research and Development Management	30 Mar - 1 Apr
PD515	Dimensioning and Tolerancing Principles for Gages and Fixtures	30 Mar - 1 Apr
PD619	Risk and Reliability Strategies for Optimizing Performance	30 Mar - 1 Apr
PD359	Practical Welding Technology	30 Mar - 2 Apr
PD675	ASME NQA-1 Lead Auditor Training	30 Mar - 2 Apr
PD679	Selection of Pumps and Valves for Optimum System Performance NEW!	30 Mar - 2 Apr
PD602	Elevator and Escalator Combo Course	30 Mar - 3 Apr
PD665	BPV Code, Section I: Power Boilers ASME CODE COURSE	30 Mar - 3 Apr
PD449	Mechanical Tolerancing for Six Sigma	1-2 Apr
PD102	ASME A17.1 Safety Code and ASME A17.2 Inspection Requirements ASME CODE COURSE	1-3 Apr

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APRIL 2015 – SACRAMENTO, CALIFORNIA USA

PD391	ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME CODE COURSE	13-14 Apr
PD570	Geometric Dimensioning and Tolerancing Fundamentals 1 ASME CODE COURSE Top Seller	13-14 Apr
PD624	Two-Phase Flow and Heat Transfer	13-14 Apr
PD146	Flow Induced Vibration with Applications to Failure Analysis	13-15 Apr
PD190	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME CODE COURSE	13-15 Apr
PD231	Shock and Vibration Analysis	13-15 Apr
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME CODE COURSE Top Seller	13-15 Apr
PD467	Project Management for Engineers & Technical Professionals	13-15 Apr
PD506	Research and Development Management	13-15 Apr
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME CODE COURSE	13-15 Apr
PD720	Layout of Process Piping Systems NEW!	13-15 Apr
PD603	Geometric Dimensioning and Tolerancing Combo Course SAVE UP TO $380!	13-16 Apr
PD620	Core Engineering Management	13-16 Apr
PD691	Fluid Mechanics, Piping Design, Fluid Transients & Dynamics	13-16 Apr
PD013	B31.1 Power Piping Code ASME CODE COURSE	13-17 Apr
PD443	BPV Code, Section VIII, Division 1 Combo Course ASME CODE COURSE SAVE UP TO $645	13-17 Apr
PD629	Project Management Combo Course SAVE UP TO $635!	13-17 Apr
PD686	Layout of Process Piping Systems and Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems Combo Course NEW! SAVE UP TO $635!	13-17 Apr
PD561	Geometric Tolerancing Advanced Applications with Stacks and Analysis Top Seller	15-16 Apr
PD596	Developing a 10-Year Valve Inservice Testing Program	15-17 Apr
PD441	Inspections, Repairs and Alterations of Pressure Equipment ASME CODE COURSE Top Seller	16-17 Apr
PD496	Preparing for the Project Management Professional Certification Exam	16-17 Apr
PD706	Inline Inspections for Pipelines NEW!	16-17 Apr
PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems NEW!	16-17 Apr

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APRIL 2015 – CHICAGO, ILLINOIS USA

PD107	Elevator Maintenance Evaluation	20-21 Apr
PD539	Bolted Joints and Gasket Behavior	20-21 Apr
PD583	Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance **ASME CODE COURSE**	20-21 Apr
PD077	Failure Prevention, Repair and Life Extension of Piping, Vessels and Tanks **ASME CODE COURSE**	20-22 Apr
PD349	Design and Applications of Centrifugal Pumps	20-22 Apr
PD395	API 579-1/ASME FFS-1 Fitness-for-Service	20-22 Apr
PD618	Root Cause Analysis Fundamentals	20-22 Apr
PD674	International Business Ethics & Foreign Corrupt Practices Act	20-22 Apr
PD702	Process Safety and Risk Management for Mechanical Engineers **NEW!**	20-22 Apr
PD711	ASME NQA-1 and DOE Quality Assurance Rule 10 CFR 830 **ASME CODE COURSE** **NEW!**	20-22 Apr
PD014	ASME B31.3 Process Piping Design **ASME CODE COURSE** **Top Seller**	20-23 Apr
PD394	Seismic Design and Retrofit of Equipment and Piping	20-23 Apr
PD448	BPV Code, Section VIII, Division 2: Alternative Rules - Design and Fabrication of Pressure Vessels **ASME CODE COURSE** **Top Seller**	20-23 Apr
PD622	BPV Code: Plant Equipment Requirements **ASME CODE COURSE**	20-23 Apr
PD581	B31.3 Process Piping Design, Materials, Fabrication, Examination and Testing Combo Course **ASME CODE COURSE** **SAVE UP TO $575!**	20-24 Apr
PD601	Bolting Combo Course **SAVE UP TO $1,260!**	20-24 Apr
PD681	International Business Ethics and Foreign Corrupt Practices Act Combo Course **SAVE UP TO $635!**	20-24 Apr
PD386	Design of Bolted Flange Joints	22 Apr
PD410	Detail Engineering of Piping Systems	22-24 Apr
PD631	Manufacturing, Fabrication and Examination Responsibilities in Codes, Standards and Regulations for Nuclear Power Plant Construction **ASME CODE COURSE**	22-24 Apr
PD575	Comprehensive Negotiating Strategies®: Engineers and Technical Professionals	23-24 Apr
PD577	Bolted Joint Assembly Principles Per PCC-1-2013 **ASME CODE COURSE**	23-24 Apr
PD606	NQA-1 Requirements for Computer Software Used in Nuclear Facilities **ASME CODE COURSE**	23-24 Apr
PD680	Understanding the Foreign Corrupt Practices Act	23-24 Apr
PD690	Economics of Pipe Sizing and Pump Selection **NEW!**	23-24 Apr
PD692	Communication Essentials for Engineers **NEW!**	23-24 Apr
PD457	B31.3 Process Piping Materials Fabrication, Examination and Testing **ASME CODE COURSE** **Top Seller**	24 Apr

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APRIL-MAY 2015 – COLORADO SPRINGS, COLORADO USA

MasterClass Program at ASME Boiler Code Week

MC104	Bases and Application of Heat Exchanger Mechanical Design Rules in Section VIII of the ASME Boiler and Pressure Vessel Code	26-27 Apr
MC110	Bases and Application of Piping Flexibility Analysis to ASME B31 Codes	27-28 Apr
MC107	Design by Analysis Requirements in ASME Boiler and Pressure Vessel Code Section VIII, Division 2 – Alternative Rules	28 Apr
MC113	Techniques and Methods Used in API 579-1/ASME FFS-1 for Advanced Fitness-For-Service (FFS) Assessments	29 Apr
MC111	Piping Vibration Causes and Remedies - A Practical Approach	29-30 Apr
MC114	Repair Strategies and Considerations for Pressure Vessels and Piping	30 Apr
MC117	Piping Failures - Causes and Prevention	1 May

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MAY 2015 – LAS VEGAS, NEVADA USA

PD100	Introduction to Elevators and Escalators	4-5 May
PD313	Fundamentals of Fastening Systems	4-5 May
PD456	Tools and Methods of Finite Element Analysis	4-5 May
PD370	B31.8 Gas Transmission and Distribution Piping Systems **ASME CODE COURSE**	4-6 May
PD389	Nondestructive Examination - Applying ASME Code Requirements (BPV Code, Section V) **ASME CODE COURSE**	4-6 May
PD513	TRIZ: The Theory of Inventive Problem Solving	4-6 May
PD515	Dimensioning and Tolerancing Principles for Gages and Fixtures	4-6 May
PD571	The Taguchi Design of Experiments for Robust Product and Process Designs	4-6 May
PD621	Grade 91 and Other Creep Strength Enhanced Ferritic Steels	4-6 May
PD683	Probabilistic Structural Analysis, Design and Reliability-Risk Assessment	4-6 May
PD632	Design in Codes, Standards and Regulations for Nuclear Power Plant Construction **ASME CODE COURSE**	4-7 May
PD644	Advanced Design and Construction of Nuclear Facility Components Per BPV Code, Section III **ASME CODE COURSE**	4-7 May
PD675	ASME NQA-1 Lead Auditor Training	4-7 May
PD679	Selection of Pumps and Valves for Optimum System Performance **NEW!**	4-7 May
PD432	Turbo Machinery Dynamics: Design and Operation	4-8 May
PD598	Developing a New Inservice Testing Program	4-8 May
PD602	Elevator and Escalator Combo Course **SAVE UP TO $635!**	4-8 May
PD665	BPV Code, Section I: Power Boilers **ASME CODE COURSE**	4-8 May
PD102	ASME A17.1 Safety Code and ASME A17.2 Inspection Requirements **ASME CODE COURSE**	6-8 May
PD584	Centrifugal Compressor Performance Analysis	6-8 May
PD619	Risk and Reliability Strategies for Optimizing Performance	6-8 May
PD445	B31 Piping Fabrication and Examination **ASME CODE COURSE**	7-8 May
PD567	Design, Analysis and Fabrication of Composite Structure, Energy and Machine Applications	7-8 May

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MAY 2015 – DUBAI, UNITED ARAB EMIRATES

PD577	Bolted Joint Assembly Principles Per PCC-1-2013 **ASME CODE COURSE**	10-12 May
PD583	Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance **ASME CODE COURSE**	10-12 May
PD720	Layout of Process Piping Systems **NEW!**	10-12 May
PD645	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications **ASME CODE COURSE**	13-14 May
PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems **NEW!**	10-13 May
PD643	B31.3 Process Piping Code **ASME CODE COURSE** **Top Seller!**	10-14 May
PD686	Layout of Process Piping Systems and Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems Combo Course **NEW!**	10-14 May
PD725	BPV Code, Section VIII, Division 1: Design and Fabrication with Inspections, Repairs and Alterations of Pressure Vessels **ASME CODE COURSE**	10-14 May

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MAY 2015 – ATLANTA, GEORGIA USA

PD387	Understanding Chiller Performance, Operation and Economics	18 May
PD475	The New Engineering Manager: Moving from Technical Professional to Manager	18-19 May
PD531	Leadership and Organizational Management	18-19 May
PD673	Design and Selection of Heat Exchangers	18-19 May
PD146	Flow Induced Vibration with Applications to Failure Analysis	18-20 May
PD190	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME CODE COURSE	18-20 May
PD231	Shock and Vibration Analysis	18-20 May
PD395	API 579-1/ASME FFS-1 Fitness-for-Service	18-20 May
PD410	Detail Engineering of Piping Systems	18-20 May
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME CODE COURSE Top Seller	18-20 May
PD523	Quality Assurance (QA) Considerations for New Nuclear Facility Construction ASME CODE COURSE	18-20 May
PD633	Overview of Nuclear Codes and Standards for Nuclear Power Plants ASME CODE COURSE	18-20 May
PD685	The New Engineering Manager: Moving from Technical Professional to Manager and Strategic Thinking Combo Course SAVE UP TO $465!	18-20 May
PD184	BPV Code, Section III, Division 1: Rules for Construction of Nuclear Facility Components ASME CODE COURSE	18-21 May
PD620	Core Engineering Management	18-21 May
PD657	HVAC Systems and Chiller Performance Combo Course SAVE UP TO $475!	18-21 May
PD672	BPV Code, Section XI, Division 1: Inservice Inspection 10-Year Program Updates for Nuclear Power Plant Components ASME CODE COURSE	18-21 May
PD443	BPV Code, Section VIII, Division 1 Combo Course ASME CODE COURSE SAVE UP TO $645!	18-22 May
PD027	Heating, Ventilating and Air-Conditioning Systems: Sizing and Design	19-21 May
PD676	Strategic Thinking	20 May
PD690	Economics of Pipe Sizing and Pump Selection NEW!	20-21 May
PD441	Inspections, Repairs and Alterations of Pressure Equipment ASME CODE COURSE Top Seller	21-22 May
PD634	Comparison of Global Quality Assurance and Management System Standards Used for Nuclear Application ASME CODE COURSE	21-22 May

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MAY 2015 – LONDON, UNITED KINGDOM

PD445	B31 Piping Fabrication and Examination ASME CODE COURSE	18-19 May
PD577	Bolted Joint Assembly Principles Per PCC-1-2013 ASME CODE COURSE	18-19 May
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME CODE COURSE	18-20 May
PD714	BPV Code, Section VIII, Division 2: Pressure Vessels ASME CODE COURSE	18-20 May
PD643	B31.3 Process Piping Code ASME CODE COURSE Top Seller	18-21 May
PD675	ASME NQA-1 Lead Auditor Training	18-21 May
PD684	BPV Code Section III, Division 1: Rules for Construction of Nuclear Facility Components ASME CODE COURSE	18-22 May
PD621	Grade 91 and Other Creep Strength Enhanced Ferritic Steels	20-22 May

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JUNE 2015 – HOUSTON, TEXAS USA

PD391	ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME CODE COURSE	1-2 Jun
PD539	Bolted Joints and Gasket Behavior	1-2 Jun
PD570	Geometric Dimensioning and Tolerancing Fundamentals 1 ASME CODE COURSE Top Seller	1-2 Jun
PD583	Pressure Relief Devices: Design, Sizing, Construction, Inspection and Maintenance ASME CODE COURSE	1-2 Jun

CONTINUED, JUNE 2015 – HOUSTON, TEXAS USA

PD467	Project Management for Engineers & Technical Professionals	1-3 Jun
PD597	Risk-Informed Inservice Testing	1-3 Jun
PD711	ASME NQA-1 and DOE Quality Assurance Rule 10 CFR 830 ASME CODE COURSE NEW!	1-3 Jun
PD014	ASME B31.3 Process Piping Design ASME CODE COURSE Top Seller	1-4 Jun
PD359	Practical Welding Technology	1-4 Jun
PD448	BPV Code, Section VIII, Division 2: Alternative Rules - Design & Fabrication of Pressure Vessels ASME CODE COURSE Top Seller	1-4 Jun
PD603	Geometric Dimensioning and Tolerancing Combo Course Save Up To $380!	1-4 Jun
PD192	BPV Code: Section XI: Inservice Inspection of Nuclear Power Plant Components ASME CODE COURSE	1-5 Jun
PD581	B31.3 Process Piping Design, Materials, Fabrication, Examination and Testing Combo Course ASME CODE COURSE Save Up To $575!	1-5 Jun
PD601	Bolting Combo Course SAVE UP TO $1,260!	1-5 Jun
PD629	Project Management Combo Course SAVE UP TO $635!	1-5 Jun
PD386	Design of Bolted Flange Joints	3 Jun
PD496	Preparing for the Project Management Professional Certification Exam	3-4 Jun
PD561	Geometric Tolerancing Advanced Applications with Stacks and Analysis Top Seller	3-4 Jun
PD115	The Gas Turbine: Principles and Applications	4-5 Jun
PD577	Bolted Joint Assembly Principles Per PCC-1-2013 ASME CODE COURSE	4-5 Jun
PD593	FRP Pressure Piping Construction Process NOW 2 DAYS!	4-5 Jun
PD617	Design of Buried High Density Polyethylene (HDPE) Piping Systems	4-5 Jun
PD692	Communication Essentials for Engineers NEW!	4-5 Jun
PD457	B31.3 Process Piping Materials Fabrication, Examination and Testing ASME CODE COURSE Top Seller	5 Jun

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JUNE 2015 – MILAN, ITALY

PD577	Bolted Joint Assembly Principles Per PCC-1-2013 ASME CODE COURSE	22-23 Jun
PD410	Detail Engineering of Piping Systems	22-24 Jun
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME CODE COURSE Top Seller	22-24 Jun
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME CODE COURSE	22-24 Jun
PD635	ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications ASME CODE COURSE	22-24 Jun
PD645	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME CODE COURSE	22-24 Jun
PD616	API 579 /ASME FFS-1 Fitness-for-Service Evaluation	22-25 Jun
PD644	Advanced Design and Construction of Nuclear Facility Components Per BPV Code, Section III ASME CODE COURSE	22-25 Jun
PD672	BPV Code, Section XI, Division 1: Inservice Inspection 10-Year Program Updates for Nuclear Power Plant Components ASME CODE COURSE	22-25 Jun
PD679	Selection of Pumps and Valves for Optimum System Performance NEW!	22-25 Jun
PD716	BPV Code, Section 1: Power Boilers ASME CODE COURSE	22-25 Jun
PD192	BPV Code: Section XI: In-service Inspection of Nuclear Power Plant Components ASME CODE COURSE	22-26 Jun
PD443	BPV Code, Section VIII, Division 1 Combo Course ASME CODE COURSE Save Up to €800!	22-26 Jun
PD441	Inspections, Repairs and Alterations of Pressure Equipment ASME CODE COURSE Top Seller	25-26 Jun

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MC121	Design by Analysis Requirements in ASME Section VIII, Division 2 – Alternative Rules	22-23 Jun
MC116	Techniques and Methods Used in API 579-1/ASME FFS-1 for Advanced Fitness-For-Service (FFS) Assessments	24 Jun
MC104	Bases and Application of Heat Exchanger Mechanical Design Rules in Section VIII of the ASME BPV Code	25-26 Jun

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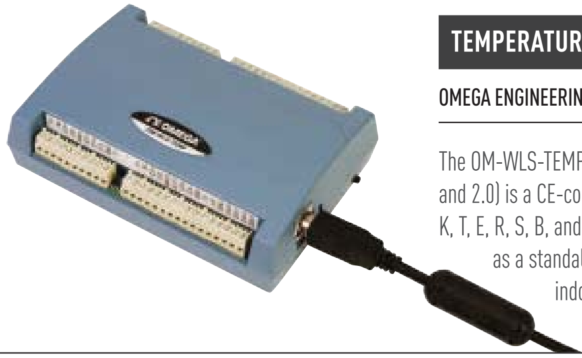

TEMPERATURE INPUT MODULE

OMEGA ENGINEERING, STAMFORD, CONN.

The OM-WLS-TEMP series of wireless USB 2.0 full-speed temperature input module (fully compatible with both USB 1.1 and 2.0) is a CE-compliant product that features eight temperature input channels and supports thermocouple types J, K, T, E, R, S, B, and N, RTDs, thermistors, and semiconductor temperature sensors. The OM-WLS-TEMP can be operated as a standalone plug-and-play USB device or as a remote wireless device with a range of up to 46 m (150 ft.) indoors and 732 m (2400 ft.) outdoors.

REACTION TORQUE SENSOR

SENSORDATA TECHNOLOGIES, SHELBY TOWNSHIP, MICH.

The Model T120 features high torsional stiffness along with a compact and lightweight torque sensor design. The higher stiffness of the Model T120 offers substantial increases in overhung moments, shear weight, and maximum thrust. Units feature a 2-in. diameter, overall length of 1.75 in., and total weight of less than 1 lb. The reduced size and weight of the unit allow for added ease and flexibility of installation at either the driver or absorber end of the measurement chain.

DOOR HANDLES

J.W. WINCO, INC., NEW BERLIN, WIS.

These RoHS-compliant door handles are used when the application requires both a locking mechanism and a handle. A rotary movement limited to 90° shifts the key bolt behind the doorframe. The key bolt is beveled, making the door-closing action easier. The choice of 22 differently shaped catch plates provides a range of latching distances from 4 to 50 mm, or 0.157 to 1.97 inches.

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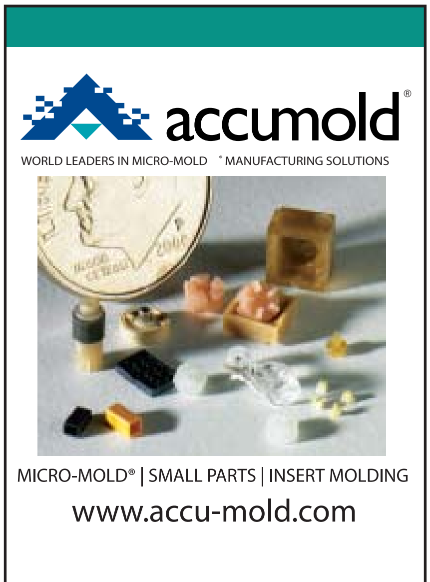

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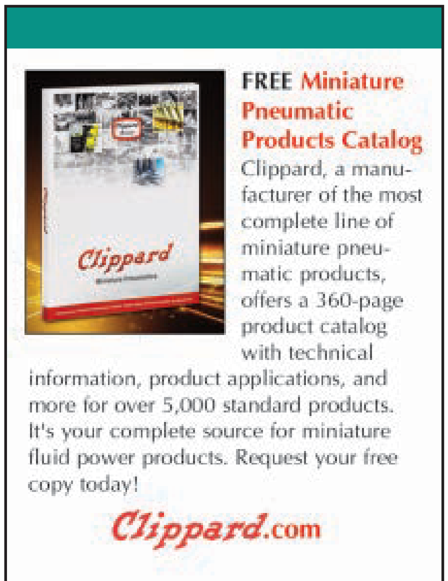

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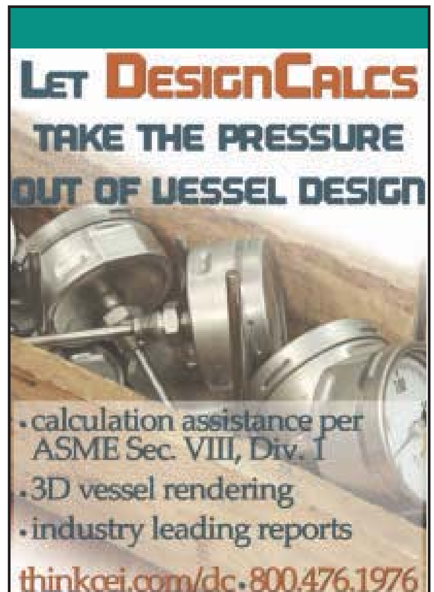

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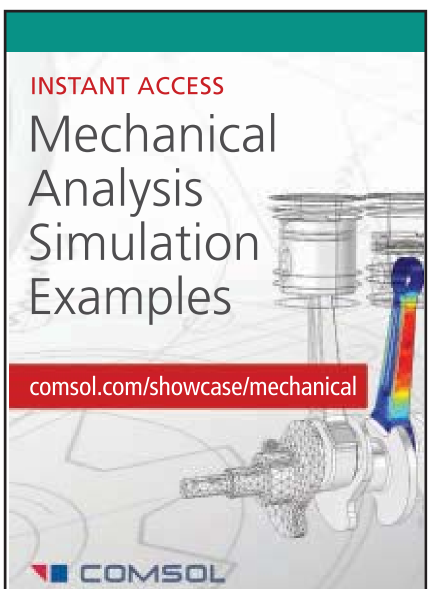

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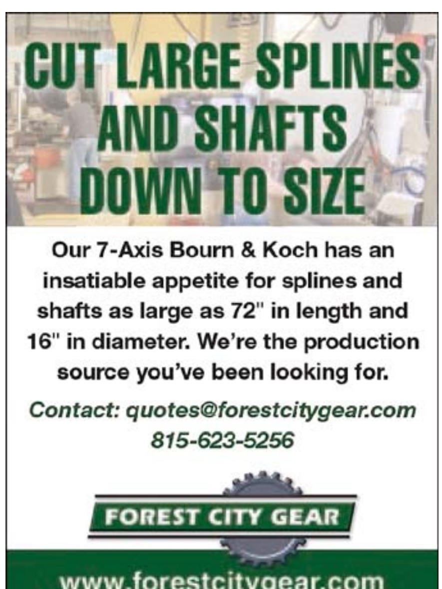

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FOTOFAB

MASTER BOND

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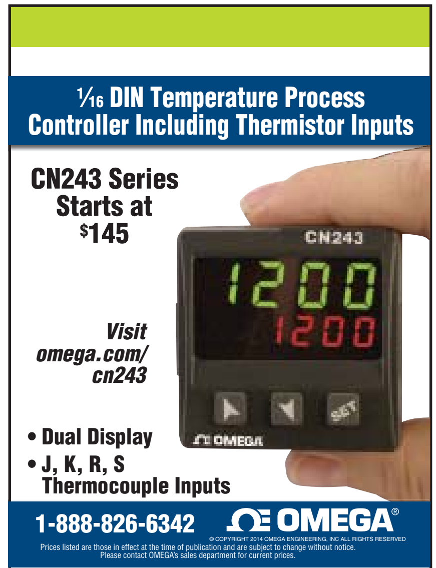

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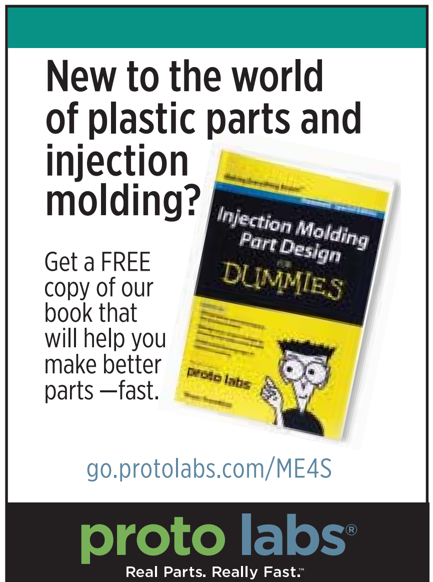

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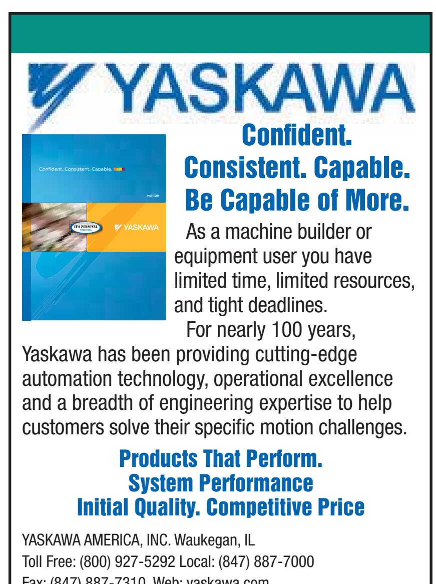

YASKAWA

POSITIONS OPEN

LOUISIANA TECH UNIVERSITY Invites applications for multiple **TENURE-TRACK POSITIONS IN MECHANICAL ENGINEERING WITH EMPHASIS IN DESIGN, MANUFACTURING, MEASUREMENT, OR CONTROL SYSTEMS.** Candidates must hold a doctorate or equivalent degree in Mechanical Engineering and demonstrate high-quality teaching and research potential. Candidates at the assistant, associate and full professor level will be considered. The successful candidate will be expected to teach courses at the undergraduate and graduate levels, develop an effective program of externally funded research, advise M.S. and Ph.D. students, and engage in university, professional and program service activities. Research activity is leveraged through one of the College's multidisciplinary centers of excellence in micromanufacturing, biotechnology and nanotechnology, engineering education, and trenchless technology. See the College website for more information: http://www.coes.latech.edu. Send curriculum vitae, statement of research interests and goals, a description of teaching experience and interests, and names and contact information for at least three references in a single PDF file electronically to facsearch@latech.edu with the subject line "your last name, your first name: mechanical engineering." Review of applications and nominations will begin on December 1, 2014 and will continue until suitable candidates are identified. The starting date for each position is September 1, 2015. Louisiana Tech University is an EEO/AA employer. Women and minorities are encouraged to apply. See the College website for more information: http://www.coes.latech.edu.

THE DEPARTMENT OF MECHANICAL ENGINEERING AT THE UNIVERSITY OF MEMPHIS invites applications for the position of **TENURE TRACK ASSISTANT PROFESSOR** beginning August 2015. Positions at higher rank will be considered for exceptionally qualified candidates. Duties include teaching undergraduate and graduate courses, externally-funded research, supervising graduate students and providing professional service. Candidates at the Assistant/Associate Professor rank are expected to demonstrate the potential to develop a visible nationally recognized and externally-funded research program. Required qualifications are a PhD in Mechanical Engineering or closely related field. While candidates in all areas related to Mechanical Engineering will be considered, the department is especially interested in candidates with demonstrated expertise in the areas of (1) advanced manufacturing and materials, and (2) energy including generation, harvesting and storage. Candidates are expected to collaborate on multi-disciplinary research. The Herff College of Engineering at The University of Memphis is in a growth phase, and several hires are expected in the Mechanical Engineering department over the next few years. Additional information about the college and the department can be found at http://www.memphis.edu/herff. The University of Memphis is the largest engineering program in western Tennessee. Memphis is home to three Fortune 500 companies and has a strong presence in biomedical, transportation, automotive and entertainment industries. Salary will be competitive and the University also provides a comprehensive benefits package that includes choices for health, retirement, and long- and short-term disability, and a research incentive compensation program. Information about most of these programs is available at www.memphis.edu. Applications are to be submitted via https://workforum.memphis.edu. Click on the faculty box to find the posting for the Assistant Professor position. Applications must include a research and teaching plan, a comprehensive curriculum vitae, and the full names and contact information (the address, phone number, and email address) of five professional references. The committee will begin screening applications on January 12, 2015 and will continue until the position is filled. A Tennessee Board of Reagents Institution. An Equal Opportunity-Affirmative Action University. Multiple Tenure-track Faculty Positions

THE DEPARTMENT OF AEROSPACE ENGINEERING AT AUBURN UNIVERSITY invites applications for multiple **TENURE TRACK FACULTY POSITIONS AT THE ASSISTANT OR ASSOCIATE PROFESSOR RANK**. Candidates with exceptional background and experience may be considered at a higher rank. Areas of interest include air-breathing and rocket propulsion, aerospace structures and structural dynamics, aeroelasticity, computational fluid dynamics, and combustion. Other areas related to aerospace engineering may also be considered. Applicants must have an earned doctorate in aero-

IOWA STATE UNIVERSITY

Tenured or Tenure-Track Faculty Position

The Department of Aerospace Engineering (www.aere.iastate.edu) and the Center for Nondestructive Evaluation (www.cnde.iastate.edu) at Iowa State University invite experienced applicants for a faculty position in the areas of NDE and engineering mechanics. Areas of interest include, but are not limited to: theoretical and experimental studies applied to ultrasonics, NDE, and NDE for advanced materials throughout a product life cycle including during advanced manufacturing.

The successful applicant will participate in the missions of the department and Center, including development of a strong externally funded research program, teaching and supervising students, and participation in service to the university. The successful applicant must be eligible to work on export controlled projects.

All interested persons must apply for this position online by visiting www.iastatejobs.com. Please refer to vacancy #400034. For full consideration, applications must be received by December 31, 2014.

Iowa State University is an Equal Opportunity/Affirmative Action Employer.

Duke | PRATT SCHOOL OF ENGINEERING

Mechanical Engineering Faculty Position Announcement

The Department of Mechanical Engineering and Materials Science (MEMS) of the Duke University Pratt School of Engineering invites applications for a tenure track faculty position to begin September 2015. An applicant whose work bridges an area of mechanical engineering with an area of materials science will be well suited for this position. Current strengths of the department include aerospace engineering, bio and computational materials, control and dynamics, fluid mechanics and thermodynamics. A PhD in Mechanical Engineering or Materials or a closely related field is required at the time of employment. Whereas the position is available at the Assistant Professor rank, truly exceptional candidates may be considered at the rank of Associate or Full Professor.

The successful candidate is expected to carry out high quality scholarly research and collaborate with other faculty. He or she should have a clear plan to establish a vibrant research program, secure external research funding, and actively participate in teaching at both the undergraduate and graduate levels. Full consideration will be given to applications received by January 1, 2015, but applications will continue to be accepted until the position is filled.

Applicants should electronically submit: (1) cover letter including email and snail mail addresses and phone number, (2) complete curriculum vitae, (3) two-page statement of achievements in teaching and research, and (4) names, email and snail mail addresses, and telephone numbers of five references to https://academicjobsonline.org/ajo/jobs/4972.

The Pratt School of Engineering is committed to fostering a diverse educational environment and encourages applications from members of underrepresented groups. Duke University is an Equal Opportunity/Affirmative Action Employer. It is committed to recruiting, hiring, and promoting qualified minorities, women, individuals with disabilities, and veterans.

space engineering, mechanical engineering, or a closely related field. They will be expected to fully contribute to the department's mission, including the development of a strong, nationally recognized, funded research program. Auburn's Aerospace Engineering has a long-standing legacy that begins at the turn of the twentieth century and extends, quite magnificently, from the Wright Brothers to the Space Station, and from the Aeronautical Program that evolved under the leadership of Robert Knapp (1907) to the Aerospace Engineering Department, which took off under the direction of Robert Pitts (1942). Auburn University was chartered in 1856 and was designated as a land grant institution in 1872. The Samuel Ginn College of Engineering, the most prestigious engineering college in Alabama, produces more than one third of the state's engineering graduates. Its enrollment exceeds 4,000 undergraduates and 850 graduate students. The college was recently ranked 28th among public universities, while its graduate programs were ranked 37th. Auburn, "The Loveliest Village On The Plains," is located 90 miles southwest of Atlanta on I-85, 50 miles of Montgomery. Applicants are encouraged to provide a cover letter, current CV, research vision, teaching philosophy, and three references to the job posting at: http://aufacultypositions.peopleadmin.com/postings/711. Cover letters may be addressed to: Prof. Winfred A. (Butch) Foster, Faculty Search Committee Chair, 211 Davis Hall, Auburn, AL 36849. The review process will begin December 1, 2014 and will continue until the positions are filled. Additional information may be found at: http://www.eng.auburn.edu/aero/.

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Auburn University is an EEO/Vet/Disability employer.

MILWAUKEE SCHOOL OF ENGINEERING (MSOE) invites applications for a **FACULTY POSITION AT THE ASSISTANT OR ASSOCIATE PROFESSOR LEVEL** for Fall 2015 teaching in the Mechanical Engineering Program. The full-time faculty position is open to applicants of all areas of mechanical engineering; however, preference will be given to applicants with expertise in the area of Fluid Dynamics. This position requires an earned doctorate in Mechanical Engineering (or a related field), relevant industrial experience, and a strong interest in effective undergraduate teaching, integrating theory, applications and laboratory practice. In addition to teaching duties, the successful candidate will be expected to become involved with academic advising, course/curriculum development, supervision of student projects, and continued professional growth through a combination of consulting, scholarship, and research. Excellent communication skills are required. The review of applications will begin as they are received and continue until the position is filled. Please visit http://www.msoe.edu to learn more about the position and to apply. EEO Employer F/M/Vet/Disabled

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THE DEPARTMENT OF MECHANICAL SCIENCE AND ENGINEERING AT THE UNIVERSITY OF ILLINOIS at Urbana-Champaign invites applications for **MULTIPLE FACULTY POSITIONS AT THE RANKS OF ASSISTANT, ASSOCIATE AND FULL PROFESSOR**. While excellent candidates will be considered in all relevant areas, em-

POSITIONSOPEN

phasis will be placed on: manufacturing and materials processing; experimental fluids; mechatronics and robotics; and computational sciences. A doctoral degree is required, and salary is commensurate with qualifications and experience. Full consideration will be given to applications received by December 31, 2014 with an earliest start date of January 2015. A full position description and information on how to apply can be found at the online jobsite http://jobs.illinois.edu. Questions regarding application procedures may be addressed to: mechse-facultyrecruiting@illinois.edu. Illinois is an EOE employer/Vet/Disabled www.inclusiveillinois.illinois.edu.

NANJING TECH UIVERSITY FACULTY POSITIONS IN COLLEGE OF MECHANICAL AND POWER ENGINEERING. This announcement invites applications for tenure-track faculty positions in: Mechanical Engineering, New Energy Science and Engineering, Welding Technology and Engineering, Mechanical Design Manufacturing and Automation, Vehicle Engineering, Process Equipment and Control Engineering. Required Qualifications: Ph.D. in Mechanical Engineering or a closely related field is required. Initial appointments are at the assistant professor level. Exceptionally qualified candidates at the associate or full professor level may also be considered. Rank and salary are commensurate with experience and accomplishments. Candidates should send application to chunlei-shao@njtech.edu.cn. A CV, list of publications, statements of research and teaching plans are required. Applications received before December 31, 2015

Faculty Position in Dynamics: Mechanical and Aerospace Engineering

THE OHIO STATE UNIVERSITY

COLLEGE OF ENGINEERING

The Department of Mechanical and Aerospace Engineering at The Ohio State University invites applications from outstanding individuals for a tenured or tenure-track faculty position in the broad disciplinary area of dynamics. Successful applicants for the position will demonstrate deep expertise in one or more of the following topics: vibration, acoustics and ultrasonics, structural mechanics, nonlinear dynamics, multi-body dynamics, system modeling, identification and diagnostics, adaptive structures, probabilistic methods including Bayesian modeling, experimental dynamics, and measurement systems.

Research specialization areas under consideration include, but are not limited to: design of robust, highly optimized structures with an emphasis on lightweight and multi-material structures, possibly with complex topologies; optimization of dynamic structures for energy efficiency and energy harvesting from structural vibrations; study of noise, vibration, and human-vehicle interactions arising due to structural dynamics; health monitoring and sensor-based diagnostics of engineered systems; dynamics of geared devices and power transmission systems; design of smart devices, vehicles, and structures, enabling context-dependent dynamics.

The new faculty member will complement and advance existing research Centers, for example the NSF I/UCRC Smart Vehicle Concepts Center, the OSU Center for Automotive Research, the Gear and Power Transmission Research Laboratory, and the OSU Institute for Materials Research, while creating synergy in one or more areas of strategic interest to the department and college such as advanced manufacturing, energy and environment, materials for a sustainable world, and data analytics.

QUALIFICATIONS: Candidates must have, by the start date, an earned doctoral degree in mechanical engineering or a closely related field. The new faculty member will be expected to teach core undergraduate and graduate courses in the Dynamic Systems Technical Area (for instance system dynamics, vibrations, acoustics, nonlinear dynamics, experimental methods, and smart materials and structures), develop new graduate courses in his/her research area, develop and sustain active sponsored research programs, and provide intellectual leadership in his/her research field. The anticipated start date is fall 2015. Screening of applicants will begin immediately and continue until the position is filled. Interested candidates should upload a complete curriculum vitae, statements of research and teaching goals, and the names, addresses, and e-mail addresses of four references. The website link is http://www.mecheng.osu.edu/faculty_positions/.

To build a diverse workforce, Ohio State encourages applications from individuals with disabilities, minorities, veterans, and women. Ohio State is an EEO/AA Employer. Columbus is a thriving metropolitan community, and the University is responsive to the needs of dual career couples. For more information about the Department of Mechanical and Aerospace Engineering at OSU, please visit http://mae.osu.edu/.

NPS

PRAESTANTIA PER SCIENTIAM

Faculty Positions

Heat Transfer and Thermal/Energy Sciences
Naval Postgraduate School
Monterey, California

The Department of Mechanical and Aerospace Engineering seeks applicants for one (1) tenure-track faculty position at the assistant professor level in the areas of Heat Transfer and Thermal/Fluid Sciences with emphasis on Energy Systems. Candidates must have the ability to teach at the graduate level, obtain a security clearance, and create nationally recognized research programs. Exceptional candidates at the associate professor level will also be considered.

Candidates must have an earned Ph.D. in Mechanical/Aerospace engineering or a closely related field. Good oral and written communication skills are essential.

The Department has 12 tenure-track faculty, 22 adjunct faculty, and 12 support staff and offers Masters, Engineers, and Doctoral Degrees.

Candidates should send an application letter, along with curriculum vitae and names of three references by December 15, 2014 by email to gvhobson@nps.edu, or mail to:

Garth Hobson
Professor and Chairman
Department of Mechanical and Aerospace Engineering
700 Dyer Road, Watkins Hall, Room 338
Naval Postgraduate School
Monterey, CA 93943-5100 USA

Position will remain open until filled.

The Naval Postgraduate School (www.nps.edu/mae) is an Equal Opportunity Employer.

JOHNS HOPKINS
UNIVERSITY

FACULTY POSITION
Department of Mechanical Engineering

Mechanical Engineering – Dynamic Behavior of Materials and Structures

The Department of Mechanical Engineering at Johns Hopkins University invites applications for a tenure-track faculty position in the area of dynamic behavior of materials and structures. Areas of particular interest include, but are not limited to, high strain rates, impact dynamics, wave propagation and shocks. Preference will be given to applicants at the assistant professor level, but exceptionally qualified candidates at all ranks will be considered.

The successful candidate for this position will have a primary appointment in the Department of Mechanical Engineering and be an integral member of the Hopkins Extreme Materials Institute (hemi.jhu.edu), a multidivisional institute devoted to advancing the fundamental science associated with materials and structures under extreme conditions.

The successful candidate must have an earned doctorate in mechanical engineering or related fields, and is expected to establish a strong, independent, internationally recognized research program as well as contribute fully to both undergraduate and graduate instruction. The candidate will continue a strong tradition of excellence in Mechanics and Materials at Johns Hopkins.

All applications should be submitted electronically to: https://academicjobsonline.org/ajo?joblist---1725. The electronic application should include a cover letter describing the principal expertise and accomplishments of the applicant, a curriculum vita, 1-2 page teaching statement, 2-3 page statement of research including research directions and future plans, and two representative journal publications. Candidates applying for the position of Assistant Professor should also provide the names and contact information of at least three (3) references. Candidates applying for Associate or full Professor positions are not asked to include this additional information. The application package should be received by January 20, 2015 for full consideration. However, applications will be accepted until the position is filled. Johns Hopkins University is committed to building a diverse environment; women and minorities are strongly encouraged to apply. The Johns Hopkins University is an EEO/AA Employer.

THE UNIVERSITY of TENNESSEE UT
KNOXVILLE

Institute of Biomedical Engineering Director and Professor of Biomedical Engineering

The College of Engineering at the University of Tennessee, Knoxville is seeking exceptionally qualified candidates to serve as Director of the Institute of Biomedical Engineering (iBME, http://ibme.utk.edu/about-us/) and to hold a full professorship in biomedical engineering in the Department of Mechanical, Aerospace, and Biomedical Engineering (MABE, http://www.mabe.utk.edu/). The academic appointment is in MABE and is based at the UT Knoxville campus. The iBME Director reports to Dean of the College of Engineering regarding the leadership and coordination of biomedical research across the UTK College of Engineering, the Graduate School of Medicine, the College of Veterinary Medicine, and other UTK Colleges. The position is responsible for biomedical engineering graduate degree programs, curricula and activities. Applications and nominations are invited for this senior position. Prior academic experience is desirable but not required. Applicants with outstanding industrial biomedical research accomplishments are welcomed.

The successful candidate will have a doctorate in engineering or a related field, a proven track record of developing research funding, and a substantial and active research program with archival publications in biomedical engineering and science. The successful candidate must be qualified for tenure at the rank of full professor at the time of hire. Equally important, the successful candidate will be an internationally recognized leader in his or her area of specialty, a team player, and able to build and lead multi-participant research programs across colleges and departments.

Review of applications and nominations will begin February 1, 2015, and will continue until the position is filled. Applications should include (1) a concise letter of intent outlining the applicant's research and teaching goals and objectives; (2) a comprehensive curriculum vitae; and (3) the names, addresses and telephone numbers of at least five references. The preferred method of application or nomination is by e-mail to whamel@utk.edu. As an alternative, materials may be mailed directly to:

Dr. William R. Hamel, Professor MABE Department
403 Dougherty Engineering Building
The University of Tennessee, Knoxville, TN 37996-2210

The University of Tennessee is an EEO/AA/Title VI/Title IX/Section 504/ADA/ADEA institution in the provision of its education and employment programs and services. All qualified applicants will receive equal consideration for employment without regard to race, color, national origin, religion, sex, pregnancy, marital status, sexual orientation, gender identity, age, physical or mental disability, or covered veteran status.

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will be guaranteed full consideration. Additional information is available at http://www.njtech.edu.cn.

MECHANICAL AND AEROSPACE ENGINEERING DEPARTMENT. NTT ASSISTANT TEACHING PROFESSOR (Ref #00061252). The Department of Mechanical and Aerospace Engineering at the Missouri University of Science and Technology (formerly the University of Missouri-Rolla) invites applications for a non-tenure-track (NTT) teaching assistant professor position (exceptional candidates may be considered for a higher rank). NTT teaching faculty members contribute to the core activity of teaching and are expected to be fully engaged in the department's curriculum development and delivery. The successful candidate should have skills and experience that add value to the department's teaching mission. The initial appointment will be for one year and is potentially renewable for a multiple year appointment, with an expected affiliation with the department over an extended period. Applicants for this position are expected to provide high-quality teaching at the undergraduate level in the area of design in mechanical and/or aerospace engineering. Examples of the courses that are expected to be taught include introduction to engineering design for general engineering students, introduction to mechanical design, aircraft/spacecraft design, and other design courses at higher levels. As NTT teaching faculty at Missouri S&T may be promoted, it is anticipated that the successful candidate would achieve a sustained level of recognition by students and peers as a stimulating, inspiring and effective teacher, as well as develop excellence in the production of effective learning materials, improved teaching techniques, and state-of-the-art delivery systems. The typical workload for this position is four (3 credit hour) courses per semester during the academic year. The position may include laboratory supervisory responsibilities, undergraduate advising, or professional and service activities related to the teaching assignment. It is expected that the teaching assignments will be a minimum of 75% of the workload of this position. An earned doctorate in Mechanical or Aerospace Engineering, or closely related field, is required for this position. Ability to teach at the undergraduate level in a variety of areas of mechanical/aerospace engineering is desired, with particular interest in teaching in the area of design. Successful prior teaching experience will be an important consideration, and industrial experience is also desirable. The department currently has 38 full-time faculty members (three of which are teaching faculty), over 800 undergraduate and approximately 200 graduate students. The Department offers the B.S., M.S., and Ph.D. degrees in both Mechanical and Aerospace Engineering. A recently completed $29 million construction and renovation project has produced a state-of-the-art Mechanical and Aerospace Engineering complex with 144,000 square feet of teaching and research laboratory space. Details regarding the department can be found at http://mae.mst.edu. The search committee will begin the review process immediately upon receipt of applications, and the search will remain open until the position is filled. Please submit an application consisting of a current curriculum vitae, a statement of teaching interests and philosophy, and contact information for five professional references. All application materials must be electronically submitted to Missouri S&T's Human Resource Office at: http://hraadi.mst.edu/hr/employment/. Acceptable electronic formats that can be used for email attachments include PDF and Word; hardcopy application materials will not be accepted. The final candidate is required to provide official transcript(s) for any college degree(s) listed in application materials submitted. Copies of transcript(s) must be provided prior to the start of employment. In addition, the final candidate may be required to verify other credentials listed in application materials. Failure to provide official transcript(s) or other required verification may result in the withdrawal of the job offer. Missouri S&T is an AA/EO Employer and does not discriminate based on race, color, religion, sex, sexual orientation, national origin, age, disability, or status as Vietnam-era veteran. Females, minorities, and persons with disabilities are encouraged to apply. Missouri S&T is responsive to the needs of dual-career couples. Missouri University of Science and Technology participates in E-Verify. For more information on E-Verify, please contact DHS at: 1-800-464-3218. NOTE: All application materials must refer to position reference number (R00061252) in order to be processed.

THE DEPARTMENT OF MECHANICAL ENGINEERING AT THE UNIVERSITY OF SOUTH FLORIDA invites applications for **TENURED/TENURE-TRACK POSITIONS AT THE ASSISTANT/ASSOCIATE/FULL PROFESSOR** levels starting August 2015. The positions require an earned doctorate degree in Mechanical Engineering or

LAFAYETTE COLLEGE

Lafayette College *is a small, private, undergraduate-only institution emphasizing superior education in engineering and the liberal arts. The College is located in eastern Pennsylvania, 70 miles from both New York City and Philadelphia. The ME Department has approximately 180 students across all classes and outstanding resources for faculty research and professional development.*

Assistant Professors of Mechanical Engineering

The Department of Mechanical Engineering of Lafayette College in Easton, Pennsylvania, is pleased to announce two tenure-track positions, at the Assistant Professor level, for a July 2015 appointment. The Department seeks new colleagues with strong interests in teaching and mentoring undergraduate students, laboratory development, hands-on instruction, and experiential education including the supervision of multidisciplinary design projects and student research. The candidate will be expected to develop a sustained research program and publish in respected journals. The service expectations include curriculum development, participation in College committees and an active role in professional societies. The first opening is in the areas of controls, dynamic systems and instrumentation. The second is in the area of design with an emphasis on designing with modern materials, the engineering design process and/or manufacturing. The department prizes instructional effectiveness and engagement; the ability to contribute to the major program and to engage students from other majors is desirable.

Applicants should have a Ph.D. in mechanical engineering or a closely related field. A cover letter, statement of teaching interests, research plans, and a curriculum vitae should be addressed to: Dr. Jeffrey Helm, Search Committee Chair, Dept. of Mechanical Engineering, Lafayette College, Easton, PA 18042. Please indicate if the application is for the design or controls position. Email applications for the controls position to: MechEngrgSearchC@Lafayette.edu. Email applications for the design position to: MechEngrgSearchD@Lafayette.edu. Review of applications will begin January 1, 2015, and will continue until a suitable candidate is hired.

Lafayette College is committed to creating a diverse community: one that is inclusive and responsive, and is supportive of each and all of its faculty, students, and staff. All members of the College community share a responsibility for creating, maintaining, and developing a learning environment in which difference is valued, equity is sought, and inclusiveness is practiced. Lafayette College is an equal opportunity employer and encourages applications from women and minorities.

BAYLOR UNIVERSITY

1845

Tenure Track Faculty Position in Mechanical Engineering

The Department of Mechanical Engineering in the School of Engineering and Computer Science at Baylor University seeks highly qualified candidates for a tenure-track faculty position in solid mechanics, materials, and/or biomaterials/biomechanics. Special consideration will be given to applicants with research in areas related to national initiatives in next generation and/or nano-materials, manufacturing, and energy. The position will begin in August 2015. Applicants at the Assistant Professor level are preferred, however, exceptional candidates with outstanding qualifications could be considered at a higher rank. Responsibilities include establishing an externally funded research program, undergraduate and graduate teaching, course curriculum development, and professional service. Requirements include an earned doctorate in Mechanical Engineering or a closely related field, outstanding English communication skills, a commitment to teaching and research excellence, and involvement in professional activities. The position will support the new Mechanical Engineering Ph.D. program that began in Fall 2014, and will include a highly competitive start-up package. In light of Baylor's strong Christian mission, the successful applicant must have an active Christian faith.

Baylor offers ABET/EAC-accredited B.S. programs in Mechanical Engineering, Electrical and Computer Engineering, and Engineering. The Department of Mechanical Engineering has state-of-the-art research facilities in the mechanics and materials areas and has plans for continued faculty hires in support of its growing research mission. Additional information about this position may be found at http://www.ecs.baylor.edu/mechanicalengineering/.

To receive full consideration, please submit a cover letter and the following: A current curriculum vitae, an individualized statement of teaching and research interests related to Baylor's programs, contact information for at least three professional references, a statement describing an active Christian faith. Review of applications begins December 15, 2014 and will continue until the position is filled. Further information, including official transcripts and letters of recommendation, will be required of finalists. Applicants should send electronic materials in PDF format to the search committee chair, Dr. Douglas Smith at Douglas_E_Smith@baylor.edu.

Chartered in 1845 by the Republic of Texas, Baylor University is the oldest university in Texas and the world's largest Baptist university. It is a member of the Big XII Conference and holds a Carnegie classification as a "high-research" institution. Baylor's mission is to educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community. New faculty will have a strong commitment to the classroom and to discovering knowledge as Baylor aspires to become a top tier research university as described in Pro Futuris (http://www.baylor.edu/profuturis/).

Baylor is a Baptist university affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Employment Opportunity employer, Baylor encourages minorities, women, veterans, and persons with disabilities to apply.

Assistant, Associate, or Full Professor Mechanical Engineering (tenure-track)

The Department of Mechanical Engineering at The City College of the City University of New York invites applications from outstanding individuals for tenure-track faculty at the Assistant or Associate Professor rank in areas related to thermal-fluid engineering and energy systems of any scale, renewable energy and advanced materials, including smart materials. Candidates with an exceptional record of achievement may be considered for the rank of Full Professor.

The successful candidate is expected to collaborate with colleagues, develop an innovative externally funded research program, participate in on-going research activities and teach and develop courses in the graduate and undergraduate programs.

For information about the Grove School of Engineering and the Mechanical Engineering Department please see http://www.ccny.cuny.edu/engineering/index.cfm.

To apply, please view the job posting (Job ID 11627) at http://www.cuny.edu/employment/jobsearch.html and follow all instructions.

The City College of New York

Tenure-track Assistant and Associate Professor Positions in Mechanical Engineering University of Nevada, Reno

The University of Nevada, Reno Mechanical Engineering Department, due to its continuing growth, is hiring six tenure-track positions. Five positions at the Assistant Professor level are open to applicants in any area of Mechanical Engineering with particular emphasis on Advanced Manufacturing, Thermal Science, and/or Computational Mechanics (e.g. fluid/solid interaction, multi-physics). One position, to be filled at the Assistant or Associate level, is open to applicants with appropriate qualifications in the area of Autonomous Systems. Candidates for all positions are expected to develop an independent, nationally-recognized and externally-funded scholarly research program, and to become active in professional service. She or he will teach existing courses and develop new innovative undergraduate and graduate courses. The candidate must hold an earned doctorate in Mechanical Engineering or closely related field.
The positions will be available July 1, 2015. Full consideration will be given to candidates who apply by January 12, 2015. The salary, benefits, and start-up package will be highly competitive. To apply, please use the following link: https://www.unrsearch.com/postings/16499

POSITIONS OPEN

a closely related field. The candidates should have the background and demonstrated scholarly achievements to contribute to fundamental research thrust areas in the College of Engineering. Preference will be given to candidates in the Energy field (such as Sustainable Energy Systems) and Advanced Manufacturing (such as Digital Manufacturing). The candidates will be expected to provide leadership to establish a strong externally funded research program and demonstrate a commitment to undergraduate and graduate teaching and mentoring. Information about the Department and details on these open positions can be found at http://me.eng.usf.edu. Applicants must electronically submit the application packet to the following website: employment.usf.edu. Women and underrepresented minorities are strongly encouraged to apply. Review of applicants will begin on January 5, 2015 and applications will be accepted until the position is filled. USF is an equal opportunity/equal access/affirmative action institution.

GRADUATE RESEARCH AND TEACHING ASSISTANTSHIPS. UNIVERSITY OF MASSACHUSETTS LOWELL. The Department of Mechanical Engineering at the University of Massachusetts Lowell currently has openings for graduate research and teaching assistantships in the following research areas: Aerodynamics, Composite Materials, Diagnostics and Prognostics, Mechanics of Materials and Experimental Mechanics, MicroElectroMechanical Systems (MEMS), Micro/Nano-fluidics, Multiphase Computational Fluid Dynamics, Multiscale Heat/Mass Transfer and Energy Transport, Nanomanufacturing, Robotics, Rotating Machinery Dynamics, Structural Dynamics, Structural Health Monitoring, Sensors and Sensing Technologies, Smart Materials, Sports Engineering, Sustainable Energy, Textiles, Unmanned/Micro Aerial Vehicles, Vibration and Acoustics, Wind and Solar Energy. UMass Lowell has a distinguished reputation for academic excellence and high-quality engineering research. UMass Lowell is a Carnegie Doctoral High Research (RU/H) university ranked in the top tier of US News' National Universities, and is strategically located 30 miles northwest of Boston in the northeast Massachusetts high-tech region. The department has over 600 undergraduate students and over 100 graduate students. Prospective students are encouraged to contact faculty members in their respective areas of interest. Current annual research expenditures for the college are $11M with a target of $30M by 2020. For more information please visit the UML Mechanical Engineering website: http://www.uml.edu/engineering/mechanical/default.aspx. For an application to the graduate program, visit: http://www.uml.edu/grad/. The University of Massachusetts Lowell is an Equal Opportunity/Affirmative Action, Title IX employer. All qualified applicants will receive consideration for employment without regard to race, sex, color, religion, national origin, ancestry, age over 40, protected veteran status, disability, sexual orientation, gender identity/expression, marital status, or other protected class.

ASSISTANT PROFESSOR IN THE AREA OF MECHANICAL AND AUTONOMOUS SYSTEMS. The Division of Engineering and Applied Science at the **CALIFORNIA INSTITUTE OF TECHNOLOGY** invites applications for a tenure-track faculty position in the Department of Mechanical and Civil Engineering. We are interested in applicants from a broad range of research areas related to mechanical and autonomous systems. Specific areas include, but are not limited to robotics, controls, energy systems, distributed sensing, manufacturing and structural control and monitoring systems. The search is aimed at the assistant professor level. Interested applicants should submit an electronic application at https://applications.caltech.edu/job/mce. Review of applications will begin on 15 November 2014 and will continue until the position is filled. The term of the initial appointment at the assistant professor level is normally four years, with appointment contingent upon completion of a PhD in a relevant field. EOE of Minorities/Females/Protected Vets/Disability. Questions about the application process may be directed to mas-mce@caltech.edu.

FACULTY POSITION SOUTHERN ILLINOIS UNIVERSITY EDWARDSVILLE (SIUE). The Department of Mechanical and Industrial Engineering has experienced consistent and sustained growth over the past eight years. In response to recent growth, two tenure-track faculty positions have been created. The ideal candidate for the first position is expected to have a primary research focus on MEMS, microsystems, or biosystems. The research focus for the second position is in the area of dynamic systems, vibrations, controls, and mechatronics. The appointments are expected to be at the assistant professor level. However, applications of candidates with other research interests or appointment at a higher rank may also be con-

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FACULTY POSITION IN MECHANICAL ENGINEERING

The Department of Mechanical Engineering (www.me.udel.edu) at the University of Delaware (UD) invites nominations and applications for a tenure-track faculty position at the Assistant Professor level. We are seeking ambitious, creative, and innovative individuals in the area of mechanics of materials who have demonstrated excellence in research, interdisciplinary spirit and vision and the drive to become leaders in their field while maintaining high-quality teaching and mentoring activity. Exceptional candidates in other areas of interest to the department will also be considered.

The department consists of 21 full-time faculty members actively engaged in the core research areas of biomechanics, clean energy and environment, composite and advanced materials, nanotechnology, and robotics and controls; annual research expenditures are $ 9.7 M. In addition to hosting the Center for Fuel Cell Research and the Center for Biomechanical Engineering Research, we have strong ties to several strategic campus-wide institutions such as the Center for Composite Materials, the Center for Carbon-free Power Integration, the Delaware Biotechnology Institute, the Delaware Environmental Institute, the Delaware Rehabilitation Institute, the Institute for Energy Conversion, and the UD Energy Institute. The undergraduate program is in high demand (over 500 students enrolled) and places a strong emphasis on research and real-world design.

The University of Delaware combines a rich historic legacy in engineering (www.engr.udel.edu/) with a commitment to undergraduate education and the creation of new impactful knowledge. With external funding exceeding $200 million, the University ranks among the top 100 universities in federal R&D support for science and engineering. Supported by state-of-the-art facilities, research is conducted across all seven colleges and numerous interdisciplinary institutes and centers. The main campus in Newark, Delaware, provides the amenities of a vibrant college town with convenient access to the major cities of the East Coast. The newly erected 194,000-square-foot Interdisciplinary Science and Engineering Laboratory greatly expands opportunities and resources for interdisciplinary research and education, and the recently acquired 272-acre STAR (Science, Technology and Advanced Research) campus offers even more opportunities for research, academic, and commercial development.

Applicants must hold a Ph.D. in mechanical engineering, or closely related field.
The search will continue until the position is filled.

For additional information and application procedures about this position and all open other positions please visit the UDJOBS website at: http://apply.interfolio.com/26779

The University of Delaware is an Equal Opportunity Employer which encourages applications from minority group members, women, individuals with a disability and veterans. The University's Notice of Non-Discrimination can be found at http://www.udel.edu/aboutus/legalnotices.html. Employment offers will be conditioned upon successful completion of a criminal background check. A conviction will not necessarily exclude you from employment.

Dare to be first.

University of Delaware

POSITIONSOPEN

Open Rank Faculty Position in Aerospace Engineering

The Department of Aerospace Engineering at The Pennsylvania State University invites nominations and applications for a full-time, tenure-track or tenured open-rank faculty position starting in Fall 2015. Expertise in one or more of the following areas is of particular interest: spacecraft–environment interactions; rarefied gas dynamics; chemical and electric spacecraft propulsion; reentry and rocket-nozzle and -plume flows; and space- and propulsion-related plasmas. Applicants must have an earned doctorate in aerospace engineering or a related field; at least one degree in aerospace engineering or related aerospace experience is preferred. Responses received before January 7, 2015, are assured full consideration, but the search will remain open until the position is filled. Applicants should submit electronically a single pdf file that contains a cover letter, a CV, a statement of research and teaching interests, and the names and contact information for at least three references at **apptrkr.com/530766** .

The Department of Aerospace Engineering enjoys an excellent international reputation in aeronautics and astronautics. The Department currently has 16 full-time faculty members, with more than 225 juniors and seniors and more than 120 graduate students. Annual research expenditures exceed $6 million.

Penn State at University Park is a land-grant institution located within the beautiful Appalachian mountains of central Pennsylvania. State College and nearby communities within Centre County are home to roughly 100,000 people, including over 40,000 students, and offer a rich variety of cultural, recreational, educational, and athletic activities. State College is a wonderful community in which to raise a family and has an excellent public school system.

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to http://www.police.psu.edu/clery/ , which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to minorities, women, veterans, disabled individuals, and other protected groups.

sidered for candidates with exceptional qualifications. The positions start in August 2015. SIUE is a strong advocate of the teacher-scholar model, and therefore, the successful candidate is expected to teach undergraduate and graduate courses in Mechanical Engineering, advise graduate students in master and doctoral levels, conduct research, and participate in service activities. The candidates should have a doctoral degree in Mechanical Engineering or a related field. The large and beautiful SIUE campus is located about 20 miles from St. Louis, MO. The Engineering Building, completed in 2000, houses Mechanical Engineering laboratories with state-of-the-art equipment. An annex of the Engineering Building has recently been added to the original building to accommodate the growth of the engineering programs. The current faculty members in Mechanical Engineering are actively engaged in both fundamental and applied research. Interested persons should email a curriculum vita with a list of at least three references, and statements of research and teaching interests to coljame@siue.edu with "Application for Faculty Position" in the e-mail subject line, or mail to Search Committee Chair, Department of Mechanical and Industrial Engineering, Southern Illinois University Edwardsville, Box 1805, Edwardsville, IL 62026-1805. The application should arrive by January 15 to receive full consideration. However, the review of the applications will continue until the position is filled. Southern Illinois University Edwardsville is an affirmative action/equal opportunity employer.

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WEBINAR EXPLORES ENGINEERING WITH BIG DATA

AHMED K. NOOR, WILLIAM E. LOBECK PROFESSOR at Old Dominion University's Department of Modeling, Simulation, and Visualization Engineering, and **Simon Davidoff,** business manager, data services, at Siemens Industry Services, discussed how to capture, analyze, and manage data effectively to make informed decisions and advance manufacturing during an ASME webinar held in October. Entitled "Empowering Engineers with Big Data to Improve Manufacturing," an archive of this webinar may be found online at ASME.org.

Noor is a frequent contributor to *Mechanical Engineering* magazine, and his recent article, "Game Changers," was the cover story for the September issue.

PETERSON REAPPOINTED TO SCIENCE BOARD

The White House has reappointed Georgia Institute of Technology president **G.P. Peterson** to the National Science Board, the policymaking body for the National Science Foundation.

Peterson, an ASME Fellow, was first appointed to the NSB in 2008 by President George W. Bush, and has served as the chair of the Audit and Oversight Committee charged with ensuring that the National Science Foundation is properly evaluating and managing its operational risks. In 2011, President Obama appointed Peterson to the Advanced Manufacturing Partnership steering committee and in September 2013 appointed him to the AMP 2.0 steering committee.

ABAID IS ONE OF BRILLIANT 10

ASME MEMBER NICOLE ABAID, AN ASSISTANT professor with the Virginia Polytechnic Institute and State University Department of Biomedical Engineering and Mechanics, has been selected as one of *Popular Science* magazine's 2014 Brilliant 10. The 10 were featured in the October 2014 issue.

Abaid collaborates with her colleague, **Rolf Mueller**, to study how animals—most prominently bats—swarm. Their research aims to gain insights for improving the control of multi-agent systems, such as underwater robotic vehicle teams that rely on sonar. The ability of bats to fly in a swarm without the danger of collision is seen as key in building underwater vehicles and other robotics systems that can operate in a similar fashion.

Abaid, Mueller, and their research teams plan to build a team of robotic ground vehicles that can mimic a bat swarm and avoid not only collision, but jamming, by using bat-inspired behavioral and sensing strategies.

ASME CURRICULUM

EIGHTY-NINE SCHOOLS ACROSS the United States adopted the new ASME Inspire digital engineering course in the first month of its launch in September. This enables as many as 2,400 middle and high school students in 19 states to access the new program, which teaches students about algorithms, coding, and other math and science skills essential for entry into technology fields.

ASME and the ASME Foundation are sponsoring the new initiative, which aims to improve math and science literacy among young people and build their awareness of and interest in engineering.

ASME Inspire is an online, in-class instruction tool, which was developed with the education technology company EverFi. Inspire comprises 16 modules addressing STEM-related topics such as basic computer science and the real-world application of algebra.

The online modules also cover binary numbers, encryption and decryption, and other technology topics in the context of computer games and interactive screen simulations. The modules' engaging lessons focus on building students' STEM skills while highlighting the career possibilities that a STEM education can make possible.

The ASME Foundation has agreed to fund the ASME Inspire program for next three years, with an ultimate goal of launching the program into at least 1,000 U.S. schools during that time.

ASME tested a pilot program in Washington, D.C., area schools over the past two academic years.

For more information on the program, visit the ASME Pre-College Group Page on ASME.org, or contact Patti Jo Snyder at snyderp@asme.org.

NEMB 2015 SET FOR APRIL

LEADING TECHNOLOGISTS AND bioengineers will speak at the ASME 2015 Fourth Global Congress on Nano-Engineering for Medicine and Biology, to be held in Minneapolis. In addition, technical tutorials, papers, and posters will be presented during the four-day event running from April 19 through 22, 2015.

Among the speakers already confirmed for NEMB 2015 are **Paul Weiss**, the Fred Kavli Chair in NanoSystems Sciences and director of the California NanoSystems Institute at the University of California, Los Angeles, and **Shuichi Takayama**, professor of bioengineering at the University of Michigan in Ann Arbor.

Other speakers include **Rashid Bashir**, professor of electrical and computer engineering and bioengineering at the University of Illinois, Urbana-Champaign, and director of the university's Micro and NanoTechnology Laboratory and Center for Nanoscale Science and Technology; **Lihong Wang**, professor of bioengineering at Washington University in St. Louis; and **Denis Wirtz**, professor of chemical and biomolecular engineering and vice provost for research at Johns Hopkins University.

The 2014 edition of the conference, held in San Francisco, attracted more than 300 attendees and featured 45 technical sessions.

The NEMB 2015 technical program will be divided into six tracks, covering the areas of nano-imaging and nanophotonics; nano-therapeutics; nano and microfluidics; nano-to-macro multiscale modeling; nanotoxicology in public health and the environment; and biomimetic materials.

Tutorials are scheduled on such topics as cardiotoxicity of emerging cancer nanotherapies, opportunities for women and under-represented minorities in nanoscience and biotechnology, the National

AID EAGERLY ADOPTED

Students from William W. Hall Academy middle school in Capitol Heights, Md., who participated in the ASME Inspire pilot program last year, display their certificates of completion for finishing all 16 of the program's modules.

Cancer Institute funding in nanotechnology, and integrated multiscale biomedical modeling and experiments.

The conference will feature a special ASME NEMB poster competition, which will give students the opportunity to present their research in front of hundreds of people and discuss their ideas with peers, professors, and representatives from government and industry. Selected finalists will take part in the competition's lightning round, during which cash prizes and certificates will be awarded.

Researchers and students interested in presenting technical papers and posters at the conference must submit their abstracts before Jan. 5, 2015.

To submit a paper or poster abstract, visit www.asmeconferences.org, and follow the instructions on the web page. For more information on the Fourth Global Congress on NanoEngineering for Medicine and Biology, visit www.asmeconferences.org/NEMB2015 or contact Christine Reilley at reilleyc@asme.org.

LAMB RECEIVES ENGINEER-HISTORIAN AWARD

ASME Fellow **J. Parker Lamb, Jr.**, retired mechanical engineering department chair at the University of Texas at Austin, was selected to receive the 2014 Engineer-Historian Award from the ASME History and Heritage Committee at the ASME Central Texas Section meeting that took place on Nov. 20.

Lamb, who was a founding member of the Central Texas Section, was recognized with the award for his two books, *Perfecting the American Steam Locomotive* (Railroads Past and Present) and *Evolution of the American Diesel Locomotive*. The Engineer-Historian Award, which was established in 1990 by the ASME History and Heritage Committee, honors an outstanding published work or works by an engineer dealing with the history of mechanical engineering, and is intended to encourage the active interest by mechanical engineers in the history of their profession.

COMBINED POWER AND ENERGY EVENT SET FOR JUNE

Four of ASME's major conferences are joining forces to create ASME Power & Energy 2015. The event aims to bring together more than 1,000 research and industry leaders in fossil and nuclear power generation, renewable energy and fuel cell applications, and many other sectors.

ASME Power & Energy 2015 will take place June 28 to July 2 at the San Diego Convention Center. It will encompass four major events: the ASME Power Conference, the ASME Conference on Energy Sustainability, the ASME Nuclear Forum, and the ASME Fuel Cell Conference.

The combined event will feature high-level, high-impact keynote sessions, 45 technical tracks consisting of more than 800 paper presentations, and up to 100 energy companies in the exhibition area, as well as workshops, student competitions, poster presentations, receptions, special demonstrations, and networking opportunities. The sessions will encompass such critical topics as state-of-the-art power engineering solutions in plant operations and maintenance, recent developments in the nuclear power industry, and the latest technology research and solutions for fuel cells.

To learn more about the areas to be covered by the program's various technical tracks and additional information about the four conferences, visit http://go.asme.org/powerenergy, or contact Brandy Smith, program manager, at smithb@asme.org.

Analysis suggests the copper of this corroded needle found in the Jordan Valley may have originated in the Caucasus region.

ANCIENT AWL REWRITES HISTORY

A 7,000-year-old copper artifact discovered in Israel brings new light to the birth of metallurgy.

A CORRODED SCRAP OF COPPER HAS REWRITTEN THE history of technology in the Middle East. It also sheds light on very early trade practices.

According to a recent paper, the artifact is a copper awl, and it was found in a grave at Tel Tsaf in the Jordan Valley of Israel, about 25 miles south of the Sea of Galilee. Calibrated carbon dating places the grave in the late sixth millennium or early fifth millennium B.C.E.

The awl came to light in 2007 during an excavation conducted by Yosef Garfinkel of the Hebrew University of Jerusalem. The published results were co-authored by Garfinkel, Danny Rosenberg, the head of the Laboratory for Ground-stone Tools Research in the University of Haifa's Zinman Institute of Archaeology, Florian Klimscha of the German Archaeological Institute in Berlin, which is conducting the renewed project at Tel Tsaf, and Sariel Shalev of the Department of Archaeology at the University of Haifa, who conducted the chemical analysis of the awl.

The grave site (in the round structure at the top left) contained various high status goods in addition to the awl.

The corroded item was analyzed by PXRF, a technique for chemical compositional measurement in which X-rays of a known energy are directed towards a target or sample, causing the atoms within the material to emit "fluorescent" X-rays at energies characteristic of its elemental composition.

Rosenberg, said that "until this unique find was discovered, the oldest evidence of metallurgy in the region was several centuries younger, dating from the last quarter of the fifth millennium B.C.E and thus we have unique opportunity to study the very early roots of this advanced technology and how it was introduced to this area."

Chemical examination of the metal suggests it may have come from the Caucasus, more than 600 miles away. According to Rosenberg and Klimscha, "While the long-distance commercial ties maintained by village communities in our region were already known from even earlier periods, the import of a new technology combined with the processing of a new raw material coming from such a distant location is unique to Tel Tsaf and provides additional evidence of the importance of this site in the ancient world."

According to the paper, "The Beginning of Metallurgy in the Southern Levant," published in the journal, *PLOS One*, Tel Tsaf was an extremely wealthy community for its time. The site has the remains of complexes buildings, and the scale of its grain silos was unprecedented in the ancient Middle East.

According to the authors, it is possible that metallurgy was first diffused to the southern Levant through exchange networks and only centuries later involved local production. This copper awl, the earliest metal artifact found in the southern Levant, indicates that later metallurgy in the region developed from a more ancient tradition.

It seems possible that the Tel Tsaf copper awl was the result of smelting and melting, but the poor preservation and heavy corrosion of the object make the chemical analysis difficult to interpret.

The copper awl was found among other grave goods that make the grave a very elaborate burial. The grave contained the skeleton of a woman about 40 years old. The burial included a necklace of 1,668 beads made of ostrich egg shell. It is "the most elaborate burial of its period in the entire Levant," the paper says, and the authors take that as a sign of the prestige value of metal objects at the time. ME

JAMES PERO

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