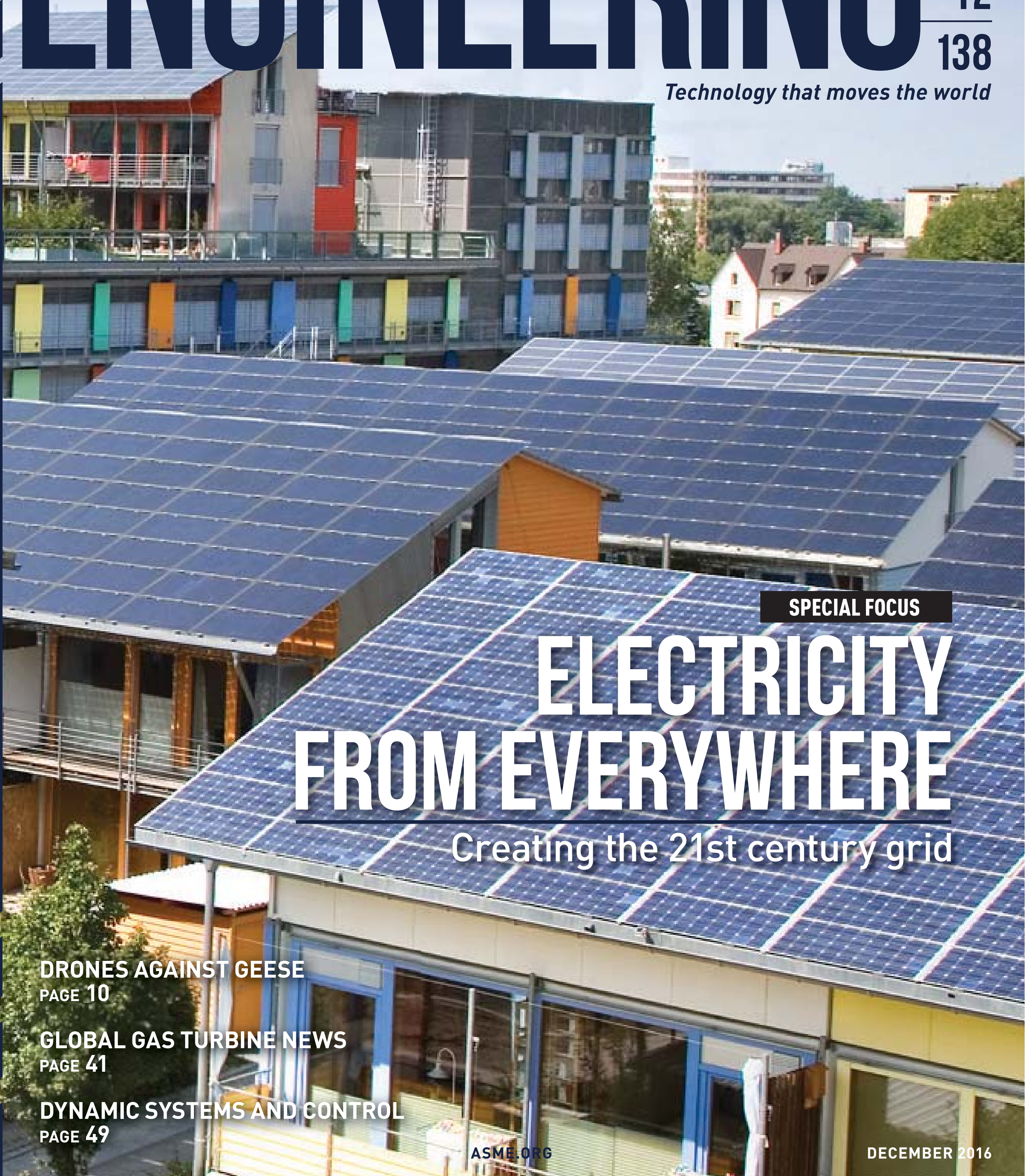
MECHANICAL ENGINEERING

THE MAGAZINE OF ASME

No. 12 138

Technology that moves the world



SPECIAL FOCUS

ELECTRICITY FROM EVERYWHERE

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DECEMBER 2016

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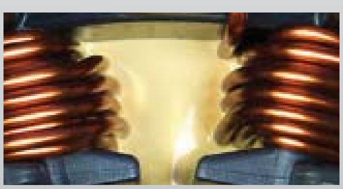
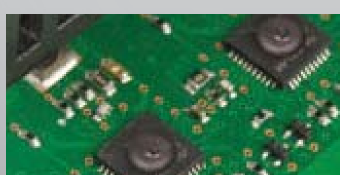


SILICONE-SENSITIVE APPLICATIONS

The increased use of camera and sensor applications have created the need for products that possess low volatility silicones or are completely silicone-free.



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THE 3-D PRINTED OFFICE OF THE FUTURE

FROM THEIR HUMBLE DOT-MATRIX DEBUT TO TODAY'S LASER-SHARP, light-speed models, printers have been the workhorses of office productivity for decades. But the government of Dubai has taken the idea of office printing to a new—and literal—extreme by printing an actual office. Unveiled in May 2016, Dubai's Office of the Future is said to be the world's first fully functional, 100% 3-D printed office building, constructed entirely of 3-D printed parts, inside and out. Structural components, interior furniture, fixtures, and detailing were all produced using a variety of industrial-grade 3-D printers, most notably a 20-ft.-tall robotic-arm-equipped goliath used to create the primary sections.

MANUFACTURING RELIES MORE ON SOFTWARE

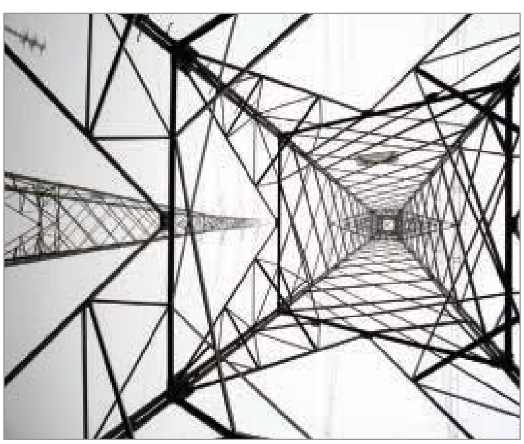
THE ROLE OF MECHANICAL ENGINEERS in machine design is being altered by a German manufacturer of advanced packaging equipment. Recognizing the growing importance of software in operating the machines, the firm is changing its sequential design process and emphasizing early development of software.

NEW GENERATION OF GAS TURBINES

JOHN LAMMAS, VICE PRESIDENT of gas power technology for General Electric, describes advances in gas turbines and the role advanced manufacturing and data analytics play in their design.

RIT READY FOR 3-D PRINTING 2.0

WHILE ROCHESTER INSTITUTE OF TECHNOLOGY has been building its additive manufacturing capabilities for nearly a decade, the establishment of a dedicated program and center devoted to 3-D printing is taking the technology to the next level.



SECURING THE POWER GRID AGAINST CYBER ATTACK

A CYBERATTACK ON THE POWER grid could have devastating consequences, yet the grid can't be secured with the same methods used for the Internet. Georgia Tech researchers have demonstrated a way to keep the U.S. power grid safe.

NEXT MONTH ON ASME.ORG

A SMATTERING OF SMART FABRICS
Researchers are at work on textiles that incorporate nanomaterials, sensors, and electronics that can automatically cool or warm the wearer, can generate electricity—and even recycle greenhouse gases.

HOW IoT IMPROVES DRIVER SAFETY
Dr. Yifan Chen, technical lead at Ford Motor Co., discusses how in-vehicle technology is changing the driving experience and the impact it will have on driver's safety.

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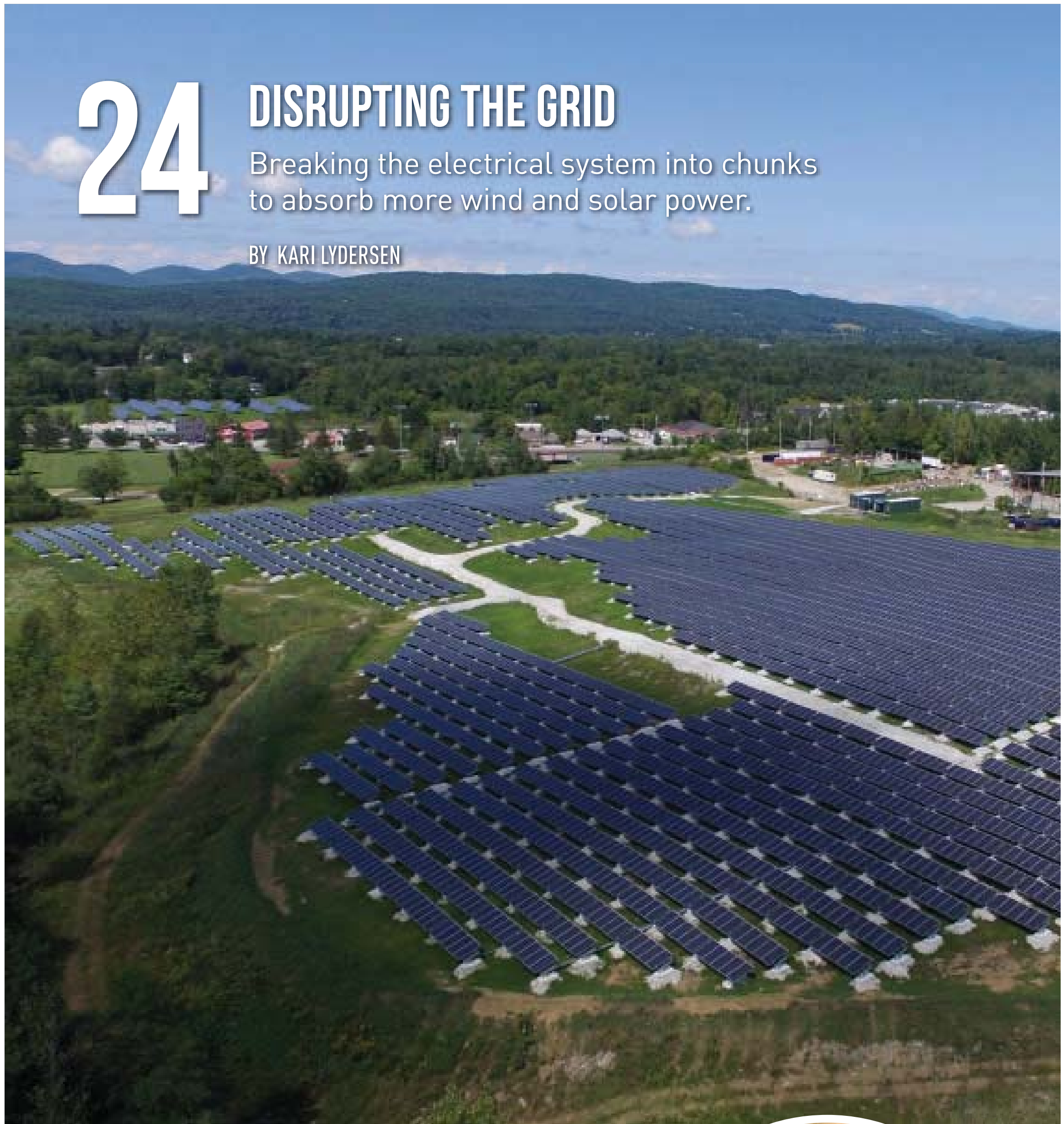
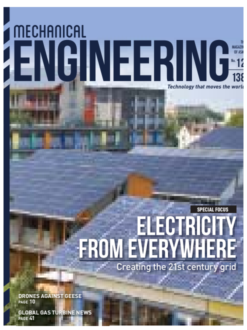


FEATURES



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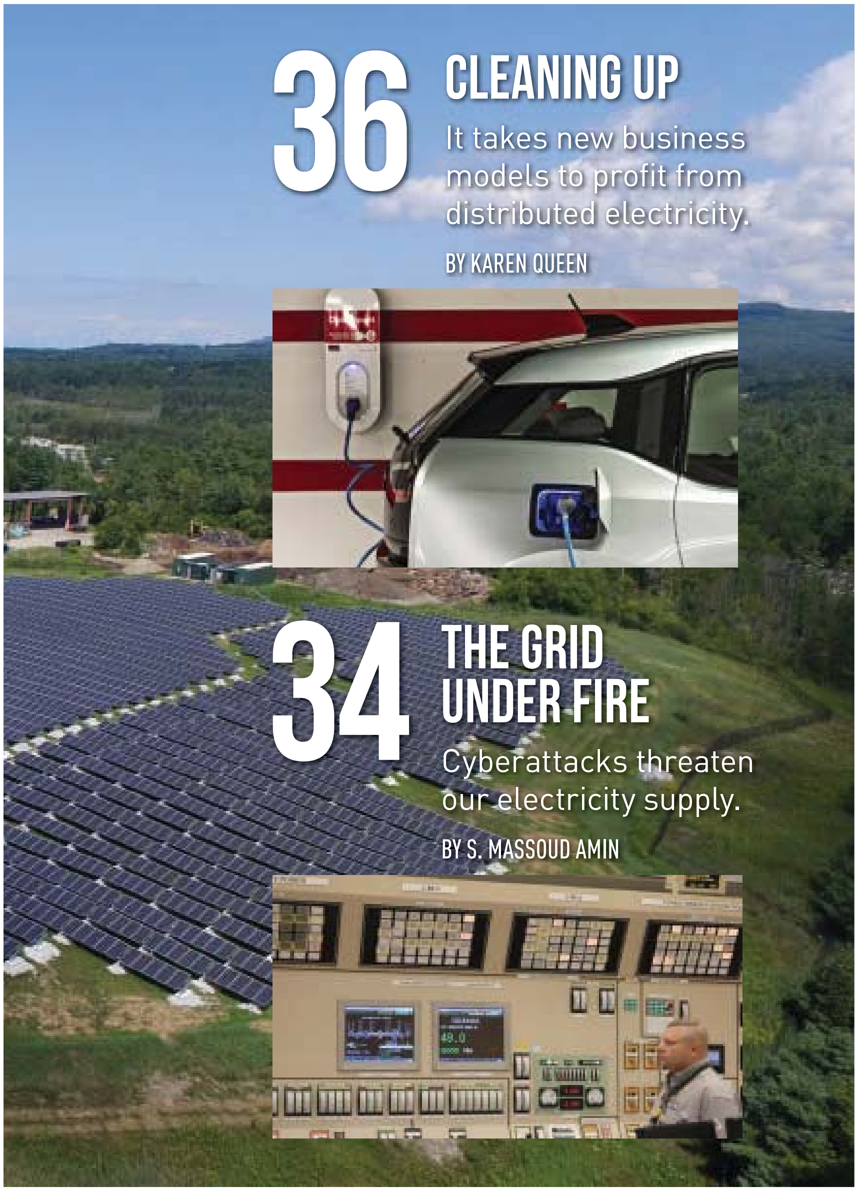
SETTING THE STANDARD



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It takes new business models to profit from distributed electricity.

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Cyberattacks threaten our electricity supply.

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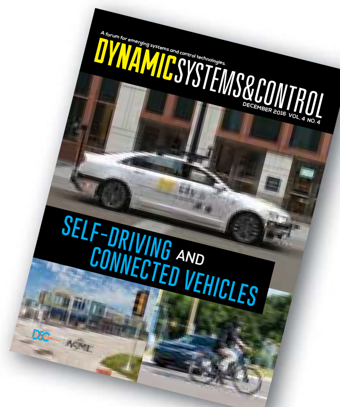

88 BUILDING WITH COCONUT WASTE

Turning sustainable fiber into an alternative to particleboard.

BY JEFF O'HEIR

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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, 150 Clove Road, 6th Floor, Little Falls, NJ 07424-2139. Return Canadian undeliverable addresses to P.O. BOX 1051, Fort Erie, On, L2A 6C7. PRICES: To members, annually $37 for initial membership subscription, single copy $7; subscription price to nonmembers available upon request.

John G. Falcioni
Editor-in-Chief

FLIPPING THE SWITCH ON RENEWABLES

Imagine flipping on the light switch at home and wondering: Will the lights come on? Those of us lucky enough to live in parts of the world where the electric grid is robust rarely consider that question unless a strong storm or unusual circumstances cause a blackout.

But we can't take the grid for granted. It's the world's largest supply chain with zero inventory, says Don Sadoway, the professor of materials science and engineering at the Massachusetts Institute of Technology who has been called the Socrates of Batteries.

I met the dapper Sadoway a few weeks back at the *MIT Technology Review* EmTech conference in Cambridge, Mass., but he's no newcomer to the energy space (you can view both his EmTech presentation and his 2012 TED talk online). His lab invented a liquid metal battery that some—including investor Bill Gates—think will revolutionize the way energy is stored and pave the way to broadening the use of renewable energy. Sadoway's company, Ambri, promises to deliver electricity where and when it's needed at low cost.

Storage is one of the hurdles renewables such as wind and solar have to overcome in order to become mainstream.

Just as energy storage may be the key enabler to promoting the diversity of our energy sources, technologies that increase the connection between electricity producers and end users are at the heart of the smart grid—a combination of sensors and controllers plus a process for using information and communication technologies to integrate the components across the electric system.

Those technological advances will contribute to what is expected to be the most fundamental change to the U.S. power system since its inception a century ago. Engineers will be on the forefront of developing the new products to improve the efficiency and resiliency in the evolving grid.

Some of the products that make the grid more interconnected and responsive include advanced meters, automated feeder switches, voltage regulators, and other controls technology intended to give the grid stability and resilience.

"By increasing the analytic data available to grid operators and energy users, smart technologies create an information bridge linking generation, transmission, and distribution with consumers," concluded a report this year from the Pew Charitable Trusts, an independent, non-partisan organization. "These capabilities allow grid managers and end users to make more informed decisions about how and when to use energy, based on grid requirements and price signals. And the additional information helps utilities manage their increasingly diverse generation portfolios."

Improving the efficiency and robustness of the grid—and enhancing the capabilities of renewable energy sources that connect to it—is important, but even more critical is safeguarding it. Grid and security experts agree that the grid is becoming increasingly and dangerously susceptible to cyber and physical threats.

A few months ago, Senior Editor Dan Ferber took on the challenge to coordinate and serve as lead editor for a package of related articles addressing these important energy topics. This month's comprehensive special focus on the grid is the culmination of Ferber's hard work.

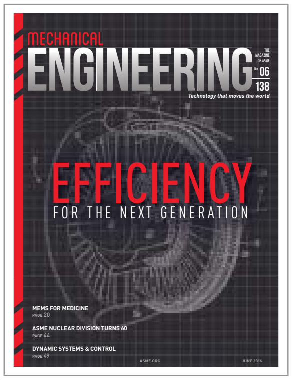
Our coverage provides a glimpse of what the electric grid of tomorrow might look like, even if we haven't yet fully flipped on the switch on renewable energy. ME

FEEDBACK

Are you worried about the robustness of the electric grid? Email me.

falcionij@asme.org

LETTERS & COMMENTS



JUNE 2016

Reader Sanders suggests that social change is key to stabilizing the climate.

« One reader touts combined heat and power, while three others comment on the necessity (if any) of tackling climate change.

POWER DIFFERENTIAL

To the Editor: In his April 2016 Trending article ("Renewable Energy Competitive on Costs") Jeffrey Winters seems to regard increasing the cost of coal energy as eliminating the price penalty.

If the article's key message rings true with utility execs (who should know 10 times more about this than either of us), then why are power utilities not rushing to close down current generation plants and open new, more efficient alternative energy plants?

Maybe they are, but the article did not tell us. Could it be the capital expense?

The bigger question that the article does not address is why some large metro areas have electricity costs four to seven times those of others, as depicted in the bar chart. Looks like what we all should be doing is trying to sell power generated in Atlanta to New York or Boston!

Allen R. York, P.E., *Raleigh, N.C.*

COMBINE HEAT AND POWER

To the Editor: The article "Renewable Energy Competitive on Costs" was interesting and informative, but there is one technology that you missed that is well worth mentioning: combined heat and power, or CHP.

Combined heat and power involves locating an industrial scale gas turbine generator near a "thermal host" and recovering the high temperature exhaust in a heat recovery steam generator.

This provides several advantages. For instance, transmission and distribution losses, which average 7 percent nationally, are virtually eliminated, and overall CO_2 emissions drop by about 45 percent when compared power from the wider grid and gas from a pipeline. What's more, reliability increases on the local grid and for the industrial host, and low-cost, highly dispatchable power is generated.

Waste heat can be sold in the form of steam to the nearby industrial host at a price lower than it could produce on its own in standard efficiency boilers. When that revenue is taken as a credit to fuel cost, CHP is among the most economically efficient forms of power generation on the planet.

Some utility companies and some state regulators are starting to see the benefits of having CHP included in the utility's integrated resource plans.

CHP brings social, economic, and financial benefits to our industrial and manufacturing base. It should play a much larger role in providing clean and reliable power.

Edward A Stoermer, *Cincinnati*

REALITY CHECK

To the Editor: The June 2016 feature on the international resolution to eliminate net human carbon footprint by 2050 ("New Engineering Thinking for a New Climate" by Michael E. Webber) made me think, "How typical to see politicians and academics celebrating an agreement that requires solutions to which they will have virtually no contribution."

Instead, as the author contends, the solutions will require another heroic effort by the technical community, specifically mechanical engineers. But is it reasonable that technical solutions can be found and implemented to reduce the net carbon emissions to the levels agreed on by 2050? Maybe it is time for a reality check.

The current human population of the earth is approximately 7.6 billion. Can earth resources sustain this population level?

Further, consider that the population is projected to reach between 9.5 and 10.5 billion by 2050, and that by then nearly 85 percent of that population will be in developing countries.

Is it reasonable to assume that people and governments in developing nations will voluntarily forgo economic and social advancement in favor of progress toward the global greenhouse gas emissions goal?

The real solution to global environmental stabilization and resource management is not strictly a technological problem. It will require significant, even revolutionary change in cultural, social, and economic systems around the world.

Those changes can only be driven by a governmental and political system with more insight and resolve than exists today.

Without that element to the solution, it will only be technology enabling mankind to move ever closer to more cataclysmic events and a decaying world environment.

Walter R. Sanders, *Vancouver, Wash.*

NOT SO TRANSFORMATIVE

To the Editor: Michael E. Webber erroneously assumes that all future electrical power generation must not produce carbon dioxide (June 2016). His argument is that such decarbonization must transform engineering practice, education, and society.

But Webber's solution to reduce carbon dioxide is to build natural gas plants,

plants whose design requirements are well known. What features of natural gas plant design requires massive transformation of society, education, and engineering?

Frederick Willis, *Haddonfield, N.J.*

WHO IS THIS "WE"?

To the Editor: Michael E. Webber states, "We need to drive down net emissions of carbon before 2050."

I know that anyone that speaks out against the Intergovernmental Panel on Climate Change is considered an outlier, but the number of credible climate scientists that disagree with the IPCC is growing.

The science of climate change and the credentials of the IPCC need to be looked at with open eyes.

Barry Toppings, P.Eng., *Calgary*

ENGINEERING ETHICS

To the Editor: I want to respond to a letter in the February 2016 issue which stated that licensed PEs have higher ethical standards than those of us working in industry.

I have some personal experience working for a defense contractor, and I would be interested in seeing actual data about engineering misbehavior comparing non-defense employed civil engineers, almost all of whom are licensed, with mechanical engineers working for defense contractors, most of whom are not licensed.

The letter may be correct, but someone disparaging vast armies of working engineers should have numerical backup.

It seems to be wise advice that we do well by doing good, and that the ASME Code of Ethics Principles and Canons are excellent guidelines for all of us. Ethical behavior is smart behavior. If you tell the truth, the entire universe supports you. The consequence of being caught in a lie is that people will not believe you in the future.

Someone once wrote, "Out of the crooked timber of humanity, no straight thing was ever made." The person who said this evidently never worked in a defense factory, where great efforts are made to be completely transparent with the DOD.

Dudley M. Jones, ASME Life Member, *Princeton, N.J.*

FEEDBACK Send us your letters and comments via hard copy or e-mail memag@asme.org (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.

ROBOTS TO THE RESCUE

LIFELIKE FALCON OFFERS GENTLER, PERMANENT SOLUTION FOR CHASING AWAY PROBLEM BIRDS

Aircraft are in danger of bird strikes every time they take off or land. Some strikes can be crippling, such as the one that forced a US Airways jet to ditch into the Hudson River in 2009. But less devastating strikes into windshields, turbines, propellers, and elsewhere caused an estimated $1.2 billion in aircraft damage worldwide last year.

Airport authorities have responded to the threat by culling flocks of geese from nearby waterways. Mechanical engineer Nico Nijenhuis, CEO of Clear Flight Solutions in Enschede, Netherlands, has a gentler solution: flying robots that chase away the problem birds.

Other non-lethal deterrents, such as flares or flash-bang grenades, are short-term solutions, Nijenhuis said. His robot instead taps into the birds' most primal drive—the fear of predation.

Robird taps into the primal fear of predation that's shared by all birds, whether they gather at airports, farms, or waste management facilities.

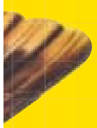
The Robird, with its carefully detailed 3-D printed nylon fiber body and foam wings, mimics the look and flight pattern of a Peregrine falcon, one of the most widespread birds of prey and one known to feed exclusively on medium-sized birds, such as gulls, pigeons, and waterfowl. The company also makes an eagle to chase different species of birds in specific locals.

"Because of the way they look and move, the Robird triggers an evolutionary reaction of a bird to a predator. The birds don't come back because the predation risk is too high," Nijenhuis said, adding that the Robird chased away about 70 percent of the birds from areas where they've been tested.

"We're really baiting nature against nature."

Replicating nature, though, isn't easy.

The biggest challenge was designing a foam wing that would move enough like a falcon's to duplicate the way it flies and trick prey into thinking they're being hunted by the real thing. That's difficult because the surface of the wing constantly changes as it reacts and adjusts to moving air during flight, making it nearly impossible to create accurate 3-D aerodynamic computer simulations, Nijenhuis said.



The greatest challenge was creating a wing that replicates a falcon's movement.

Nijenhuis discovered that fewer moving parts, along with the right sensors and stabilization software, produced a satisfactory wing motion and beat frequency. He also figured out a way for the wing to automatically twist and adjust so that it moves through the air with maximum efficiency.

"That's our secret," Nijenhuis said, adding that the Robird can fly at speeds up to about 50 mph and withstand impacts while travelling up to 30 mph. "The bird is a smart machine that takes incoming signals and translates what it's supposed to do."

Developing a system to communicate those commands was also problematic. The motion of the Robird's constantly moving body creates lots of "noise" that disrupts communications between the robot's onboard flight computer and its sensors, gyroscope, and accelerometer. To overcome that, Nijenhuis and his team programmed "very smart filters" into the flight computer.

Clear Flight is currently working on a fully autonomous Robird with cameras that will gather data during flight and help the robot make intelligent decisions. For now, the company uses trained pilots to operate the robots via remote control.

After about three months of patrolling by the robot, Nijenhuis said, the local birds internalize that there's a predator in the area and decide to find a new home—hopefully one that isn't adjacent to an airport. **ME**

JEFF O'HEIR

The ARES system stores energy by running heavy trains uphill. Slowing the trains as they return downhill sends electricity back to the grid.
Illustration: ARES

POWER TRAIN

A California company builds locomotives to store electricity from the grid.

Solar- and wind-powered systems claim increasing shares of power production. The U.S. Energy Information Administration reports renewable sources now generate 13 percent of the nation's power, with wind and solar providing 40 percent of that total.

But the intermittent nature of wind and solar production is a problem. Energy storage can take up some of the slack, and engineers and researchers are looking mostly to batteries for that task, but scaling them up to handle megawatts of power remains elusive and costly.

Now, a California startup is turning to an old but improved standby technology to feed the grid on as as-needed basis. Advanced Energy Rail Storage (ARES) has developed a mechanical system patterned after pumped-storage hydroelectric projects, which continue to be the most efficient system to provide peaking power. But those projects require lots of land as well as water. Permitting is complex and can take years. ARES points to the simplicity of its system and lower costs as an alternative.

Instead of pumping water to an upper reservoir and releasing it back to the lower reservoir, ARES runs trains of ore carriers loaded to 120 tons up a grade when electric demand is low, and then brings them back down when demand is high. Inductive motors fitted to the wheels provide power for the uphill run, and then generate electricity on the downhill run. The system has the same regenerative braking principals as electric cars such as the Toyota Prius or Chevy Bolt.

"We're just using gravity, not water," said Francesca Cava, ARES vice president of operations. "It's relatively simple, and that's the genius in it really."

ARES has successfully operated a pilot project in Tehachape, Calif. Now, it is building a 50-MW project in Nevada with Valley Electric Association. The utility will provide the interconnection to California, where ARES will sell the ancillary service power. ARES is funding the $55-million

continued on p.13 »

MAKING RENEWABLES WORK

Grid operators face real challenges in integrating wind and solar power. Maybe we need to **rethink the relationship between electricity supply and demand.**

As the nation pushes for cleaner forms of energy, solar and wind power are increasingly popular choices. To the consternation of grid operators pushing for six 9s of reliability, however, wind and solar do not behave like traditional power plants. Rather than being dispatched by a central control center, wind and solar power come and go according to a schedule set by the forces of nature.

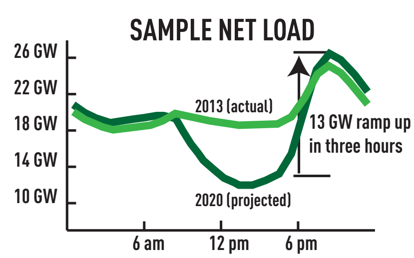
Conventional wisdom holds the very clear and firm conviction that this makes renewables bad for reliability. Many esteemed organizations and deep thinkers have declared that once renewables pass a fairly low percentage of grid capacity, usually something like 20 percent, the system faces severe challenges.

But is that true?

Unquestionably, wind and solar are variable and that variability can be problematic. The sun doesn't shine at night, and wind is far from steady. If the wind dies down suddenly or if we have weeks of overcast skies, then the balance of the grid must fill in the gap, which can be expensive or a strain on the entire system.

Wind is particularly vexing because in the mid-continent, where we have abundant wind resources, the wind blows strongest in the spring in the middle of the night—which is when demand for electricity is the lowest. And onshore wind is weakest on the hot summer afternoons when we need it the most.

Solar power matches up a little better. It is most abundant on sunny days, when our demand is usually highest. But solar energy has its own problems: Sunshine peaks in the early afternoon, but the latency in heating up the thermal masses such as the air, land, and water shifts the hottest part of the day to a few hours later, as the sun moves toward the horizon. That means just as demand is rising from air conditioners and people coming home from work and turning on their residential appliances, the amount of electricity produced from solar panels is crashing and dispatchers have to rapidly ramp up many other thermal generators to balance the load.



These ramps can be as steep as several GW of capacity coming on line each hour. Thermal plants don't like to be cycled up and down, so each of these rapid ramps induces strains on the equipment, driving up costs and introducing safety risks.

In sunny California, which has the highest penetration of solar panels in the nation, the gap between total load and the part that solar doesn't satisfy is called a Duck Curve—a fat middle during the heart of the day followed by a steep ramp upwards, which is the ducks' neck. (See inset.) In Texas we call it the dead armadillo curve, as it is reminiscent of the familiar roadkill.

Is that a symbol of what renewables do to grid reliability? It doesn't have to be.

Turning power plants up and down so that the supply matches our demand represents legacy thinking. Instead, what if we turned our demand up and down to match when the supply is available? Electricity storage systems—such as batteries, pumped hydropower, or compressed air in underground caverns—can help us achieve that goal, storing wind and solar electricity when it's available and letting us consume it later when we need it or want it.

We can also shift a lot of our processes to work sometime other than the peak of the day. Treating water, operating data centers, and many types of manufacturing can be done flexibly. Pumps for municipal water systems often work 8-to-5, coinciding with the worker's shift, but a lot of those processes could be done just as easily at night. There are many more examples of this type of load-shifting.

It will take some ingenuity and an embrace of a new relationship between electricity supply and demand, but a renewable-dominated power system can be just as reliable—or even more reliable—than what we have today. ME

MICHAEL E. WEBBER is deputy director of the Energy Institute at the University of Texas at Austin.

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ENERGY: POWER TRAIN

project in-house, mostly through private investment, Cava said.

ARES will provide the power through seven trains operating on a 5.5-mile-long track built on an 8-degree grade, gaining about 2,000 feet in elevation. Each train will have two locomotives and seven unpowered rail cars. Each locomotive is weighted to achieve a 38-ton axle loading, Cava said, and the 120-ton cars are loaded with rocks, which operate at a 30-ton axle loading.

The locomotives are powered by remanufactured EMD SD-40 Bogies converted from dc traction drive to ac traction drive. The motors reverse to operate as generators on the downhill run. Power is provided to the system via a 25 kV overhead catenary system.

ARES executives see the responsiveness of the system and its low environmental footprint as two large advantages. It can go from full discharge to full charge in 10 seconds in response to the grid operator, which sends signals every four seconds to balance supply and demand. Maximum speed is 20 mph, and Cava said the seven trains can respond to the grid's signals, moving up and down the track in small increments as determined by the need.

Although a 50-MW system is considered large for a battery-storage project, its economics are improved by increasing the scale. ARES executives say they could double capacity of a 500-MW system and increase capital costs by only 20 percent

ARES Nevada costs are estimated at $4,400 per kWh storage with capital costs of $1,100 per kW. An analysis by Deloitte reports the cost of lithium ion batteries at $1,000 to $2,000 per kW; compressed air storage systems at $1,600 to $2,200 per kW; and pumped hydro storage at $1,200 to $2,100 per kW.

"The market is huge," Cava said. California alone has a mandate to add 1.3 GW of storage by 2020. "If the country goes more and more to renewable energy, if it goes beyond 30 percent, you'll need energy storage," she said. "For cities or small towns, batteries may be the answer. But in the West, we're not the only alternative but we are the cheapest."

While the Tehachapi tests showed the system operates best on grades of six percent to eight percent, ARES is already developing plans to adapt the system to steeper grades. Cava said the next demonstration could use a cog railroad. "We could operate at a steeper grade over a shorter length," she said, which would open the system up to more terrain. **ME**

JOHN KOSOWATZ, ASME.ORG

Q&A AUDREY ZIBELMAN

NEEDED: A POWER GRID THAT'S more resilient, where clean, affordable power from solar and wind is easily balanced by electricity demand. As chair of the New York State Public Service Commission, Audrey Zibelman spearheads Reforming the Energy Vision, the state's ambitious plan to strengthen the grid, spur clean-energy innovation, and make New York an energy-policy leader. Zibelman, an attorney, has also served as chief operating officer of PJM, which manages the mid-Atlantic electrical grid, and as founder and CEO of Viridity Energy, a smart-grid startup.

ME: You've devoted decades of your life to the energy sector. What drew you to the business?

A.Z: What is fantastic about the energy sector is that there are very few areas of the economy where you can say you can have such a huge positive effect in getting it right and such a huge negative effect if you get it wrong. Being part of that was always intellectually challenging and stimulating.

ME: You were a successful executive at Viridity Energy. Why did you leave the private sector to become a regulator?

A.Z: I became convinced that the impediment to innovation in the energy sector was not a technology issue. It's an issue of how to think about the regulatory and the business models differently. We really need to rethink how energy is supplied, delivered and consumed in the state.

ME: What needs to be rethought?

A.Z: As we start looking at climate change, we [first] need to recognize, as we've done in New York, that the environment is not a subsidiary of the economy. The economy is a subsidiary of the environment. Second is recognizing that the power system itself is designed around some principles of usage inelasticity that were true in the last century, but are not true anymore. If we can make the system more responsive to price using distributed energy resources and energy efficiency better, we can make the system more [resilient], capital efficient, and help it maintain affordability. Third is recognizing that we need to stop thinking about customers as passive. The role of the utility is no longer simply to deliver to the meter, but how to integrate in these distributed resources and think about demand as a balancing resource.

ME: What needs to be changed in the regulatory model?

A.Z: We're doing that in New York by enabling utilities to look at innovative ways to develop their services and charge for them, so they become new sources of revenues, rather than a form of revenue erosion. The goal is to reduce the total consumer bill by making the system more efficient.

ME: Why is it important to increase the percentage of distributed renewable resources on the grid?

A.Z: The issue is not necessarily to increase the level of distributed renewable resources on the grid. The state has a goal to [obtain] 50 percent of its [energy] from renewable resources by 2030. But because these renewable resources are intermittent by nature, you need to be able to make sure you maintain balance all the time. The traditional way of looking at this was, Let's put in more fossil fuel, and we'll run the fossil fuel plants when wind and solar isn't available. The modern way to think about it is to say, "How do we use distributed energy resources, and have demand management and load responsiveness become a balancing resource [to match fluctuating supply]?" Rather than generation following load, how about load following generation? That was one of the things that we identified as a huge opportunity.

ME: What renewable resources and energy conservation strategies do you use at home and in your life?

A.Z: I don't let [my family] keep the air conditioners on if they're not in the room. Keep the lights out. We have all LED lighting. I take public transportation. We walk everywhere. On energy efficiency, my family will tell you I'm a pain in the neck to live with. **ME**

KAREN HAYWOOD QUEEN is a Virginia-based technology writer.

TWO SUSTAINABLE SOLUTIONS TO WASTE MANAGEMENT

Not every organization has to take the same approach to manage the growing mountain of waste generated in the developing world.

Three billion people—some 40 percent of world's population—lack access to safe waste disposal facilities, according to the UN Environment Program. Two billion do not even receive basic trash pickups. That's a big problem, since waste that is not collected or disposed of safely jeopardizes public health, degrades quality of life, and pollutes the environment.

Waste will be a major global challenge for our generation, and we can solve it through innovation and leadership.

Innovation and leadership can arise from every part of the society and from anyone, wherever they are in the world. Wecyclers in Nigeria and Haritha Gramam in India are two organizations that are improving lives in their communities by solving their waste management needs.

Lagos, Nigeria, is a megacity with nearly 20 million people, but only 40 percent of the city's waste is collected. The rest of the waste and recyclables end up on the streets where they eventually clog sewers. The narrow streets and an underdeveloped road network in densely populated parts of the city make it difficult to use trucks to collect waste.

Wecyclers' solution is a fleet of three-wheeled bicycles with tall chutes. The bikes go around Lagos collecting recyclables and rewarding households that provide materials with points through an SMS-based system. The bicycles can easily pass through narrow streets, and families can redeem points for groceries, mobile services, or other household items as incentives to participate.

Last year, Bilikiss Adebiyi, a co-founder of Wecyclers, told me that it was difficult to get people to participate initially. But, once they saw improvement in their surroundings and children's health, getting people to enroll for their service has become easier.

Meanwhile, areas of India are urbanizing rapidly, which is severely stressing its waste collection infrastructure.

The waste in Thiruvananthapuram, a city of nearly a million in southern India, used to be sent to an outlying dumpsite where it caused respiratory illness and infection. The villagers near the dump went on a hunger strike and carried out demonstrations to get the dumpsite closed.

With nowhere to dump, garbage piled up on the streets of Thiruvananthapuram. The garbage was openly burned—other methods of handling the waste were difficult because the residents of Thiruvananthapuram were mixing organic and inorganic waste.

Out of the few options available to manage waste at such a scale, composting mixed waste is gaining momentum in India. However, compost generated from mixed waste

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HOT BODY, HIGH ENERGY

New types of thermoelectric generators use body heat to power wearable electronics. *Photo: NCSU*

NO ONE WANTS TO STOP to recharge mobile devices, especially their wearables. That's why researchers are developing applications that use motion, sunshine, and unique materials to generate sustainable electrical power. This month we focus on two labs that are taking the research in new directions. has developed a clothing fabric that harvests energy from friction and light, while the other has created wearable thermoelectric generators that use body heat and air to create electricity.

When Daryoosh Vashaee's team at North Carolina State University began making a personal lightweight thermoelectric generator to power wearable electronics, they decided to use ultrathin heat spreaders instead of larger, more common heat sinks. More experienced engineers laughed. They said spreaders could never generate sufficient energy. In the end, Vashaee had the last laugh.

"It was a big surprise that we could produce this much power with this type of design," he said.

The team's new generator converts body heat to 10 to 100 microwatts of electricity from one-centimeter square surface area of the skin. This is up to 20 times more power than some versions that use a heat sink. Designed to replace batteries in low-power wearables, the generator is small, flexible, and comfortable enough to sit next to the skin.

Personal generators that use heat sinks are too bulky and stiff for that type of application, Vashaee said. Yet designing such a small, efficient generator posed a few big challenges.

Thermoelectric materials, Vashaee explained, generate electrical current when their electrons move from a hot side of the material to the cold side. The greater the temperature difference, the greater the current and the power generated. The

WEARABLE GENERATOR

THE LAB NanoScience and Engineering Research Group, North Carolina State University; Daryoosh Vashaee, principle investigator.

OBJECTIVE Develop wearable technologies for long-term health monitoring devices.

DEVELOPMENT A lightweight, wearable thermoelectric generator that harvests body heat and converts it to energy.

trick is to dissipate enough heat to keep one side cool while the other heats up, which is difficult when the entire device is only 2 mm thick.

"You don't have a lot of room to play with," Vashaee said.

To overcome those challenges, the team sandwiched the generator, a bismuth telluride alloy, between two heat spreaders made from thin, flexible copper sheets. The sheet closest to the skin absorbs body heat. The researchers capped that sheet off with a layer of polymer, which forces the heat into the generator rather than letting it escape into the outside air. Excess heat passes from the generator to the outside heat spreader, where it's quickly dissipated, the team wrote in a recent paper published in *Applied Energy.*

The team further optimized its TEG with a customized supercapacitor that can store power for up to three months and a DC-DC boost converter that increased voltage from a millivolt to a volt, enough to power sensors, accelerometers, transmitters, and other components found in wearables.

"The challenge is to make the system work efficiently as a whole," Vashaee said. ME

Special fabrics generate energy from sunlight and movement.
Photo: Georgia Institute of Technology

ENERGY HARVEST

THE LAB The Nanoscience Research Group at the Georgia Institute of Technology School of Materials Science and Engineering; Zhong Lin Wang, lead professor.

OBJECTIVE Create textiles that simultaneously harvest energy from sunshine and motion.

DEVELOPMENT Combined two types of electricity generation into one fabric.

Back in 2009, Zhong Lin Wang developed a hard device based on zinc oxide nanowire arrays that generated electrical power from motion and sunlight. But that device was not nearly as practical as his new invention: a fabric that harvests mechanical and solar energy to power mobile devices. The fiber can be sewn into clothing, flags, tents, sails, curtains, and many other products.

"People today are so interested in flexible, wearable electronics. So we began to think about ways to use the energy that's always with us to power the devices that are always with us," said Wang, a professor of materials science and engineering at Georgia Tech.

The fabric consists of two kinds of fibers: photovoltaics that generate power from sunlight, and triboelectrics that convert mechanical contact and motion to power. Copper electrodes collect the current they generate.

To harvest friction-generated power, Wang uses copper strips coated with a fluoropolymer. The material becomes electrically charged when it rubs against the copper electrode, much the same way a balloon picks up a static charge when rubbed on clothing.

The photovoltaic fibers consist of zinc oxide-nanowire arrays grown on a manganese-plated polymer wire.

The researchers wove the fibers for the two fabrics using conventional industrial weaving equipment into a pattern that delivered the highest illumination area ratio and current density. The two textiles are then woven together and can be integrated with other fabrics, depending on the use.

In tests, a 4-by-5-centimeter piece of the fabric under sunlight and normal movement charged a commercial capacitor up to 2 V in one minute. Under movement and sunlight, the fabric generates from 1 to 10 mW of power; it produces 1 to 5 mW using sunlight only. It takes about 10 mW to power a typical electronic sensor, Wang said.

Wang believes he can improve the fabric's performance and durability to prepare it for commercial use in about three years. ME

JEFF O'HEIR

LOOKING BACK

Researchers were still working to understand the mechanics of firestorms when this article was first published in December 1986.

THERMOHYDRODYNAMICS OF DESTRUCTION

GEORGE F. CARRIER, DIVISION OF APPLIED SCIENCES, HARVARD UNIVERSITY, CAMBRIDGE, MASS.

FRANCIS E. FENDELL, ADVANCED TECHNOLOGY DIVISION, TRW, REDONDO BEACH, CALIF.

Two experts in heat transfer look at the firestorms that led to the destruction of cities such as Dresden during World War II.

The term firestorm is, in this context, an apt one. In a conventional meteorological sense, a storm is usually a cyclonic wind with a center of low surface pressure. This is generally accompanied by precipitation and convectively induced advection. That is, if low-altitude, warm, moist air is lifted to its height of saturation, further buoyancy-induced ascent takes place because of the release of condensational heat. Under continuity, a radial influx accompanies updraft, as, perhaps, does "spin-up" under conservation of angular momentum associated with the rotation of the earth or with some locally enhanced ambient circulation.

Just as firestorms are exceptional fire events, so mesolows (thunderstorms with organized, Rankine-vortex-type rotation, also referred to as tornado cyclones and supercells) are uncommon relative to the total number of thunderstorms. Mesolows are characterized by a horizontal scale of several kilometers and a lifespan of about six hours. Further, just as the mesolow is characterized by towering cumulonimbi ascending through the depth of the troposphere to the tropopause, so the firestorm is characterized by a convective column ascending to exceptionally great heights.

A firestorm may be a "heat cyclone," a mesolow in which exothermicity of combustion, as distinguished from the condensation of water vapor, induces free convection. For natural polymers (woods), the exothermicity, even when desiccation and pyrolysis losses are taken into account, may approach 20,000 kilojoules per kilogram of fuel burned; the exothermicity of gasoline is 45,000 kilojoules per kilogram, a value approached by some synthetic polymers (plastics) that were relatively uncommon at the time of the Second World War.

The observation at low altitudes of appreciable radial influx from all directions toward the base of the central convective column is consistent with a primarily rotating air motion through much of the depth of the local troposphere. Investigation of the near-surface inflow layer near the center of a vigorously rotating air mass over a fixed flat surface shows that high-speed, purely swirling motion is altered to equally high-speed, purely radial influx near the ground, although at immediate ground level the nonslip constraint holds. ME

AROUND THE WORLD IN NINE DAYS

As Carrier and Fendell were describing firestorms, a record-breaking aeronautical feat was taking place. The Rutan Voyager took off from Edwards Air Force Base in California on December 14, 1986, piloted by Dick Rutan and Jeana Yeager. The 2,250-pound fiberglass, carbon fiber, and Kevlar aircraft headed west over the Pacific Ocean laden with more than 7,000 pounds of fuel and supplies. Voyager remained in the air—without refueling—for 9 days, 3 minutes, and 44 seconds before returning to Edwards after circumnavigating the globe, flying 26,366 statute miles at an average altitude of 11,000 feet. Rutan and Yeager had little room for error: When they landed, they had burned through 98.5 percent of their fuel.

The Voyager on its round-the-world flight. *Credit: NASA*

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SUSTAINABILITY: WASTE MANAGEMENT

is of low quality and contains heavy metals, which could enter the food chain.

Thiruvananthapuram did have two key advantages: most households had space for growing plants, and the population was well educated. The startup Haritha Gramam leveraged those features by providing nearly 3,000 households with briquettes made of coconut fiber laced with a bacterial culture. The bacterial culture activates when wet organic waste is added, converting the waste into a rich compost. The remaining household waste, which is mostly recyclables, is easily collected and recycled.

Haritha Gramam also provides gardening services to encourage people to use this compost in their households.

These are just two of many concepts to dealing with waste disposal in the developing world. As people better realize the urgency of the global waste problem, more innovators and leaders will step in with additional solutions.

RANJITH ANNEPU is an international waste management consultant and a co-founder of the non-profit organization, Be Waste Wise. For more information on development engineering, visit Engineeringforchange.org.

BIG NUMBER

1.5 Billion

ESTIMATED NUMBER OF PACKAGES DELIVERED IN THE U.S. BETWEEN THANKSGIVING AND CHRISTMAS IN 2015.

SANTA ISN'T THE ONLY ONE busy delivering gifts over the holidays. The rise of online retailing has led to a booming business for parcel delivery companies. Last year, the United States Postal Service and UPS estimated that they would deliver close to 600 million packages each between Thanksgiving and Christmas Day, while FedEx projected it would deliver more than 300 million. In spite of all the talk of drone deliveries, each one of those 1.5 billion parcels was delivered by a human courier.

BY THE NUMBERS:
THE COMPETITIVENESS COMPETITION

Nations use international comparisons as measuring sticks—or cudgels. But not every measurement is useful.

If there's anything that nation-states love, it's competing against one another. The world slows down to watch international sporting events such as the Olympics or the World Cup, and reports ranking countries by some arbitrary metric are widely read and cited.

Take, for instance, the Global Competitiveness Index produced by the World Economic Forum, the non-profit group that gathers thought leaders in Davos, Switzerland, each winter. The index synthesizes dozens of data sets across what the group calls the 12 pillars of competitiveness. Those pillars are: institutions, infrastructure, macroeconomic environment, health and primary education, higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, market size, business sophistication, and innovation.

One can argue about the importance of any given "pillar" or how well the data supports it—for instance, just how do you measure wasteful government spending in hundreds of different national settings? And too often politicians use those sorts of metrics to bolster support for policies in the name of competitiveness, no matter what their real-world effect would be.

One can even question whether these comparisons are meaningful at all.

Take the top 15 countries on the index. They are a grab bag of major industrial powers, small nation-states, and two city-states that have made the most of their locations on major trade routes. Economic competitiveness likely means something different in Switzerland and Singapore than it does in the United States, but those countries are listed first, second, and third on the index.

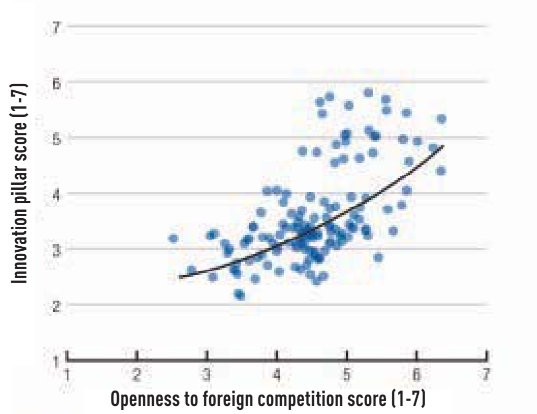
To the extent that the measurements are meaningful, the relative rankings shed some light on the concept that the United States and other Western industrial democracies are being out-competed by developing nations, especially China. According to the World Economic Forum data, at least, China lags behind every major industrial nation, especially in measures of innovation and use of Internet technologies. Brazil—another member of the so-called BRICS group, with Russia, India, and South Africa—is docked for, among other things, high tax rates, weak institutions, and pervasive corruption.

To be sure, nations can learn from the best practices of other countries. One of the insights the authors gleaned from this year's data is the positive correlation between overall innovation and openness to foreign trade, investment, and competition. (See the chart above.) The report cites the importance of global value chains (GVCs) in promoting innovation, especially at the city level.

"GVCs provide a vehicle for cities to take part in the global economy through trade and investment," the report states. "They can contribute to making cities vibrant magnets for innovation, productivity increases, and employment." That's an especially important lesson in an era when many countries are drawn toward economic protectionism.

Sometimes it makes sense to leave the zero-sum international competition at 11 versus 11, rather than millions versus millions. ME

The level of openness of a nation corresponds with the amount of innovation it produces.



Source: World Economic Forum

JEFFREY WINTERS

Bastian Schweinsteiger celebrates Germany's win at the 2014 FIFA World Cup.

GCI GLOBAL COMPETITIVENESS INDEX

Major industrial powers, small nation-states, and two city-states are rated as most competitive, while some countries thought to be emerging powers lag well behind.

RANK	COUNTRY/ECONOMY	SCORE
1	Switzerland	5.8
2	Singapore	5.7
3	United States	5.7
4	Netherlands	5.6
5	Germany	5.6
6	Sweden	5.5
7	United Kingdom	5.5
8	Japan	5.5
9	Hong Kong SAR	5.5
10	Finland	5.4
11	Norway	5.4
12	Denmark	5.3
13	New Zealand	5.3
14	Chinese Taipei	5.3
15	Canada	5.3

THE BRICS NATIONS:

28	China	5.0
39	India	4.5
43	Russian Federation	4.5
47	South Africa	4.5
81	Brazil	4.1

Source: World Economic Forum,
The Global Competitiveness Report 2016–2017

The New, New

The electric grid powers our homes and businesses, transports us nationwide, fuels prosperity, and saves lives by the thousands.

It's so important that the National Academy of Engineering called the grid the greatest engineering achievement of the 20th century. In recent years, however, concerns about climate change, pollution, and energy independence have led to new policies to promote wind, solar, and other forms of renewable energy. These policies, along with technological advances and shifting economics, have pushed the grid to the brink of a historic transformation.

Today, most of our electricity comes from large central power plants, typically coal, natural gas, or nuclear plants. It moves one way through transmission lines, substations, and feeder lines to our businesses, schools, and homes. Little energy is stored on the grid, so the grid functions as a just-in-time delivery system, where electricity generation must constantly match demand.

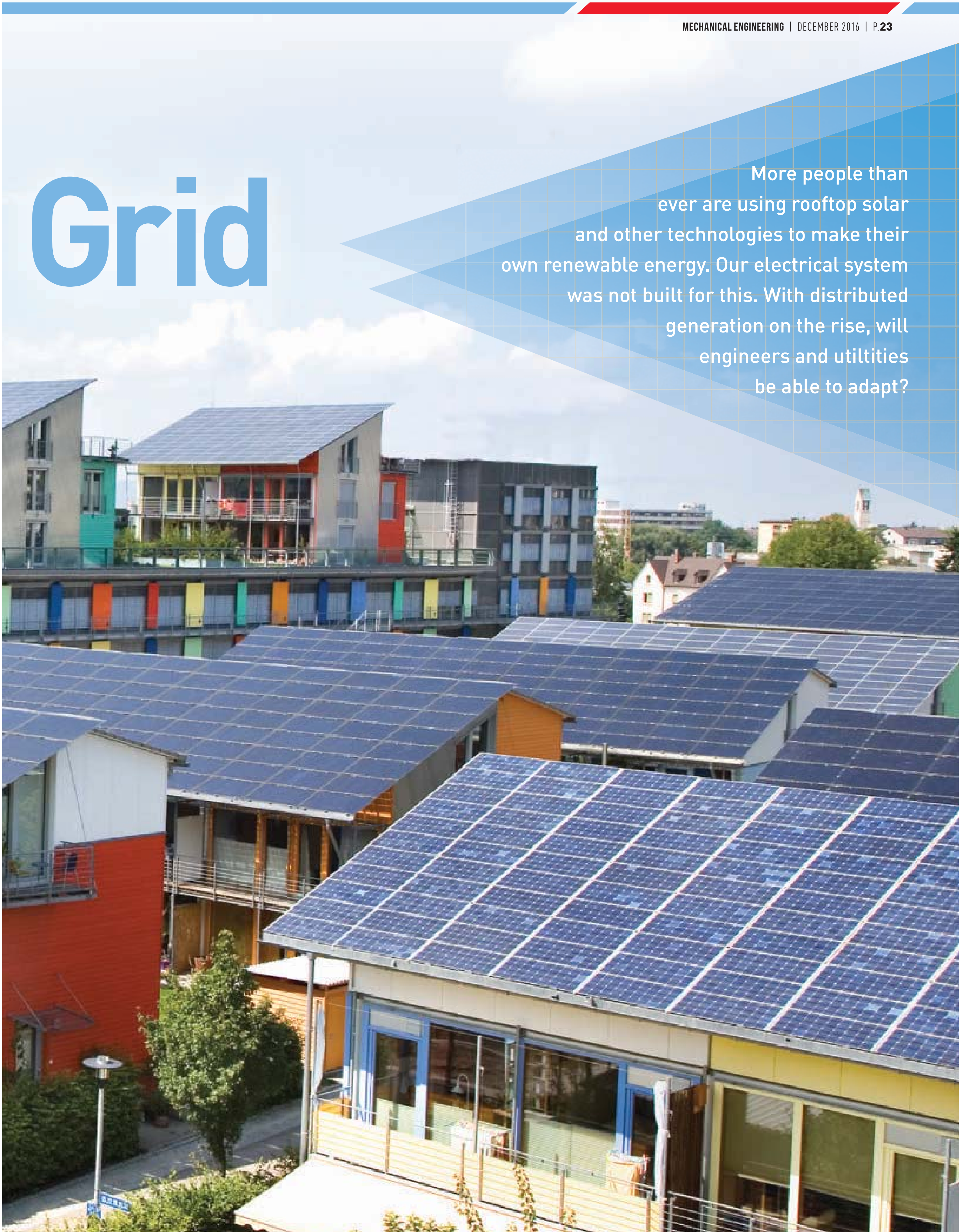
On tomorrow's grid, more electricity will come from wind and solar. Wind fluctuates with the weather, solar fluctuates with the cloud cover and time of day, and this intermittency makes it harder to balance supply with demand. In addition, more customers will generate their own electricity from rooftop solar panels, small wind turbines, and other distributed generation sources, with excess electricity flowing back to the grid. The existing grid was built to manage one-way power flow, so to handle the two-way power flow, it will have to be retrofit.

Building the clean, smart grid of tomorrow requires new technologies, new policies, and new business models. This special package explores this transformation, which has already begun.

—*Dan Ferber, Senior Editor*

Grid

More people than ever are using rooftop solar and other technologies to make their own renewable energy. Our electrical system was not built for this. With distributed generation on the rise, will engineers and utiltities be able to adapt?



Disrupting the Grid

By Kari Lydersen

When its famous marble quarries closed in the 1980s, Rutland, Vermont, lost hundreds of jobs and its once-thriving economy fell into decline. Foreclosures, unemployment, population loss, heroin addiction, and other ills plagued the town of about 16,500 residents.

But Rutlanders dreamed of a brighter future—literally.

In this far northeast corner of the country, which is known more for its environmental consciousness than its sun, many Rutland residents developed a keen interest in solar energy. They soon found a strong supporter in Mary Powell, the CEO of Green Mountain Power, the local electrical utility.

Powell, a refugee from the world of banking, is an unconventional executive who earned her degree in arts and music, works behind a standing desk, founded a company selling reflective wear for pets, and has a pet pig named Oddball.

She has long been obsessed with meeting her customers' needs and desires, and since what the customers wanted in Rutland was solar power, Powell was determined to deliver it. Her quest to do so has put Green Mountain—and Rutland—on the front lines of a fundamental shift in the country's electrical grid and power generation system.

Over the last decade solar panels have spread across the landscape, thanks to rapid technological advances, renewable-friendly policies, new regulations to combat climate change, and a booming global market. Solar power now supplies clean electricity to millions of homes, schools and businesses nationwide.

But as rooftop solar and other forms of distributed electricity generation spread further, it poses critical new challenges for utilities and grid managers.

The electrical grid was designed and built in the last century to manage one-way, high-speed electricity flow from big power plants. But in a few short years it could contend with large volumes of excess electricity sent back to the grid from homegrown solar power and small wind turbines.

What's more, when the sun ducks behind a cloud or when a stiff breeze dies, solar or wind energy drops off rapidly. As rooftop solar and wind power proliferate, this intermittency could make it harder for utilities to ensure a reliable supply of electricity. Today they do that by quickly firing up, speeding, or slowing a spinning turbine at a central power plant. Controlling countless dispersed solar panels and wind turbines is not so easy.

For these reasons—and to improve the electrical system's performance—efforts are underway to modernize the grid. The federal government, states, utilities, and transmission system operators have all launched major efforts to transform the grid, with distributed solar as a central component. In 2015 the Obama administration called for Congress to invest an unprecedented $3.5 billion over ten years to modernize the grid and prepare it for higher levels of renewable energy, including an influx of distributed solar. New York state's ambitious Renewing the Energy Vision (REV) offers incentives for companies to come up with innovative business models that profit from the spread of rooftop solar and other forms of distributed renewable generation (see One-on-One, p. 14).

And while some utilities around the country have tried to curtail the growth of rooftop solar because they view the growth of distributed generation as a threat to their business, other utilities have supported it. But few have worked harder at phasing in distributed solar than Green Mountain Power, and it uses the town of Rutland, Vermont, to prove it works.

There, the utility launched an ambitious plan to scale up solar generation and pilot the responsive, interconnected grid technologies needed to create a leaner and cleaner electricity system. This meant installing solar panels to provide a massive amount of the community's power. It also meant building a self-contained solar-powered microgrid—a section of the grid that can disconnect from the larger grid to keep electricity flowing even when storms cause regional blackouts.

Ironically, Rutland's microgrid and distributed solar generation harken back to the past, when massive transmission systems were not yet possible, and electricity was generated and delivered locally.

"It's a bit of back to the future," Powell said. "Back to the future, new and improved."

> "The revolution is coming. Do you want to resist it, or do you want to be part of it?"
>
> — Mary Powell, Green Mountain Power

HERE COMES THE SUN

People have used solar power for centuries, constructing dwellings to take advantage of the sun's warmth and using glass to concentrate sunlight to start fires. Early solar cells were developed in the late 1800s, and in 1954 Bell Labs produced the first photovoltaic (PV) panel that could produce electricity from sunlight.

After decades of development, solar PV began reaching a mass market in the 1990s as technological advances made solar panels more efficient, and policy changes and market forces spurred the young industry to grow. In 1991, Germany implemented a policy that paid rooftop solar panel owners retail rates for the electricity they supplied to the grid. Rooftop solar exploded in that country. Chinese manufacturers stepped up their efforts to meet the new demand, becoming the world's leading solar panel manufacturer.

Today solar PV provides about 7 percent of Germany's electricity consumption, and up to 50

Power from All Points

On the traditional grid, electricity was generated at large fossil-fuel or hydropower plants. It was stepped up to a high voltage, then transmitted long distances via **HIGH-VOLTAGE TRANSMISSION LINES** to the industrial operations, towns, and cities where it was needed. Electricity then flowed from transmission lines to **SUBSTATIONS,** where step-down transformers reduced the voltage, and on to the distribution grid, which brought it to businesses, schools and homes.

Electricity flowed one way—to the end users.

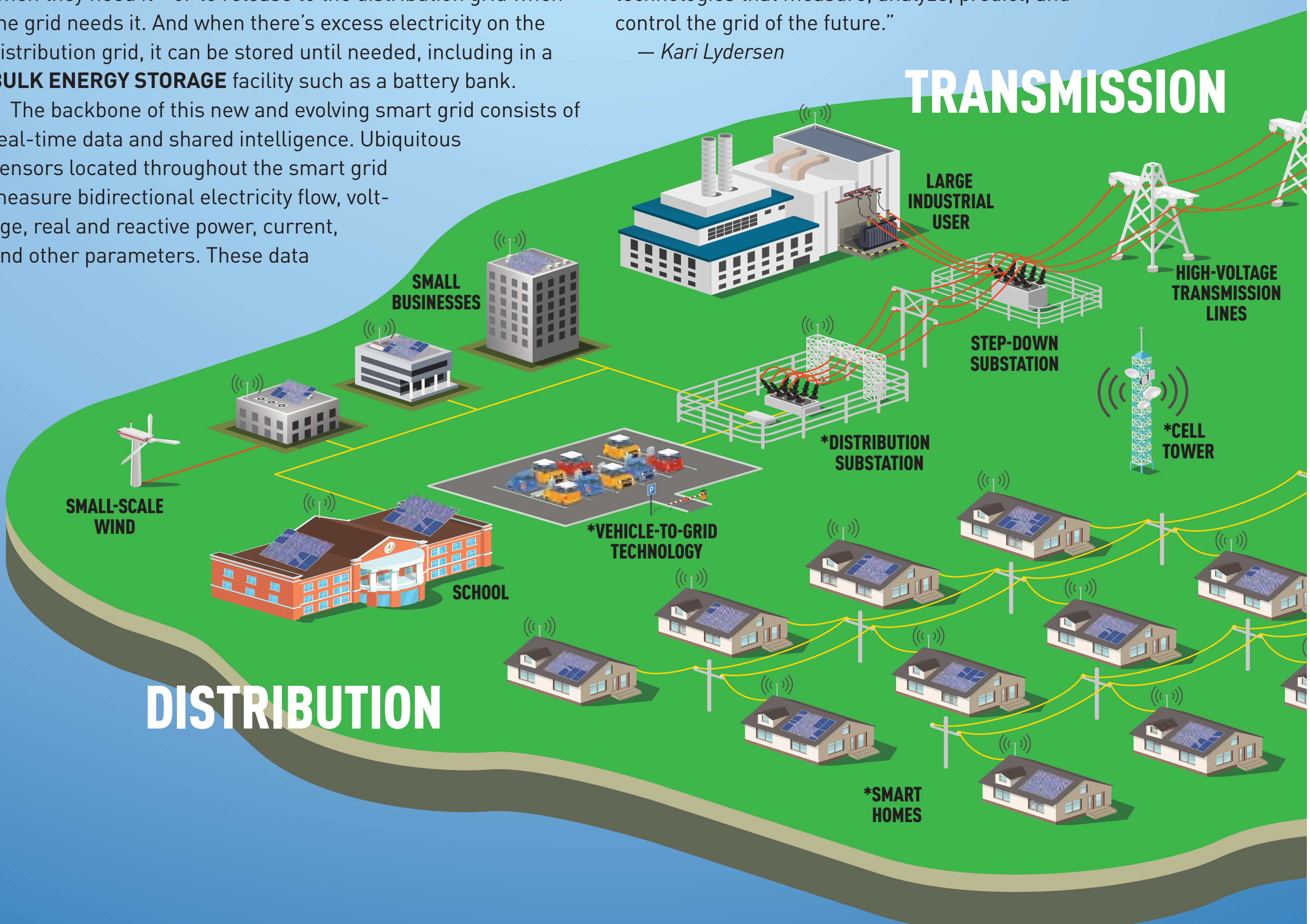
On the modern, integrated grid (shown below) all this still happens, but customers also generate more of their own energy mostly with rooftop solar, and sometimes with farm biodigesters or **SMALL-SCALE WIND** turbines. They may store the solar energy they generate in their **SMART HOMES** to use when they need it—or to release to the distribution grid when the grid needs it. And when there's excess electricity on the distribution grid, it can be stored until needed, including in a **BULK ENERGY STORAGE** facility such as a battery bank.

The backbone of this new and evolving smart grid consists of real-time data and shared intelligence. Ubiquitous sensors located throughout the smart grid measure bidirectional electricity flow, voltage, real and reactive power, current, and other parameters. These data are sent, often wirelessly, to microprocessors inside sensors, smart meters, smart appliances, and other equipment across the grid. These microprocessors detect abrupt changes in the system and predict what will happen next, allowing the smart grid to constantly and automatically readjust itself.

Software is the key to tracking and responding in real time to all the new data. "The main objective [of the smart grid] is integrating these different pieces—the computational methods, the algorithm development," said Guohui Yuan, a program manager for the Department of Energy's SunShot Initiative.

Smart-grid technology has progressed by leaps and bounds in recent years, but many challenges and opportunities remain, said Kevin Lynn, director of grid modernization for the Department of Energy. "We're focused on developing the tools and technologies that measure, analyze, predict, and control the grid of the future."

— *Kari Lydersen*



With **VEHICLE-TO-GRID** technology, parked electric vehicles can function as part of the grid, charging batteries when electricity is cheap and abundant, and sending electricity back to the grid as needed.

Sensors and processors in **SMART HOMES**, transformers, **SUBSTATIONS**, and elsewhere wirelessly signal the **UTILITY OPERATIONS CENTER**, which tracks electricity flow and overall electricity demand. When demand is high, the utility operations center signals smart homes to cut consumption or provide excess electricity to the grid. When demand is low, it signals them to store it. (See "Smarter Solar Homes," p. 29.)

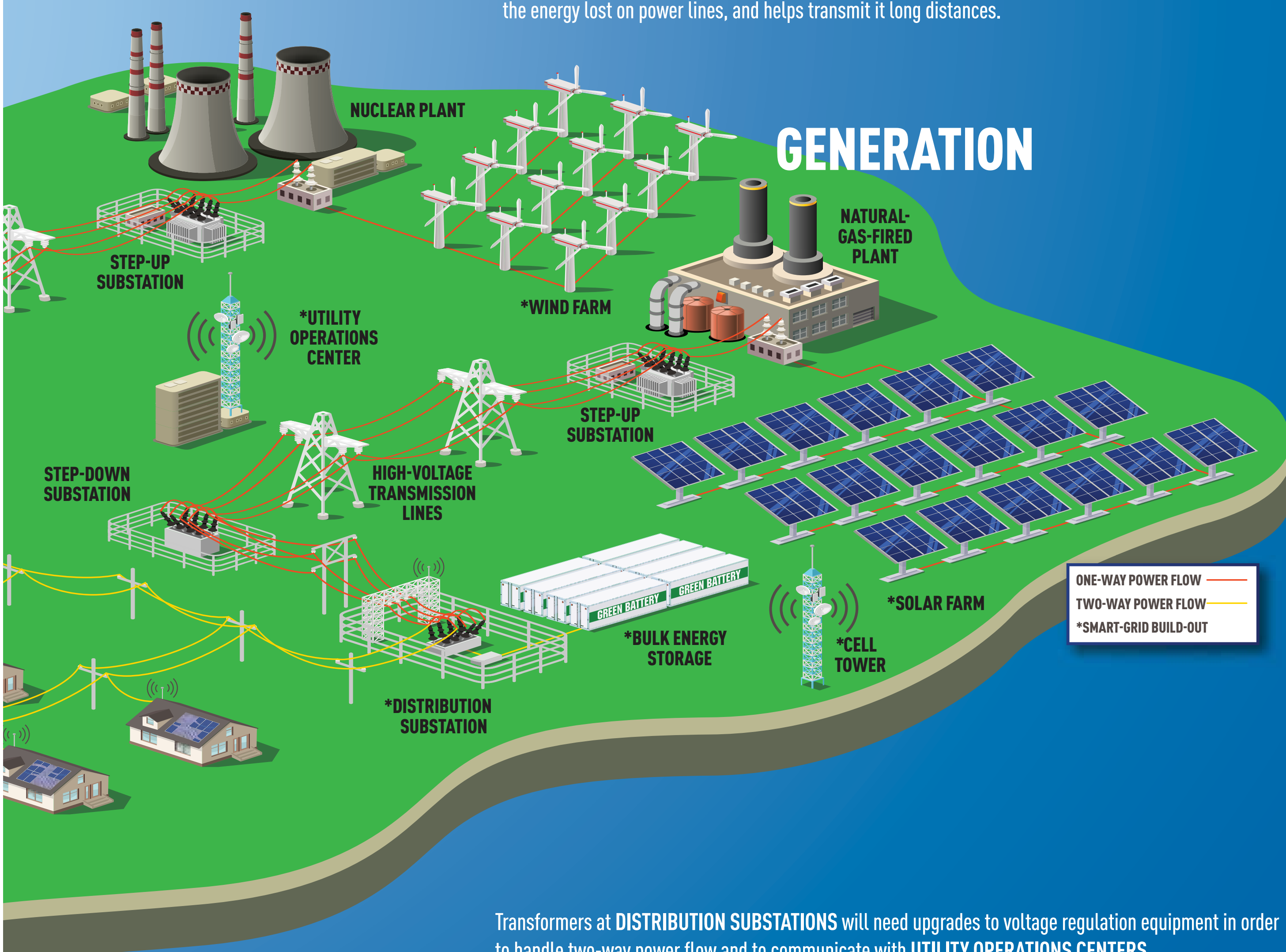
NATURAL GAS-FIRED POWER PLANTS, NUCLEAR PLANTS, and coal-fired plants have traditionally generated most baseload electricity—the bulk electricity that charges up the grid. But gas has been outcompeting coal and forcing coal plants to close. And while most existing nuclear plants will continue to run, few are being built and some are closing amid safety and cost concerns.

WIND FARMS can provide large amounts of electricity and many have been built in recent years.

SOLAR FARMS, often called utility-scale solar, are large-scale arrays of solar panels mounted on the ground. Another type of utility-scale solar plant, concentrating solar power, uses the sun's heat to boil water, which turns a turbine to make electricity in a process similar to that at other power plants.

UTILITY OPERATIONS CENTERS constantly monitor data on electricity transmission across the grid and act to make sure electricity flows efficiently, without problems or outages. "Before you would have to pick up the phone and call the local utility, they would send someone over, check all the feeders in your neighborhood and finally fix it," said Mohammad Shahidehpour, director of the Robert W. Galvin Center for Electricity Innovation at Illinois Institute of Technology in Chicago. "Now all of that is done automatically."

Step-up transformers at **SUBSTATIONS** increase the voltage going onto transmission lines. This minimizes the energy lost on power lines, and helps transmit it long distances.



Transformers at **DISTRIBUTION SUBSTATIONS** will need upgrades to voltage regulation equipment in order to handle two-way power flow and to communicate with **UTILITY OPERATIONS CENTERS**.

Advanced voltage regulation equipment on the **DISTRIBUTION** grid will also be needed, as the grid will need to deal with bursts and dips of energy from solar panels without interrupting the power flow. "All kinds of devices—switches, fuses, reclosers—are embedded on the grid to protect everything and everybody," said Tom Stanton, energy principal researcher at the National Regulatory Research Institute.

ENERGY STORAGE, including battery banks and flywheels, will be crucial for storing excess solar energy on the distribution grid until it's needed and for helping regulate energy flow.

> "(Data) adds a tremendous amount of complexity to the grid."
>
> — Jacob Pereira, IHS Technology

percent on sunny weekend days. And technological advances and economies of scale helped drive prices down worldwide. In the United States, for example, the cost of installing residential solar plummeted from more than $9 a watt in 2007 to $4 in 2014, according to the U.S. Department of Energy. This is inexpensive enough that in about 20 states—especially states like Hawaii and California with sunny weather and high energy costs—solar energy has achieved grid parity, meaning that solar costs no more than other forms of energy. Barring major changes in rate structure or incentives, grid parity is expected to spread nationwide by 2020, according to a February report from GTM Research. This could persuade even more Americans to go solar.

Some energy analysts and utilities worry that cheaper solar PV and other distributed generation could trigger a death spiral for utilities, in which customers draw less electricity from the grid, reducing revenues, and forcing utilities to raise rates. This could push more customers into the arms of competing retail energy suppliers, and motivate more people to generate their own energy, reducing utility revenues further.

Some utilities are making preemptive strikes to preserve their revenue under their traditional business model, including proposing surcharges on customers who install solar panels. But a few, including Green Mountain, have embraced the changes.

"The revolution is coming," Powell said. "Do you want to resist it, do you want to follow it, do you want to be part of it, or do you want to accelerate it? We're accelerating it."

Under CEO Mary Powell, Green Mountain Power built the biggest solar farm in Vermont.

SOLAR PLUS STORAGE

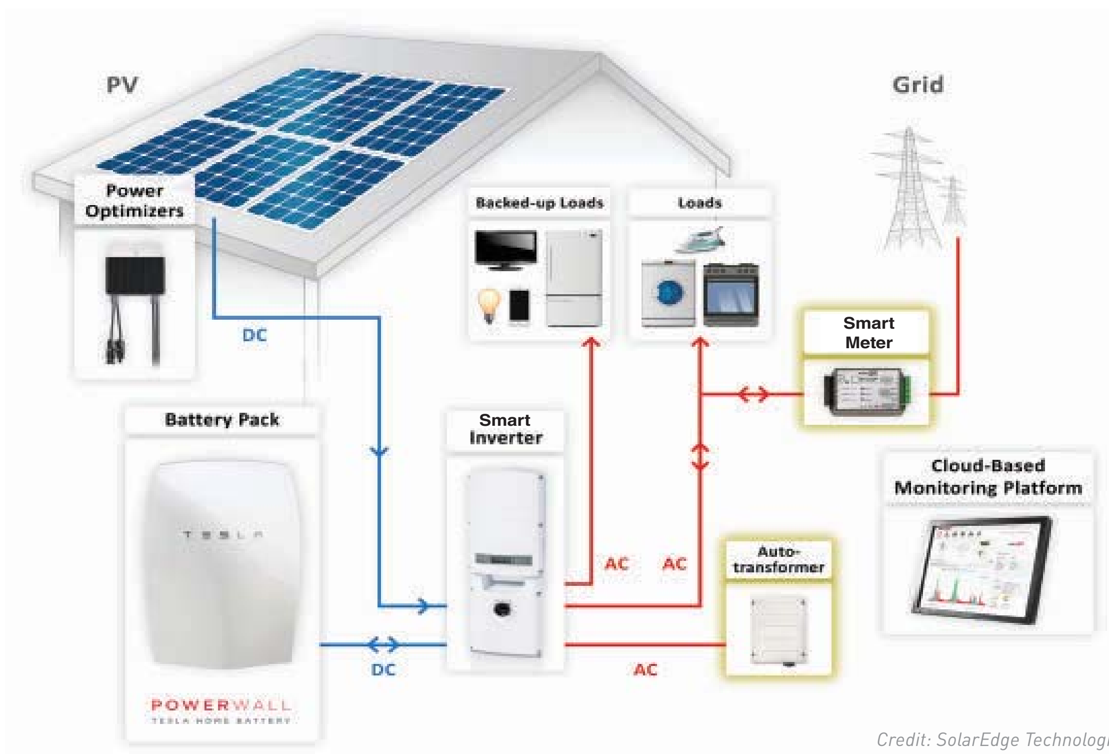
Green Mountain's first foray into solar occurred in 2007, when it built a 200-kilowatt solar farm on a brownfield in Berlin, Vermont, a village just outside the state capital, Montpelier. It was the biggest solar farm in Vermont.

A few years later, it shattered that record. In partnership with the solar developer groSolar and using state and federal funding, Green Mountain built a massive solar installation called Stafford Hill on a landfill in Rutland. It went online last summer with 7,700 solar panels that can generate 2.5 megawatts of electricity—15 times more than the utility's first solar farm, and enough to power about 3,000 homes, or more than a third of Rutland's total.

Stafford Hill was more than a solar farm—it was part of the country's first microgrid powered entirely by solar. A microgrid is a small networked section of the grid that can generate its own electricity from distributed generation—solar panels, wind turbines, combined heat and power, geothermal installations, or biodigesters—and can be disconnected from the larger grid to operate autonomously.

Microgrids can benefit utilities by feeding excess electricity they generate into the larger grid for the utility to use. And unlike the old-fashioned grid, which typically stores relatively little energy,

Smarter Solar Homes



Credit: SolarEdge Technologies

The modern grid doesn't end when electric wires enter homes. Thermostats, appliances, electric vehicles, and even windows and other parts of the house effectively become pieces of the grid.

Appliances and thermostats can be programmed to respond automatically to signals from the grid and even predictions about the weather. So when system-wide demand is high, or when an incoming cloudbank means solar power is about to drop off, refrigerators, water heaters, and air conditioners can be automatically switched off so the home's electricity use can ratchet down. When demand is low and electricity is abundant, they can switch on to heat water, dry clothes, or cool the home. Smart meters let customers know their energy use and the price of energy in real time throughout the day, rather than simply reading a summary on the monthly bill. This and a cloud-based monitoring platform can help energy geeks monitor their energy use on their smart phones, and adjust their thermostat or turn their washer on or off, for example, while others can rely on specialized software, automated smart appliances and third-party energy management companies to automatically adjust in response to signals from the smart meter and the grid.

Smart inverters, like ordinary inverters, convert the direct current produced by solar panels into the alternating current that flows to and from the grid and through our home's wiring and outlets. They also automatically monitor supply and demand on the grid and quickly adjust how much energy the home feeds to the grid. In an area heavy with rooftop solar and smart inverters, "In essence, there are thousands of small generators that can react and address problems as they're seen on the grid," said Robert Harris, director of public policy for the solar company Sunrun.

Many smart homes also store excess energy generated from solar panels, so it can be used later on-site. The excess electricity can charge home batteries like Tesla's Powerwall, or the powerful batteries in electric vehicles. If more advanced vehicle-to-grid technology catches on, smart, two-way electric-vehicle charging stations in the garage could be programmed to charge cars when the grid is flush with electricity and send power to the grid when it's not. That way, the grid as well as the home could grow smarter.

— K.L.

they can use that excess energy to charge banks of batteries to draw on later.

To help Rutland's microgrid function autonomously, for example, Green Mountain stocked it with enough lithium-ion and lead-acid batteries to store up to 3.5 megawatt-hours worth of electricity from Stafford Hill's solar panels and release it at night or on cloudy days.

Microgrids can also boost a town's disaster resilience. Rutland's microgrid includes a section of town with the local high school, which serves as an emergency shelter in a region that's frequently buffeted by severe storms and suffered massive outages in 2011 during Hurricane Irene.

NOT YOUR FATHER'S GRID

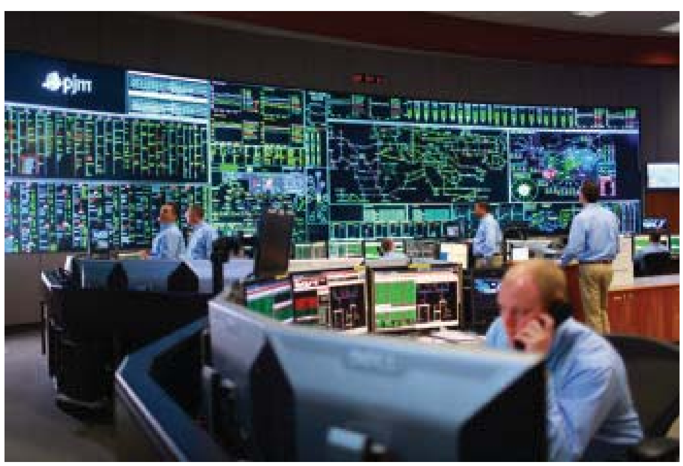
When too much electricity flows onto a traditional grid from rooftops all over town, solar's natural variability can trigger voltage fluctuations. These flickers in the electricity delivered to customers can interfere with the functioning of electronics, appliances, and industrial equipment.

What's more, distributed solar causes sharp bursts or drops in electricity when it's working normally, but those large fluctuations can cause

Transmission's Traffic Cops Adapt

Put solar panels on every rooftop, wind turbines in every field, and a microgrid in every town and the nation would still need to balance electricity supply and demand over entire regions. Achieving that balance is the job of low-profile, nonprofit organizations called regional transmission organizations or independent system operators.

RTOs and ISOs gather information on demand across the region from second to second. They then signal power plants to turn on or ramp up to meet that demand and steer power through high-voltage transmission lines to where it's needed.



As rooftop solar spreads and powers more homes, those solar panels can often generate more electricity on a sunny afternoon than a home needs. Those homes then feed electricity back into the distribution grid, the system in a city or town that brings power directly into homes and businesses and is typically managed by a utility. Enough solar power in a distribution system can reduce its need for power from the transmission lines, and enough in a region can cause net regional electricity demand to plummet lower than the RTO or ISO expects.

"One of the biggest impacts is on generation scheduling—making sure we have enough resources scheduled to meet customer demand," said Ken Schuyler, renewable services manager for PJM Interconnection, the RTO that manages transmission for the mid-Atlantic region, the northern Appalachians and parts of the Midwest. Rapid dips in demand can also affect the spot markets that RTOs and ISOs run to ensure that electricity demand and supply are perfectly matched.

To compensate for the rise in distributed solar, PJM recently changed its procedures for forecasting future electricity load to account for distributed energy resources like rooftop solar, Schuyler said.

Excess electricity can be stored, typically by using the extra electricity to pump water into a hilltop reservoir that can releases it later to drive an electricity-generating turbine. But RTOs and ISOs are also taking advantage of compact, efficient batteries to store excess electricity on the grid. And they're using either batteries or flywheels to smooth out variable electricity flow by either absorbing or delivering electricity within seconds.

Solar and other distributed energy resources are not widespread enough to affect the transmission system significantly, but "they have the potential to have a huge impact," that forces ISO and RTO managers to operate differently, Schuyler said. "We're working with our stakeholders to make sure we're prepared for that future."

– K.L.

> "The system is tremendously overbuilt and most of that capacity is underutilized."
>
> — Eric Birkerts, Clean Energy Trust

problems on a traditional grid, causing sections of the grid to be automatically disconnected as a safety measure. If a grid depends on solar generation to meet its overall energy demands, such tripping could cause unnecessary electricity shortfalls.

"The grid is like a wave pool," explained Benjamin Gaddy, director of technology development at the Clean Energy Trust, a Chicago business accelerator. "The question is how do you verify that the new wave of power you're adding to the existing wave doesn't knock that wave out of balance."

The answer is the smart grid.

The traditional grid involves wires and analog equipment delivering electricity to objects that consume it. The smart grid uses Internet of Things technology to add a layer of intelligence. It enables equipment on the grid—smart meters, smart appliances, sensors, batteries, solar panels, smart inverters—to continually collect data on electricity flow, supply and demand, and equipment performance; to communicate with each other, often wirelessly; and to analyze data and coordinate their actions based on their shared virtual intelligence.

"The term smart basically refers to data," said Mohammad Shahidehpour, director of the Robert W. Galvin Center for Electricity Innovation at the Illinois Institute of Technology. "When we say smart, there's no smartness physically in the grid. What makes it smart is [that] you provide data to the participants to make smart decisions."

That may sound simple, but the amount of data is staggering. "There's terabytes of data coming in, some people even say petabytes," said Jacob Pereira, a senior analyst with the firm IHS Technology who focuses on the electrical grid and smart meters. "It's really hard to analyze, hard to collate. It adds an incredible amount of complexity to the grid."

NETWORKED NODES

Much of the new data in the electrical system is crunched by countless microprocessors located in pieces of equipment, or nodes, all over the grid. A 5-megawatt feeder circuit on a section of the grid with 50 percent solar penetration could have 500 active nodes providing data, the Department of Energy noted. Nodes include sensors, controllers, capacitors, frequency and voltage regulators attached to the wires; smart appliances like dishwashers, thermostats, batteries, electric vehicles, and smart meters in homes; and smart inverters attached to solar panels.

Sophisticated computer programs in these nodes almost instantaneously process that data. This allows the equipment at these nodes to act autonomously on signals that they get from the utility or from other nodes on the smart grid.

The nodes can also send data through wires or wirelessly to the distribution system operator, which is a central nerve center, usually run by a utility, where staff monitors automated functions. This helps the utility keep tabs in real time on system demand, and know exactly how much energy must be fed onto the distribution grid from the high-voltage transmission lines.

When overall system demand is high, the system operator can reduce electricity demand by reaching into smart homes–a key component of the smart grid–and remotely turning appliances off or ratcheting them down. It can also tap batteries to contribute electricity to the grid. And when overall system demand is low, smart-home components soak up electricity— by charging batteries or electric vehicles or by heating water, for example. (See "Smarter Solar Homes," page 29).

The smart grid offers another key benefit: fewer power plants being built, which cuts pollution and saves ratepayers money. "The [electrical] system is tremendously overbuilt and most of that capacity is underutilized," explained Erik Birkerts, CEO of the Clean Energy Trust, which helps many smart-grid-related startups. Cutting energy use at peak demand times, such as hot summer afternoons, reduces the need to build expensive

"We were able to do things we otherwise would not be able to do to better the quality of life, to better the jobs market..."

— Chris Louras, Mayor of Rutland

"peaker plants"—natural-gas-fired power plants that are fired up only occasionally to meet peak demand.

Although the technology and products that make up the smart grid have been developing at a rapid clip over the past decade, the smart grid as a whole is still very much a work in progress. Utilities around the country are still providing their customers smart meters, a crucial piece of the smart grid. Start-up companies are developing new software to manage the smart grid's components or help consumers change their behavior based on smart-meter data. Software developers and grid managers are still working to develop algorithms and programs to wrangle all the data.

But cutting-edge smart-grid technologies alone will not be enough to facilitate a big influx of distributed solar and other renewables and forge a clean, smart electrical system. That will also require new policies.

A SUNNY OUTLOOK

As Green Mountain Power built out the Stafford Hill solar plant and the nearby microgrid, it also took its clean-energy commitment into territory that utilities often avoid: It crafted a policy that encouraged customers to generate their own power. Individuals and companies who installed solar panels on their homes or businesses, as well as some farmers who used biodigesters to turn cow manure into electricity, were all paid retail rates for power they generated and sent back to the grid.

Green Mountain, like many utilities around the country, has also crafted policies to smarten up the grid, and it has gone farther than most. It's subsidizing the installation of energy storage and smart appliances at customers' homes. And this year it became the first utility in the country to offer its customers Tesla Powerwall batteries to lease or buy. Customers receive reduced rates if they allow the utility to draw energy from the battery when the grid needs it. Such batteries have given distributed solar a boost by letting homeowners store up to 6 kWh of solar-generated electricity. That's enough to power a home through an evening, so it draws less electricity from the grid and cuts the homeowner's energy bill.

Federal investments in solar energy and microgrids could ultimately make distributed solar cheaper, which might convince other utilities to follow Green Mountain's lead. The Department of Energy's SunShot program aims to slash the per-watt price of solar installations by 75 percent from about $4 right now down to $1 by 2020, in large part by improving solar PV technology and mass production. For example, a $1.1 million DOE Sunshot grant to the University of Illinois at Chicago and partner institutions will fund development of cadmium telluride PV cells that could be twice as efficient as conventional PV at turning sunlight into electricity.

States and cities are investing as well. New York State is running a $40 million competition to spur the development of community microgrids, and in 2015 the state awarded $100,000 each to 83 applicants around the state for feasibility studies. Winners of the next round will collectively receive $8 million in awards to develop engineering designs and business plans.

And utilities nationwide, including in larger cities, have undertaken solar and microgrid efforts of their own. In Texas, Austin Energy is leveraging $4.3 million from the U.S. Department of Energy to phase in energy storage technology to reserve excess electricity until it's needed. It's also developing new software that aggregates rooftop solar power into a virtual power plant that reduces the need to build a real one. In Chicago, ComEd, Chicago's local utility, is planning a microgrid in Bronzeville, a historic, mostly low-income neighborhood on the city's South Side.

But not everyone is on board and supporting the phase-in of solar and a smarter grid. Regulators in Wisconsin, Nevada, and other states have let utilities pay those with rooftop solar wholesale rather than retail rates for the electricity they feed into the grid, and charge high monthly fees for grid upkeep. Experts say this could chill solar.

But overall the momentum is in the other direction. The Obama Administration's Clean Power Plan, if it survives court challenges, would mandate a 32 percent reduction in U.S. carbon emissions below 2005 levels by 2030. Along with other federal air-pollution rules that mandate expensive pollution controls on power plants, it would drive up the cost of fossil-fuel-fired power and make renewables more competitive.

And many major cities, including New York, Chicago, Milwaukee and San Diego (see right) are promoting solar, microgrids and other energy innovations as a way to lure employers who value clean, reliable electricity.

That is what has happened in Rutland, Vermont. The city's new grid provides clean, reliable energy—and it has helped boost the town's economy and attract 20 new businesses, Powell and local officials said. These include the solar companies groSolar, Next Sun, and SunCommon; an independent book-seller; and a regional chain of electronics stores.

Rutland's Downtown Merchants Row also hosts Green Mountain's Energy Innovation Center, an interactive museum of sorts with displays about energy and regular talks by energy experts. Since becoming a clean energy hub, "We were able to do things we otherwise would not be able to do to better the quality of life, to better the jobs market, to really transform the community," Rutland mayor Chris Louras has said.

And even though the energy issues of a small Vermont town may differ from those in most cities, the lessons learned in Rutland can translate nationwide, Powell said. Utilities everywhere should appreciate the business case Green Mountain has made for embracing a new energy model, and people anywhere are likely to welcome immediate, concrete impacts on a local level, including reliable clean power, an economic boost, and cutting-edge technology.

In fact, it may be those impacts, more than anything else, that drive an energy revolution. ME

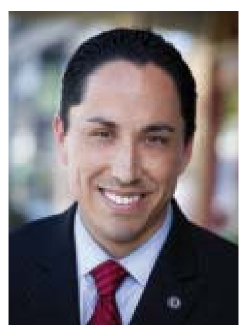
KARI LYDERSEN is a Chicago-based reporter and author who writes about science, energy, and the environment.

A Power Play to Scale Up Solar

It was a bold move.

Last December, San Diego's Republican mayor and all nine members of its city council passed a law requiring the city to get all of its energy from clean, renewable sources by 2035. This, despite the facts that more than half the city's energy currently comes from natural gas, and that the local utility, San Diego Gas & Electric, said meeting the 100 percent target was impossible.

The plan calls for 20 percent of the city's energy to come from distributed solar, meaning rooftop installations at homes, schools, and businesses. Even more would come from larger solar farms, along with wind and geothermal power.



San Diego City Councilman Todd Gloria

Reshaping the grid with an abundance of distributed solar generation and energy storage is crucial to going all renewable, according to City Councilman Todd Gloria, who spearheaded the plan during his stint as interim mayor.

And since SDG&E has said it can't and won't go all-renewable, Gloria and other city officials are pushing for the City Council to adopt Community Choice Aggregation. That's a system in which a city or town government decides where residents get their electricity, and the utility is relegated to running the distribution grid and selling power to residents who opt out of the program.

SDG&E is expected to lobby hard to defeat the proposal for Community Choice Aggregation, and it is seeking approval from the state utility commission to use shareholder dollars for that purpose.

Gloria notes that when the state passed a law mandating that each utility get a third of its energy from renewable sources, skeptics said it was impossible. But clean technology businesses took off, and SDG&E comfortably met the goal.

"Once you make a commitment like this, the marketplace will do its work," Gloria said.

The energy commitment is part of the city's larger, ambitious climate action plan, which also addresses water use, vehicle emissions, and other challenges. San Diegans are well aware of their vulnerabilities, Gloria said. "When you talk about sea level rise here, it's not an abstract concern."

—K.L.

The Grid U

By S. Massoud Amin

On an ordinary afternoon last December, with Christmas just a couple of days away, workers in the Ukraine wrapped up their duties, and families across the nation prepared for the holiday. Then, at 3:30 p.m., as the sun began heading toward the Western horizon, the lights went out.

They went out in a region in the western Ukraine served by a utility called Prykarpattya Oblenergo. A minute later, a second western Ukraine utility lost its power. Then a third. Suddenly, 225,000 people were without electricity.

Before the day was out, Prykarpattya Oblenergo said the blackout was due to outside interference in their system. Soon Ukraine's state security service blamed Russia.

Employees at the three utilities had watched helplessly that day as their operations were hijacked, and in time detective work proved what the utility and the security service had suspected: Malware had homed in on critical equipment and destroyed it, and stealthy human intruders had shut down substations.

In fact, the world had just witnessed the first well-publicized cyberattack that successfully took out a portion of the power grid.

Many people think the electric grid must be securely protected from disabling cyberattack. But while the sky is not falling, many vulnerabilities persist. And now, as the Ukrainian attack made clear, the electric grid has entered a new era of heightened vulnerability.

Our electric power infrastructure supports almost all of our economic and social foundations, including fuel-supply, telecommunications, transportation, and financial networks.

It's also under a lot of stress. Power outages in the United States have increased in size and frequency over the last two decades. Outages and power quality disturbances now cost the economy more than $80 billion annually on average, and sometimes as much as $188 billion in a single year. The grid's ability to safely support anticipated demand has been in question for over a decade.

Meanwhile, the grid is growing more susceptible to cyberattack. Much of the U.S. grid was built out from the 1950s to the 1970s, before modern computer and communication networks, let alone modern security measures. But the grid now relies on computers, many of which were added without considering how they would affect grid operations, and often without adequate cybersecurity.

And as more people generate their own electricity from rooftop solar and other distributed generation technologies, it creates more interconnected nodes on the grid, each with digital sensors, processors, and automated and manual controls. And when the software and hardware at these nodes are not properly configured, hackers can spoof, jam, or hijack them.

Despite the risks, policymakers nationwide are pushing for clean, reliable electricity, and we depend on power and electric grids to grow our

nder Fire

Photo: Tennessee Valley Authourity

economy, protect public safety, and sustain our daily lives. Therefore, despite these hurdles—or because of them—we must update the nation's end-to-end electric power grid to provide secure, resilient, and reliable electricity for the future.

WEAK LINKS

When investigators conducted their autopsy on the Ukrainian power hack, they uncovered an extremely sophisticated attack—one that showcased several of the more potent weapons utility cybersecurity personnel must contend with.

In the months leading up to the outages, the hackers sent so-called spear-phishing emails to utility workers. The emails appeared to be from friendly sources known to the victims, and asked them to click "enable content" to read an attached document. Some did, and it activated BlackEnergy attack software—a Trojan horse virus that, like the giant wooden horse of Greek legend, appeared innocuous but carried a nasty surprise.

Once activated, BlackEnergy invaded the utilities' office computers, allowing the hackers to root around. They figured out how to access the systems remotely, probably via virtual private network (VPN) connections. And they discovered high-level passwords to computers and industrial control systems that directed utility operations.

When the time was right, the hackers struck. Grid operators watched helplessly as cursors moved around screens, passwords changed, and high-voltage circuit breakers opened at doz-

The grid relies on computers, often without adequate security precautions.

The Ukrainian attack demonstrated the sophistication of today's hackers and the malware they now wield.

ens of substations, causing a blackout.

Nor were the hackers done. They used a program called KillDisk to erase selected files and corrupt firmware to disable entire utility computer systems. They sabotaged restoration efforts by remotely disabling computers needed to repair damaged grid equipment. They even flooded utilities' customer service phone lines with automated calls to prevent customers from reporting the outages.

More than any other publicized attack, the Ukrainian attack demonstrated the sophistication of today's hackers and the malware they now wield. And that malware is being put to use. Today the organizations that manage regional grid operations in North America report 100,000 malicious attempts a day.

To battle crafty hackers and advanced malware, we need advanced cyberdefenses. At the University of Minnesota, we have developed a multilayered set of defenses. Our system spots potential viruses, worms, and other malware and quarantines them into what we call a sandbox that's a virtual replica of the system being invaded.

The hackers think they've invaded our system, but in fact we're safe. And using machine-learning algorithms, we can quietly watch their every move, as if they were lab rats, and learn from their behavior how to fend them off. We also

Cleaning Up

How can a utility make more money by selling less electricity? How can a third-party vendor capitalize on reduced electricity demand? Two innovative companies have created business models to profit on the clean, integrated grid of tomorrow.

Save Now, Charge Later

As electric vehicles become more popular, utilities worry that charging them all at once could overtax the grid. But in San Francisco, EVs actually help the grid on hot days when residents turn on the AC full blast.

That's because automaker BMW helps the local utility, PG&E, meet that electricity demand by delaying at-home charging by 100 owners of BMW's i3 electric vehicles for up to an hour.

"We are working to create an ecosystem for electric cars," said Cliff Fietzek, manager for connected eMobility for BMW of North America. "This is the next step for us to integrate electric cars into the power grid without straining the grid."

Delayed charging was designed to shave 100 kW off peak demand when PG&E experienced a run on electricity. Just in case, a battery at BMW's nearby plant in Mountain View made up the difference in electricity when not enough cars could defer charging.

BMW benefited from the program by burnishing the image of EVs and giving buyers an incentive to drive them. i3 owners got paid up to $1,540.

PG&E benefits as well from this delayed charging program, called iChargeForward, because they don't have to buy or generate power at times of peak demand, when it's most expensive. At such times many utilities turn to simple-cycle natural-gas peaker plants for a stretch, but these plants are less efficient and emit more polluting carbon dioxide and nitrous oxide than combined-cycle natural-gas power plants, which are utility mainstays.

The response from i3 owners was positive.

learn within seconds how to prevent future attacks—far faster than the weeks or months it now takes to develop and install computer security patches.

Cyberattacks, of course, are not the only security threats that utilities and electric system operators face. Truck bombs or small airplanes can take out substations or even utility operations centers. High-powered rifles can pick off and disable transformers at substations, as happened to a major Silicon Valley substation in 2013.

To protect the electrical system from both cyber and physical attacks, each of its components could in theory be replaced or retrofitted. But the North American grid has 15,000 generators in 10,000 power plants; more than 450,000 miles of high-voltage transmission lines that carry 100 kV or higher and hundreds of thousands more miles of lower voltage lines in the system, so this would be logistically and financially impossible.

Back in the 1990s, however, I realized that there were better ways to protect the grid.

GRID, HEAL THYSELF

Between 1998 and 2002, my team at Electric Power Research Institute and I created and led a large joint research program with the U.S. Department of Defense to make the electric grid smarter and more resilient. The Complex Interactive Networks/System Initiative (CIN/SI) included teams from more than 28 universities, 52 utilities and independent system operators, and the DoD.

We recognized that all of our critical infrastructures–electric, fuel-supply, water, telecommunications, and financial networks–were inter-

More than 500 owners applied for the 100 spots in the 18-month pilot program, and 92 have stuck with it, Fietzek said. It helped that any owner who needed to drive his or her car immediately could opt out of delayed charging, he added.

Even before the program finished, BMW had learned important lessons. From July 2015 to June 2016, PG&E had 134 demand requests. BMW met 94 percent of those requests but needed to call on its Mountain View battery every time, Fietzek said.

iChargeForward ends this month, but BMW is exploring the feasibility of moving from a pilot program to something on a larger scale, Fietzek said. "But to provide 100 kW or more, we're going to need more vehicles," he said.

When the i3 batteries are past warranty and no longer working well enough to effectively charge a car, they can still provide residential charging and storage, and BMW is developing a Second Life Battery program to do exactly that. "Instead of recycling the batteries, it makes much more sense to reuse them," Fietzek said. ME

Virtual Power to the People

When a large cloud passes over a solar farm, the electricity supply to the area plummets. Grid managers must act to balance electricity supply and demand, and they must do it fast.

Enbala Power Networks of North Vancouver, B.C., makes software that can generate 20 MW of power within four seconds by simply reaching into the buildings of large commercial and industrial (C&I) users and switching off power-hungry equipment for short periods of time.

Everybody wins. Large C&I users enjoy lower energy bills, courtesy of utility incentives, and usually notice no loss of power. The local utility can quickly respond to changes in demand. Grid operators get the power they needs to meet demand quickly—without the power losses that inevitably occur when drawing from power plants or battery banks.

Enbala profits, too. C&I customers may pay them directly for the service, which is known as a virtual power plant, then manage their own load. Enbala also can bid its virtual power into a lucrative spot market run by the regional energy system operator—then, because of the market's rules, get paid more than they bid.

In effect, Enbala's business model turns the power system upside down, said Enbala founder and CTO, Malcolm Metcalfe. "In the past, generators have always been used to follow the load," Metcalfe explained. "Lots of people turn on lights, and generation ramps up." But Enbala instead adjusts load to match generation.

Let's say a cloud passes over a large array of solar panels, causing a brief loss of 100 MW to the grid. Multiple power providers—a hydro plant, or a coal or gas-fired plant, typically—then bid into the frequency regulation market, which maintains a continuous balance between supply and demand.

Enbala can meet the system's need by immediately reducing power to its customers' air conditioning or refrigerators—far faster than the half hour it can take to ramp up other forms of generation. The system operator pays more to generators that perform faster and better. "We get picked every time," Metcalfe said. ME

KAREN QUEEN is a Virginia-based writer.

Our goal was to build a safe, secure, resilient eletrical system that can heal itself when disrupted.

dependent and dynamically coupled. We aimed to judiciously retrofit these infrastructures to make them secure and robust. Because all other infrastructures rely on our power and energy networks, modernizing the electrical grid was central to our efforts.

Our goal—and my goal ever since—was to build a safe, secure, resilient electrical system that can heal itself rapidly when disrupted.

Our strategy for building such a grid emerged from an understanding of how large, complex networks fail. First, a threat or material failure perturbs the network but does not yet pose an emergency. It does, however, force the network into an alert state. The system, which was in a stable equilibrium, begins to lose its balance.

At that point, a well-functioning system will rapidly sense this disturbance and act to regain balance and normal function. But if it can't detect the disturbance in time, or if it can't compensate, the system will enter an emergency state and lose its balance. Part or all of it will then fail.

A self-healing smart grid needs to be supported by secure sensing and communication networks, it needs built-in computational technologies, and it has to be controllable in real time. Ideally, sensors and processors would be built into every working part—every switch, every circuit breaker, every transformer, every busbar. These devices would also need built-in communications technologies to speak with each other and with grid command centers, and they'd need built-in physical and cyber security defenses.

Such a system would also need centralized intelligence. For example, an intelligent and secure layer of devices would monitor the health of a substation's equipment and automatically report electrical problems or disruptive cyberattacks to a local control center on a college campus or in an industrial park. Alternatively, if a cyberattack disabled equipment on a substation in a microgrid—a local, mostly self-sufficient power system connected to the larger grid—the microgrid would automatically disconnect from the grid to localize the problem and fix it before reconnecting.

The sensing and communication technology on far-flung grid elements would give command-and-control centers better situational awareness. They could use this to plan for future conditions.

A grid that was truly smart, secure and self-healing, would make for fewer and shorter power outages. It would detect abnormal signals that indicate equipment failure or a brewing thunderstorm, and they would reconfigure the system to isolate disturbances or at least minimize their impact. It would detect and override human errors that can cause power outages.

To remake today's electrical system, we'll need more technology development. At the University of Minnesota, for example, we are designing, modeling, and assessing control architectures that enable the power grid to respond quickly to natural disasters, equipment failures, physical attacks, and cyberattacks. We're also testing them on an experimental microgrid and conducting cost-benefit analysis of options, designs, and policies.

And the existing grid will have to be retrofit. This would be expensive, but its benefits would far outweigh its costs. By investing about $20 billion a year for 20 years, smartening the grid would, by conservative estimates, generate $2.80 to $6 to the economy for every dollar invested.

Such a grid would prevent damage to all the other infrastructures that depend on a working electrical grid. It would allow the electrical system to safely integrate more renewable power from rooftop solar panels, small-scale wind, and other clean technologies. It would create jobs, foster a globally competitive workforce, and enable a 21st century infrastructure that supports a digital society with increased power demands. In fact, it's a must for the United States to remain an economic power.

And the next time bad actors conspire on a grid-disrupting cyberattack, the new grid might just make for a more peaceful holiday. ME

S. MASSOUD AMIN, an ASME fellow, directs the Technological Leadership Institute at the University of Minnesota and is regarded as "the father of the smart grid."

A Crystal Ball For Grid Managers

Weather forecasts are critical for managing an electrical grid reliant on renewables.

When the wind dies down or the sun ducks behind the cloud, utilities that tap them for energy must still provide reliable electricity.

"There are a lot of ways to manage variability and uncertainty," said Jessica Katz, a research analyst at the National Renewable Energy Laboratory (NREL) in Golden, Colo. "But forecasting can be among the least expensive and easiest to implement."

Grid managers count on either in-house meteorologists or third-party vendors to determine the most accurate weather forecast.

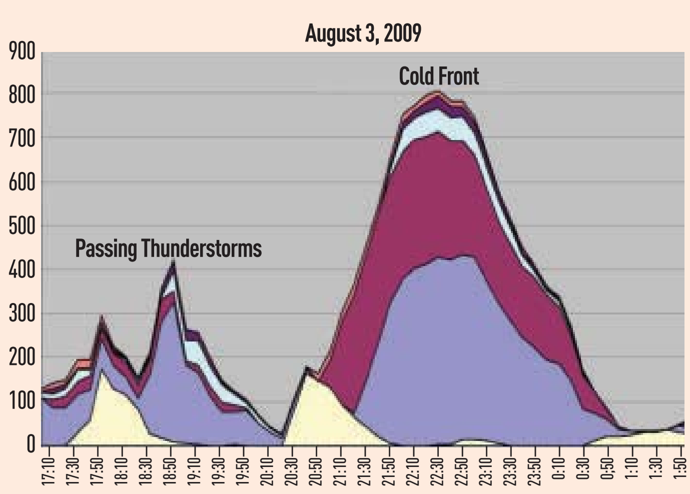
To forecast more than a couple of hours out, they rely on numerical methods. Those techniques feed data on temperature, pressure, surface roughness, and more, into computational physics models. The models then simulate in detail what happens as the atmosphere interacts with the land surface.

"If you've ever sat outside on a windy day, you notice that it's less windy downwind of trees than out on a field," said Andrew Clifton, group manager of the Sensing, Measurement, and Forecasting Group in NREL's Power Systems Engineering Center. Numerical methods account for these detailed dynamics to calculate variables such as wind speed, solar irradiance, and cloud cover, generating weather maps as fine as one kilometer in resolution.

But numerical weather calculations are so complex they can take up to four hours to calculate on a supercomputer. Shorter term forecasts draw from statistical methods that incorporate data from satellite and ground observations. A statistical method called persistence forecasting, for example, bets that the weather you have now will be similar to the weather you'll have over the next few minutes.

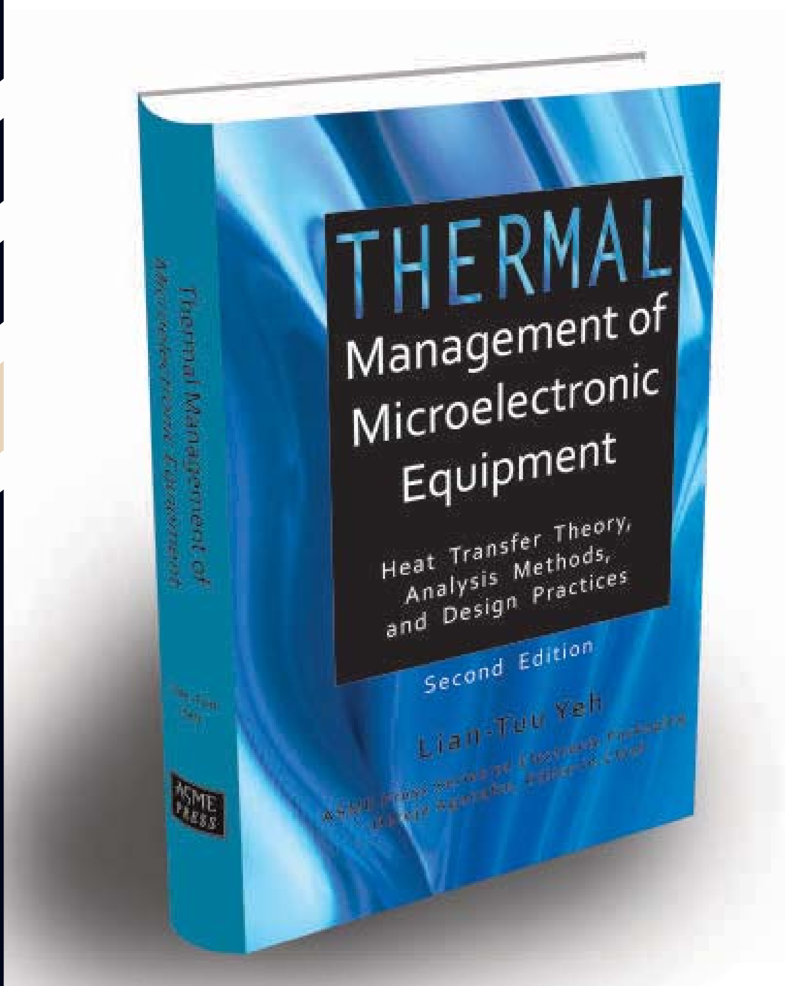
Forecasters typically combine numerical and statistical methods because "you need something to use while you're updating your latest forecast," Clifton said. For solar forecasts, they also add data from local measurements of solar radiation and from cameras on satellites, and they use machine learning to help fill in the gaps. Then they use known energy-conversion efficiencies for specific solar panels and wind turbines to convert the weather forecast into energy forecasts and generate maps of how much solar and wind power will be available—and when.

As wind and solar use rise, expect forecasting technology to be fine-tuned to generate even higher resolution predictions of wind and solar resources days ahead of time. "Wind and solar are going to form an ever-larger part of the generation mix," said Clifton. "That is going to require that we make a lot more use of forecasting." ME



Passing storms and fronts can dramatically alter wind energy production over the course of a day. *Credit: Sue Ellen Haupt, NCAR*

ALAINA G. LEVINE, a Tucson, Arizona-based science writer, is the author of *Networking for Nerds*.



FEATURED

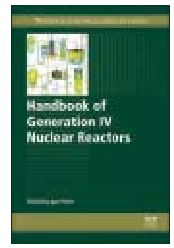
THERMAL MANAGEMENT OF MICROELECTRONIC EQUIPMENT, SECOND EDITION

LIAN-TUU YEH

ASME Press Books, Two Park Avenue, New York, NY 10016-5990. 2016.

Designers of electronic packaging, from chip to system levels, have to consider thermal effects more than ever. Yeh's book, now in a fully updated and greatly expanded second edition, emphasizes the solving of practical design problems in a wide range of subjects related to various heat transfer technologies. The inclusion of both the fundamentals and a step-by-step analysis approach to engineering makes it a valuable reference volume. One new chapter covers microwave modules and gallium arsenide chips, which have seldom been discussed in textbooks or publications dealing with the thermal management of electronic equipment. Several practical designs for systems with liquid cooling are also presented, as is a comprehensive convective heat transfer catalog that includes correlations of heat transfer for various physical configurations and thermal boundary conditions.

500 PAGES. $159; ASME MEMBERS, $127. ISBN: 978-0-7918-6109-7.



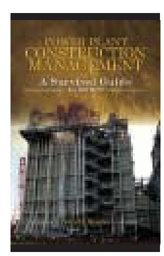
HANDBOOK OF GENERATION IV NUCLEAR REACTORS

Igor Pioro, editor

Woodhead Publishing, an imprint of Elsevier, 360 Park Ave S., New York, NY 10010. 2016.

A team of 47 nuclear experts representing countries ranging from China and India to the United States contributed to this book, which is devoted to concepts for the next generation of nuclear reactors. This so-called Generation IV was developed last decade and includes six broad categories: very-high temperature reactors, gas-cooled fast reactors, sodium-cooled fast reactors, lead-cooled fast reactors, molten salt reactors, and supercritical water-cooled reactors. Those advanced designs are the subject of widespread research and commercial interest, though none have been built as yet. Other topics covered in the book include nuclear weapons proliferation protections in the Gen IV concepts, thermal aspects of conventional and alternative fuels, and the prospects for hydrogen cogeneration.

940 PAGES. $297.50. ISBN: 978-0-0810-0149-3.



POWER PLANT CONSTRUCTION MANAGEMENT: A SURVIVAL GUIDE, 2ND EDITION

Peter G. Hessler

Pennwell Books, 1421 South Sheridan Road, Tulsa, OK 74112-6600. 2016.

Electric utilities, like all companies, invest in capital equipment with an eye on the potential for profit, selecting the technology, fuel, and plant site with ROI in mind. But Hessler, an ASME Life Member, writes that the same applies when utilities begin the planning process for plant construction. "Although the construction phase occurs at the end of the project process," Hessler writes, "it is really the tail that wags the dog." Expanding upon the first edition, Hessler provides a thorough plan for managing the financials of building a power or chemical plant and covers the entire process from preplanning to contingency planning to the business of on-site construction management.

397 PAGES. $99. ISBN 978-1-59370-337-0.

In This Issue

Global Gas Turbine News

Volume 55, No. 4 • December 2016

ASME INTERNATIONAL GAS TURBINE INSTITUTE

ASME Turbo Expo, Power & Energy and ICOPE Co-Locate in 2017.

ASME Turbo Expo, Power & Energy, and International Conference on Power Engineering will be jointly held from June 26 to 30 at the Charlotte Convention Center. The three conferences will be packed with technical education and knowledge exchange in the power and turbomachinery industry.

For over 60 years, ASME Turbo Expo has brought together turbomachinery professionals from around the world to discuss the latest advancements in turbine technology, research and development, and applications. The program for the five-day conference, which will be presented by the ASME Gas Turbine Segment, will feature a keynote panel followed by the annual awards program, two plenary sessions, pre-conference workshops, more than 300 technical sessions, an early career engineer/student mixer, and other networking opportunities. Additionally, there will be a variety of joint activities with Power & Energy and ICOPE including a welcome reception at the NASCAR Hall of Fame, a Women in Engineering Networking event and Student Poster Competitions.

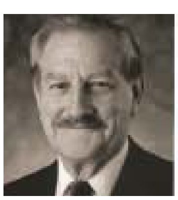
Turbo Expo's conference technical tracks will encompass a wide range of topics, including ceramics; coal, biomass and alternative fuels; combustion, fuels and emissions; controls, diagnostics and instrumentation; fans and blowers; education; electric power; general and conjugate heat transfer; industrial & cogeneration; marine; manufacturing materials and metallurgy; oil & gas applications; organic rankine cycle power systems; steam turbines; structures & dynamics; supercritical CO_2 power cycles; microturbines, turbochargers and small turbomachines; design methods and CFD modeling for turbomachinery; aircraft engine noise and innovative noise reduction; and wind energy. If warranted by review, papers may also be recommended for publication in ASME's *Journal of Turbomachinery or Journal of Engineering for Gas Turbines and Power.*

ASME Power & Energy, which focuses on topics related to power generation and energy sustainability, will include three leading Society conferences: the ASME Power Conference, sponsored by the ASME Power Division; the ASME Energy Sustainability Conference, sponsored by ASME's Solar Energy and Advanced Energy Systems Divisions; and the ASME Fuel Cell Conference, sponsored by ASME's Advanced Energy Systems Division. The event will also feature two special forums: the ASME Nuclear Forum and the ASME Energy Storage Forum.

Topics to be addressed during the various Power & Energy and ICOPE technical sessions will include fuels and combustion, power generation sources, plant equipment, operations and maintenance, plant construction and supply chain management, energy storage, fuel cells, sustainability, and thermal hydraulics and engineering analysis.

ASME Turbo Expo 2017 and Power & Energy will include a three-day exhibition showcasing leading companies in the international power and energy and turbomachinery industries. For information about sponsor and exhibitor options for ASME Turbo Expo, visit www.asme.org/events/turbo-expo/sponsor-exhibit. To learn about sponsor and exhibitor opportunities at Power & Energy, visit www.asme.org/events/power-energy/sponsor-exhibit.

For more information on ASME Turbo Expo and ASME Power & Energy, visit www.asme.org/events/turbo-expo or www.asme.org/events/power-energy.



Memorial:
Sep van der Linden

Septimus (Sep) Strathearn van der Linden, a mechanical engineer with a worldwide career in the power generation industry, passed away suddenly on August 29. After receiving his degree in mechanical engineering from the University of the Witwatersrand in Johannesburg, South Africa, in 1957, Mr. van der Linden immigrated to Canada, where he joined Worthington International. He opened company offices in Vancouver, B.C., before being transferred to the U.S. corporate headquarters in Harrison, N.J. During the next 12 years, Sep led power plant development on an international basis, requiring residence in San Juan, Puerto Rico, and Sydney, Australia. In 1970, Sep joined Curtiss-Wright Power Systems, where he launched their packaged gas turbine generating units in North and South America, the Caribbean, the North Sea, Australia and New Zealand, the Middle East and South Africa. In 1984, Septimus joined Brown Boveri Corporation (BBC) with the primary objective to re-introduce the company into the gas turbine market in

Continued on pg. 46

Honors & Awards

Young Engineer Turbo Expo Participation Award

The ASME Gas Turbine Segment Young Engineer Turbo Expo Participation Award (YETEP) 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 and present a paper which they have authored or co-authored. The purpose is to provide a way for more to participate in the annual ASME Turbo Expo. The nominee must have obtained an academic degree (Bachelor, Master, PhD, or equivalent degrees) in an engineering discipline related to turbomachinery within five years from the year of the ASME Turbo Expo that the applicant wishes to attend. The research results that the applicant wishes to present at the conference could have been obtained either while pursuing an academic degree, or afterwards (students, professionals or young academics are eligible).

For 2017, ASME IGTI will provide YETEP Award winners with:

- **One Complimentary ASME Turbo Expo Technical Conference Registration**
- **Complimentary hotel accommodations (Sunday to Friday)**
- **Up to $2,000 toward approved travel expenses**

Nomination deadline for ASME Turbo Expo 2017 - March 1, 2017:
https://www.asme.org/events/turbo-expo/present-publish/author-travel-award.

ASME IGTI Student Scholarship Program

ASME International Gas Turbine Institute has a long and proud history of providing scholarships to students who show promise for their future profession in the turbomachinery field. The aim is to attract young talent to the profession and reward their commitment, favoring their upcoming enrollment and active participation. ASME IGTI has supplied more than one million dollars to fund these scholarships over the years. The scholarship is to be used for tuition, books and other University expenses. The check will be made out to the University on the student's behalf.

Student application deadline is June 15, 2017 for the 2017-2018 School Year. Scholarship winners will be notified by the end of October 2017. Scholarships will be dispersed in November.

Eligibility of the Applicants
The nominee must be pursuing an academic degree (Bachelor, Master, PhD, or equivalent degrees) in an engineering discipline related to turbomachinery. Students must be currently registered at an accredited university (either U.S. or international). The university must have a gas turbine program of some type and only requires that a gas turbine or power course that has significant gas turbine content be offered.

Application Requirements
The application package must contain:

1. **A succinct motivational letter (max 1 page) illustrating reasons that should lead to a positive decision by the selection committee.**
2. **The application form listing the data allowing assessment of the eligibility of the applicant, duly signed; and the IRS Foreign W8BEN Form (if a non-US citizen).**
3. **A nomination form and recommendation letter by the applicant's academic supervisor, or by an industry professional involved in his/her studies. Student should follow up with nominator to confirm the packet has been sent to ASME.**
4. **Any other document the applicant wishes to attach in order to support the application. (Proof of awards and honors, memberships in honorary or professional societies showing offices held, extra-curricular activities, etc.)**

Application is available at:
https://community.asme.org/international_gas_turbine_institute_igti/w/wiki/4029.honors-and-awards.aspx.

Student Advisory Committee Travel Award

The Student Advisory Committee (SAC) represents the interest of the students who attend ASME Turbo Expo and serves as a student-specific liaison to the Gas Turbine Segment Leadership Team. The Committee will engage students by creating student-oriented programs at ASME Turbo Expo, such as poster presentation, tutorial sessions and activities that facilitate student interaction and networking with turbomachinery professionals. This year the SAC is sponsoring up to 20 travel awards for students who actively contribute to the growth of the committee. The awards are reimbursement awards that cover up to $2,000 of travel expenses for the recipients.
To apply for the Student Advisory Committee (SAC) travel award, please submit all documents in one PDF file to sac.igti@gmail.com by March 1, 2017. All applicants will be notified of the decision on their application by March 31, 2017.

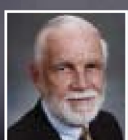
Application can be located at:
https://www.asme.org/events/turbo-expo/program/students.

For more information on the Gas Turbine Segment Honors and Awards Opportunities, visit

https://community.asme.org/international_gas_turbine_institute_igti/w/wiki/4029.honors-and-awards.aspx.

"As the Turbine Turns...."

#28 December 2016



Lee S. Langston
Professor Emeritus
Mechanical Engineering
University of Connecticut

The Single Crystal Turbine Blade-An ASME Landmark

The very first operational gas turbine powerplant [1] is in a special museum on the grounds of the Alstom Rotor Factory (now owned by General Electric) in Birr, a village not far from Zurich, Switzerland. This 1939 4 MWe Brown Boveri gas turbine power plant is an ASME Landmark (#135), designated as such in 1988, at Neuchatel, and now at Birr.

An ASME Landmark is an existing artifact, event or system that represents a significant step forward in the evolution of mechanical engineering. Too often today, our achievements in mechanical engineering, even monumental ones, go unrecognized. They are something taken for granted as part of modern life, accepted without thought or reflection on the tremendous amount of skilled design work and creative genius that went into their creation. The Landmark Program is a way of reasserting the central importance mechanical engineers - past and present - have played in meeting social and technical challenges, whether they involve creating economic value, or solving very specific and difficult human problems.

I recently joined the History & Heritage Committee, which has directed the ASME's Landmark Program, since its founding 45 years ago. Over these years, the H&H Committee has made 260 Landmark designations, ranging from the Boulton & Watt steam engine of 1785 (#111) to the Apollo Lunar Module of 1972 (#218).

This year, at its June meeting in Louisville, Kentucky, the H&H Committee voted to designate Pratt & Whitney's invention of the single crystal turbine blade as an ASME Landmark.

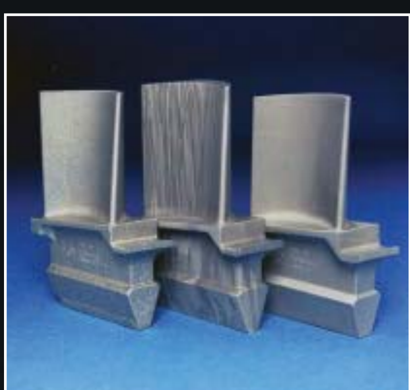


Figure 1. Turbine blades are acid-etched to show grain structure. Left is equiaxed; center, directionally solidified; right is single crystal.

Background

About sixty years ago, a small group of P&W gas turbine industry mechanical engineers and metallurgists set out to eliminate grain boundaries in superalloy turbine blades. Today, the result is a whole class of single crystal turbine blades that have increased thermal efficiencies and life, and have unmatched resistance to high-temperature creep and fatigue [2].

Conventionally cast turbine airfoils are polycrystalline, consisting of a three-dimensional mosaic of small metallic equiaxed crystals, or "grains," formed during solidification in the casting mold. Each equiaxed grain has a different orientation of its crystal lattice from its neighbors'. Resulting crystal lattice misalignments form interfaces called grain boundaries.

Life-limiting events happen at grain boundaries, such as intergranular cavitation, void formation, increased chemical activity, and slippage under stress loading. These conditions can lead to creep, shorten cyclic strain life, and decrease overall ductility. Corrosion and cracks also start at grain boundaries. In short, physical activities initiated at superalloy grain boundaries greatly shorten turbine vane and blade life, and lead to lowered turbine temperatures with a concurrent decrease in engine performance.

One can try to gain sufficient understanding of grain boundary phenomena so as to control them. But in the early 1960s, engineers and researchers at Pratt & Whitney Aircraft (now Pratt & Whitney, owned by United Technologies Corp.) set out to deal with the problem by eliminating grain boundaries from turbine airfoils altogether, by inventing techniques to cast single-crystal (SX) turbine blades and vanes.

One Dimensional Crystals

Pratt & Whitney's first step to develop SX blades was directional solidification (DS). Carried out in vacuum furnace, DS is accomplished by pouring molten superalloy metal into a vertically mounted, ceramic mold heated to metal melt temperatures, and filling the turbine airfoil mold cavity from root to tip. The bottom of the mold is formed by a water-cooled copper chill plate having a knurled surface exposed to the molten metal. At the knurled chill plate surface, crystals form from the liquid superalloy and the solid interface advances, from root to tip.

The mold is surrounded by a temperature-controlled enclosure, which maintains a temperature distribution on the lateral surfaces of the mold so that latent heat of solidification is removed by one-dimensional transient heat conduction through the solidified superalloy to the chill plate. As the solidification front advances from root to tip, the mold is slowly lowered out of the temperature-controlled enclosure.

The final result is a turbine airfoil composed of columnar crystals or grains running in a spanwise direction. For the case of a rotating turbine blade, where spanwise centrifugal forces set up along the blade are on the order of 20,000 g, the columnar grains are now aligned along the major stress axis. Their alignment strengthens the blade and effectively eliminates destructive intergranular crack initiation in directions normal to blade span. In gas turbine operation, DS turbine blades and vanes have much improved ductility and thermal fatigue life. They also provide a greater tolerance to localized strains (such as at blade roots), and have allowed small increases in turbine temperature (and, hence, performance).

Their first use by Pratt & Whitney in a production engine was in 1969, to power the SR-71 Blackbird supersonic reconnaissance aircraft. Commercial jet engine use of these airfoils followed, starting in 1974.

One Crystal, One Turbine Blade

Building upon direction solidification, Pratt & Whitney reached the goal of liquidating turbine airfoil grain boundaries in the late 1960s.

The making of a single-crystal turbine airfoil starts the same as a directional solidification airfoil, with carefully controlled mold temperature distributions to ensure transient heat transfer in one dimension only, to a water-cooled chill plate. As shown in Fig. 2, columnar crystals form at the knurled chill plate surface in a mold chamber called the "starter". The upper surface of the starter narrows to the opening of a vertically mounted helical channel called the "pigtail", which ends at the blade root. The pigtail admits only a few columnar crystals from the starter.

Crystal orientations grow at different rates into the liquid metal in the pigtail, with one orientation growing the fastest. Thus, with ample coils, only one crystal emerges from the pigtail into the blade root, to start the single crystal structure of the airfoil itself.

In the 1970s, after SX production techniques were developed, SX turbine airfoils were installed in P&W's F100 production engines, to power F-15 and F-16 jet fighters. The first commercial aviation use was in the JT9D-7R4 jet engine, which received flight certification in 1982, powering the Boeing 767 and Airbus A310.

The first use of SX turbine airfoils in electric power gas turbines was for corrosion resistance in a 163 MWe machine, the Siemens V94.3A (now SGT5-4000F), introduced to market in 1995. In more recent years electric power gas turbine inlet turbine temperatures have increased to aviation levels, so the SX airfoils with higher temperature capacity are now needed for long life. The SX turbine blades and vanes in GE's and Siemens H machines are huge, with lengths of 30 to 45 centimeters, with each finish casting weighing about 15 kilograms.

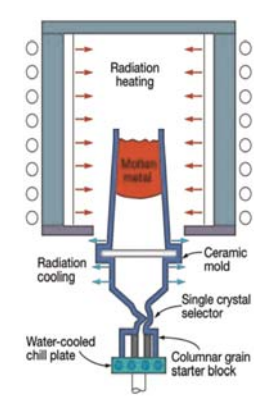


Figure 2. Original Single Crystal Casting Process [2]

Continued on pg. 48

Continued from pg. 42

the USA. After 19 years with the company, where, among other things, he made significant contributions to the CAES technology culminating in Huntorf power plant, Sep retired in 2002 (at that time Alstom) and established his engineering consulting company, BRULIN Associates LLC, which specialized in gas turbines and emerging technologies.

Throughout his career in the power generation industry, Mr. van der Linden authored and presented more than 100 technical papers at conferences around the world, and wrote numerous technical articles for global energy publications. In recognition of his years of dedicated voluntary service to the American Society of Mechanical Engineers and the International Gas Turbine Institute in a variety of roles, including author, reviewer, session chair/organizer, technical/advisory committee member and technical program chair, Sep received the ASME Dedicated Service Award in 1988. In April this year, he was presented with the ASME IGTI Outstanding Service Award. A past chair of the Electric Power Committee of IGTI, Sep also served on the Energy Storage Council as well as PowerGen International and Electric Power conference committees.

Our sincere condolences are extended to Sep's wife Liess and family. For more details with regard to Sep's life, accomplishments and remembrances please see the links below.

http://www.ccj-online.com/1q-20012/gas-turbine-historical-society/

http://www.ccj-online.com/industry-briefs-remembering-sep-van-der-linden/.

http://obits.nj.com/obituaries/starledger/obituary.aspx?n=septimus-strathearn-van-der-linden&pid=181299312&fhid=19626&eid=sp_shareobit#sthash.nuYj6TRy.dpuf

Memorial:
Harold W. Hipsky

Harold W. Hipsky, Jr., 58, of Willington, CT, passed away on Saturday, June 18, 2016. He was born in Willimantic, CT, son of Harold W. and Irene (Varga) Hipsky of Willington, CT. Harold was a graduate of the University of Connecticut and worked for United Technologies Aerospace Systems as an engineer for 36 years. Well known in the industry, he was very active in ASME-IGTI and was regarded as an expert in the turbomachinery and fluids areas, having a firm grasp of centrifugal pumps, compressors, radial inflow turbines, axial flow turbines, axial fans, mixed flow fans, diffusers, nozzles and all the associated fluid flow paths that accompany such. He was active in developing turbomachinery courses for other UTC colleagues, and was on the advisory board of the University of Hartford where he helped to establish a Masters' degree program in turbomachinery.

In addition to his technical work, he deeply enjoyed running his farm with his family and holding family parties where he treated his family to barbeque chicken, salmon, steak and lobsters. The festivities on his farm included hayrides in the fall and campfires in the summer. Besides his parents, Harold is survived by his loving wife of 22 years, Michelle (Marino) Hipsky; two sons, Benjamin M. Hipsky and James M. Hipsky, all of Willington, CT; four siblings and their spouses, Donna and Peter Latincsics, Diane and Peter Sercombe, Becky and David Kozek, and Maria and John Miller; three sisters-in-law and their spouses, Elizabeth and James Cerrone, Anita and Richard Gaffney, and Lisa and Norman Demers; several aunts and uncles; and many nieces, nephews, and cousins.

Memorial:
Friedrich ("Fred") Otto Soechting

Friedrich ("Fred") Otto Soechting, beloved husband of Gail Soechting, passed away September 21, 2016 in Tequesta, FL. He was born on June 11, 1948 in Vienna, Austria, to parents Friedrich and Elisabeth Soechting, and was raised in Wayne, NJ. Upon graduation from Newark College of Engineering (NJIT) in 1969, Fred was employed by Pratt & Whitney in Hartford, CT. High school sweethearts Fred and Gail married in 1970 followed by a relocation to Tequesta, FL. Fred retired from Pratt & Whitney after 31 years in 2000, later working for Mitsubishi, Belcan, and private consulting.

Fred was a once in a generation leader in advancing turbine airfoil heat transfer design. His ability was extraordinary to both reduce problems to fundamental physics and teach through practice with the younger engineers. Engineers who developed under Fred's direction went on to be senior leaders throughout industry, government, and academia. His innovations in turbine airfoil design are still being deployed today. His ability to team with academia & industry set the example for how to both develop future heat transfer leaders and build lasting relationships between university researchers and industry.

Fred is survived by his loving wife Gail, daughters Greta (husband Alberto) and Andrea (husband Andrew), granddaughter Nayra, mother Elisabeth, brother John, sisters Elizabeth and Anne Marie, and loving extended family and friends.

Not all Hydrophobic Filters are Equal

By Stephen Hiner
Chief Engineer – Gas Turbine Inlet Systems, CLARCOR Industrial Air | www.clarcor.com

How to best determine a filter's hydrophobicity and what is needed to be assured of a filter's performance in the real world over time.

A Gas Turbine (GT) inlet filter's hydrophobic properties determine how well it will react and resist penetration when challenged with moisture and liquid phase corrosives. Salt is hygroscopic (has an affinity for water and absorbs moisture from surrounding air) in nature and so is often found in liquid form, even when initially captured as a particle it can subsequently become a liquid when humidity changes and then leech through a filter. If allowed to pass the filtration system in this form it will cause compressor corrosion, and when sodium from the salt combines with the sulphur found in the fuel, will cause accelerated hot end corrosion as well. Salt is also a sticky substance which when allowed to reach the compressor blades, will lead to an increase in fouling by enabling dust particles to better adhere to the blades, reducing compressor efficiency.

If liquids are allowed to pass through the filter system, they increase the risk of blade erosion from fine droplets and may also carry previously captured dirt particles and wash them downstream into the compressor. This will further increase potential for reduced turbine performance due to fouling and can create problems with small passage plugging in the hot section.

Different filter types may claim to offer hydrophobic or watertight properties, but not all hydrophobic filters are equal. A hydrophobic filter media generally means a media that contains fibers that have a very low surface energy, causing water droplets to bead up, roll off, and therefore be repelled by the media. Some fibers can be naturally hydrophobic, such as PTFE and Polypropylene, but the majority in use today require an additional fiber coating to make them so. A filter unit's hydrophobic efficiency in real applications depends upon factors including the media type, but also how the filter is constructed. At the present time there are no international test standards for the hydrophobicity of complete filter units. So how can operators be sure a filter will give them the protection they need once it is installed, particularly if the installation is in harsh, real-world environments often associated with large gas turbines? Tests used to establish water-resistance of fabrics for clothing and other industries such as MIL-STD 282 and EN20811, have been adopted by filter manufacturers and are quite commonly used for the basis of hydrophobicity claims. The general test for how a media handles water is a measure of its hydrostatic head. This typically involves flat pieces of filter media being tested against a pressure head column of water, not allowing any penetration up to a certain pressure. Such tests do not check for the effect of any damage or weakness caused by the pleating of the filter media once it is packaged into the filter unit, nor do they check that the construction of the filter unit itself is robust and leak proof.

Some manufacturers carry out a "bucket test" demonstration by pouring clean water into a complete filter unit to show that it can hold water like a "bucket", and the media does not leak. The problem with such tests is that they do not test the media in real-world conditions. The media or filters used are new and clean, so a gas turbine (GT) operator has no guarantees that they will perform or continue to perform as demonstrated once installed and operating for a period of time. "Bucket tests" do not, for example, check for any degradation in the performance of the hydrophobic media coatings or partial coverage of such by dust over time. They do not even show whether there are any robustness issues with a filter after it has been packed and experienced the rigors of being shipped to site. Over time or simply during shipment, unseen cracks may appear in glue or seals which allow water (and the contaminants it contains) to bypass the filter media altogether. Fundamentally, testing a brand new filter with just water only provides some of the data, but does not give a true indication of a filter's performance in the real world over time.

So what assurance can operators get that a filter will operate as they perceive from paper specifications? Tests have been developed in conjunction with several GT OEM's to evaluate a filter for real life performance, and these require numerous cycles to simulate the types of environment it will be exposed to on site, going far beyond pouring clean water into a clean filter. Such tests are becoming recognized by independent bodies as better test methods to be incorporated into future international standards, such as for the future ISO 29461. This is, of course, what operators are ultimately interested in and want to achieve to provide representative test methods to be able to compare hydrophobic filters on an "apples for apples" basis.

Continued on next page.

Typical salt deposit on Gas Turbine compressor blades

Advanced test procedures, such as those used at CLARCOR and available at other select independent filter test houses, consider the full range of environmental factors for a GT installation and aim to test the filter in the worst possible conditions. To start with, the filter is clamped as it would be when connected into the GT system. This brings every aspect of a filter's construction into question, including its seal and the clamping system itself. At the end of the day, if water and liquid contaminants, such as salt, are allowed through the filter system into the turbine, it doesn't matter how they get there; the damage has been done.
Once installed as it would be on site, testing of the complete filter unit involves numerous cycles of prolonged wetting and drying. Salt is introduced into the challenge aerosol, and efforts made to get the salt to migrate through the filter. Tests are repeated when the filter is loaded with dust. This adds pressure to the system while the dust coats some of the fibers within the media, simulating real world degradation. Filter efficiency is measured at various points throughout the testing, with a single test typically taking ten days to complete. The whole test procedure provides comprehensive data about a filter's performance over time, including the amount of water and salt that passes through the complete filter unit during various test stages and highlights any pressure drop that occurs.

Summary

The environments in which many GTs are installed are harsh. Testing clean media and isolated system components alone do not show that a filter will retain its hydrophobic efficiency in the real world over time. A test needs to put a complete filter unit through cycles of wetting and drying while challenging it with salt aerosol and loading it with dust, to encourage salt leach through the media. Measurements of any migration through the filter along with any increases in pressure drop are vital to establishing how well a filter will protect a gas turbine.
Industries that utilize and rely on the performance of modern gas turbines are more aware than ever of the damage and cost to their business of ineffective filtration systems. Corrosion damage, reduced turbine efficiency due to fouling and sudden pressure spikes all reduce the output and availability of the system. International standards do not currently require such comprehensive testing as that carried out by CLARCOR. It is, however, increasingly being accepted that this is the best way to ensure protection of valuable machinery, system availability and profits from the often harsh, real-world environments into which gas turbines are installed.

"As The Turbine Turns" Continued from pg. 45

The Result

In gas turbine use, single-crystal turbine airfoils have proven to have as much as nine times more relative life in terms of creep strength and thermal fatigue resistance and over three times more relative life for corrosion resistance, when compared to equiaxed crystal counterparts. By eliminating grain boundaries, single-crystal airfoils have longer thermal and fatigue life, are more corrosion resistant, can be cast with thinner walls—meaning less material and less weight—and have a higher melting point temperature. These improvements all contribute to higher gas turbine thermal efficiencies.

Cost-wise, a turbine designer currently has the choice of turbine airfoils that are equiaxed (less expensive), DS (expensive), SX (more expensive) or SX with exact lattice orientation specified (most expensive). Because single crystal properties such as elastic modulus (the tendency of the material to deform along a specific axis) vary with lattice angular orientation, the optimization of this property can improve specific problem areas of blade design, such as creep life or critical vibration modes.

Technology history shows that a game changer such as single crystal turbine blades usually entails a long-term process, typically 30 years or more. Pratt's single crystal team did it in less than 10 years, from concept to a marketed product. This targeted group success is worthy of study in itself. The story of the creation of these gems of gas turbine efficiency, now to be an ASME Landmark, is an exemplar for others to follow.

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2. *Langston, Lee S., 2016, "Turbine blades: Good, better, best", Combined Cycle Journal, First Quarter, pp. 28-32.*

A forum for emerging systems and control technologies.

DYNAMIC SYSTEMS & CONTROL

DECEMBER 2016 VOL. 4 NO. 4

SELF-DRIVING AND CONNECTED VEHICLES

DSC ASME

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Tentative future issues of *Dynamic Systems & Control Magazine*

March 2017
Cyber-Physical System

June 2017
Human-Machine Interaction

Dynamics and Control in Connected and Autonomous Vehicles

Connected and Autonomous Vehicle (CAV) technologies are becoming major research areas in automotive and transportation systems. Although currently only limited numbers of automated and connected vehicles are available on the market, with the further refinement of vehicle electronics and wireless communication, vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-cloud (V2X) will become commonplace. The abundant information from wireless communication and on-board sensors, such as LIDAR (a detection system that works on the principle of radar but uses light from a laser), greatly enhances vehicle control, path and route planning, etc.

This issue of the *Dynamic System and Control* magazine provides two articles in modeling, control, and validation of connected and autonomous vehicles. In the first article, Huei Peng discusses the roles of dynamics and control for connected and autonomous vehicles. The concepts of connected and autonomous vehicles are introduced first and then the research challenges of connected and autonomous vehicles are addressed. The capabilities of the Mobility Transformation Center (MTC), a public/private R&D partnership led by the University of Michigan, are briefly discussed, where MTC aims to develop the foundations for a viable ecosystem of CAVs. Note that currently the vehicle fuel economy and emission performance are evaluated using a driving cycle, such as the FTP driving cycle, without interactions among surrounding vehicles and therefore a new evaluation method is needed for CAVs. In the second article, Mohd Azrin Mohd Zulkefli, Pratik Mukherjee, Yunli Shao, and Zongxuan Sun present an evaluation method for connected vehicles using hardware-in-the-loop simulations. Both articles provide academic visions on the roles that dynamics and control can play in connected and autonomous vehicles.

I express my deep appreciation to both authors who made contributions to this magazine.

If you have any ideas for future issues of this magazine, please contact the Editor, Peter Meckl (**meckl@purdue.edu**).

Guoming (George) Zhu, PhD
Guest Editor, *DSC Magazine*

2016 AMERICAN CONTROL CONFERENCE SUMMARY OF EVENTS

The **2016 American Control Conference** (ACC) took place July 4–8 at the Marriott Boston Copley Place Hotel. The conference featured several new programs and set a record number of 1786 registrants. The first two days of the conference were devoted to pre-conference workshops while the main conference days were on Wednesday through Friday.

A first ever outreach program called Applications Friday (AF) was introduced to engage local practicing engineers and students. The one-day program began with Professor Lucy Pao's Plenary Lecture on **Combined Feedforward/ Feedback Control of Flexible Structures: Recurring Themes across Diverse Applications** (see **Figure 1**). The plenary lecture was followed by a student poster session in the exhibits area. In particular, this marks the first time that undergraduate students as a group were slated to present work at an ACC. In the afternoon, three tracks of Applications Tutorials were presented, with content focused at practicing engineers. Applications Friday attendees were provided with memory sticks containing the AF material, which was separate from the normal conference materials.

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FIGURE 1 Lucy Pao's Plenary Lecture.

FIGURE 2 Stephen Boyd at his Public Lecture.

FIGURE 3 Jack Little's opening talk.

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FIGURE 4 AACC Award Recipients. Front row (l-r): Tariq Samad (outgoing AACC President), Brian Anderson (Ragazzini Award Recipient), Jason Speyer (Bellman Award Recipient), Mrdjan Jankovic (Control Engineering Practice Award Recipient), Glenn Masada (incoming AACC President). Back row (l-r): Sergio Pequito (O. Hugo Schuck Award Recipient), Soulaimane Berkane (Best Student Paper Finalist), Mohammad Amin Rahimian (Best Student Paper Finalist), Ernst Csencsics (Student Best Paper Award Recipient), Hector Perez and Scott Moura (O. Hugo Schuck Award Recipient).

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FIGURE 5
The ACC 2016 Student Best Paper Finalists. From left to right: Ardalan Vahidi (ACC 2016 VC for Student Affairs), Ernst Csencsics (Student Best Paper Winner), Bala Kameshwar Poolla, Soulaimane Berkane, Rahul B. Warrier, Mohammad Amin Rahimian, Danny Abramovitch (ACC 2016 General Chair), George Chiu (ACC 2016 Program Chair).

Another outreach activity was a Public Lecture by Professor Stephen Boyd (**Figure 2**) on **Mathematical Optimization in Everyday Life: The Growing Role of Hidden Algorithms in Smart Products and Systems** which provided a unified overview of how the mathematics of feedback control and optimization impact many fields in our ever connected world. The lecture was attended by over 1000 people from the conference and the community at large. The conference opened on Tuesday evening with MathWorks co-founder and CEO Jack Little (**Figure 3**), who looked backwards to the pre-Matlab days and forward to an ever more connected design environment in his talk on **Accelerating the Pace Toward Smarter Controlled Systems**.

Wednesday and Thursday saw two semi-plenary talks each day. On Wednesday, Professor Karlene Hoo and Dr. Jason Dykstra gave a tandem talk about the difficult sensing and control environment at the bottom of an oil well while Professor Neville Hogan discussed rehabilitative robotics. On Thursday, Professor Delphine Dean discussed how one can combine the high tech work of nano-measurements with the seemingly low tech problems facing health care in poor countries, while 2015 Eckman Award Winner Professor Aaron Ames spoke about bipedal robots and robotic assistive devices. Recordings of the public, semi-plenary, and plenary lectures are planned to be made available on the IEEE CSS Online Lecture Library (http://www.ieeecss-oll.org).

The AACC Awards Ceremony was highlighted by Brian Anderson receiving the John R. Ragazzini Education Award and Jason Speyer receiving the Richard E. Bellman Control Heritage Award. The Control Engineering Practice Award went to Mrdjan Jankovic while the Donald P. Eckman Award went to Javad Lavaei. The O. Hugo Schuck Best Paper Award for theory went to the team of Sergio Pequito, Soummya Kar, and George J. Pappas, while the award for practice went to the team of Hector Perez and Scott Moura. The ACC Best Student Paper Award went to Ernst Csencsics for a paper co-authored with his advisor, Georg Schitter. Award recipients are pictured in **Figures 4** and **5**.

The acceptance rate for papers submitted to the conference was 68%, where 1246 papers were accepted. ACC is truly an international

UPCOMING CONFERENCES

55TH IEEE CONFERENCE ON DECISION AND CONTROL
Las Vegas, Nevada   ARIA Resort & Casino
December 12-14, 2016
http://cdc2016.ieeecss.org/

2017 AMERICAN CONTROL CONFERENCE
Seattle, WA   Sheraton Seattle Hotel
May 24-26, 2017
http://acc2017.a2c2.org/

2017 AIM, IEEE INTERNATIONAL CONFERENCE ON ADVANCED INTELLIGENT MECHATRONICS
Munich, Germany
July 3-7, 2017
http://www.aim2017.org/

IFAC 2017 WORLD CONGRESS
Toulouse, France
July 9-14, 2017
https://www.ifac2017.org/

IEEE CONFERENCE ON CONTROL TECHNOLOGY AND APPLICATIONS
Kohala Coast, Hawaii
Mauna Lani Bay Hotel and Bungalows
August 27-30, 2017
http://ccta2017.ieeecss.org/

10TH ASME DYNAMIC SYSTEMS AND CONTROL CONFERENCE
Tysons Corner, Virginia
October 11-13, 2017
https://www.asme.org/events/dscc

THE ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION
November 3-9, 2017
https://www.asme.org/events/imece

conference where the authors represented 60 countries from all continents except Antarctica. The program included 7 tutorial sessions, 8 special sessions, and 49 invited sessions. There was also a special workshop for high school students on Friday.

We were especially appreciative of the 5 Gold and 11 Silver sponsors and exhibitors. We are also extremely grateful to MathWorks for sponsoring the opening reception.

The 2016 ACC was widely successful due to our superb Operating Committee: Sean Andersson (Local Arrangement Chair), Mike Borrello (Exhibits Chair), Aranya Chakrabortty (Vice Chair for Industry and Applications), Garrett Clayton (Registration Chair), Eric Frew (Vice Chair for Workshops), Santosh Devasia (Finance Chair), Katie Johnson (Publication Chair), Kam Leang (Publicity Chair), Kristi Morgansen (Vice Chair for Special Sessions), Daniel Rivera (Vice Chair for Invited Sessions), Rifat Sipahi (Local Outreach), and Ardalan Vahidi (Vice Chair for Student Affairs). The Program Committee was responsible for putting together the deep slate of invited sessions. **Figures 6** and **7** picture General Chair, Danny Abramovitch, and Program Chair, George Chiu, respectively.

Last and definitely not the least we like to thank volunteers at all levels and attendees for their help and encouragements. ■

Danny Abramovitch, ACC 2016 General Chair
George Chiu, ACC 2016 Program Chair

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FIGURE 6 ACC 2016 General Chair Danny Abramovitch making yet another introduction.

7

FIGURE 7 ACC 2016 Program Chair George Chiu making yet another introduction.

AWARDS AND ANNOUNCEMENTS

We would like to take this opportunity to celebrate the achievements of our ASME DSCD members!

■ **Hossein Rastgoftar** has written a hard cover book, published by Birkhäuser Basel, a division of Springer International Publishing, entitled *"Continuum Deformation of Multi-Agent Systems"*. The book presents new algorithms for formation control of multi-agent systems based on principles of continuum mechanics. Beginning with an overview of traditional methods, the author then introduces an innovative new approach whereby agents of an MAS are considered as particles in a continuum evolving in $\mathbb{R}^n$ whose desired configuration is required to satisfy an admissible deformation function. This book will provide advanced graduate students and researchers with the necessary background to understand and apply the methods presented.

■ **Innotronics**, a start-up company launched by DSCD members, was selected to be in the Top 35 University Start Ups of 2016 ranking by the National Council of Entrepreneurial Tech Transfer. The start-up company was launched by members of **Prof. Rajamani's** laboratory at the University of Minnesota. It utilizes adaptive estimation algorithms and magnetic sensors to accurately estimate positions of ferromagnetic objects. The company plans to provide position sensors for hydraulic and pneumatic actuators in mobile and industrial applications. Specifically, the company is focused on selling to OEMs in the agricultural vehicles, construction vehicles and material handling industrial systems markets. More information at: http://ncet2.org/.

BY HUEI PENG
PROFESSOR
THE UNIVERSITY OF MICHIGAN

CONNECTED AND

Tomorrow's vehicles will be more electrified, connected, automated, and shared compared with vehicles today. In 2014, the University of Michigan launched the Mobility Transformation Center (MTC), a public-private partnership dedicated to study the new mobility trends. The near-term focus of the Center is to develop and deploy connected and automated vehicles (CAVs), and to study their societal impacts. Much of the content of this paper is drawn from the author's work at MTC over the last two and half years. This article is divided into three parts. First, the background and current status of connected vehicles and automated vehicles are presented. The MTC activities in these areas are then briefly described. Finally, research challenges, particularly those in the general areas of dynamics and control are highlighted to stimulate interest and thought in these areas.

CONNECTED VEHICLES

Personal computers (PCs) first operated largely in isolation. They became a lot more useful and productive after they were connected through internet. Smart phones were subsequently invented, which keep people connected anytime and anywhere to each other and to the internet. The movement of Internet of Things (IOT) aims to connect all data sources and users to make them function better together. For ground vehicles, "function better together" could mean more convenient, safer, more energy efficient, less congested, etc.

Automotive companies and government transportation agencies soon realized that the "net neutrality" principle, universally embraced by internet and communication companies, may not work well for ground vehicles. Net neutrality is the principle that Internet service providers and governments should treat all data on the Internet the same, not discriminating or charging differentially [1]. However, information related to safety (e.g., hard braking events, vehicle running red lights, etc.) should be communicated to road users nearby immediately. These communication needs should take priority over other non-critical needs, e.g., downloading a movie. Solution to this special, safety-first need, is dedicated short-range communication (DSRC). In the US, the Federal Communications Commission allocated 75MHz bandwidth near the 5.9GHz spectrum in 1999 for ground vehicle safety applications exclusively. Since then, professional societies such as SAE and IEEE have published standards to define channels, hardware specifications, communication protocols, and messaging formats and contents to ensure that DSRC devices from different OEMs and suppliers are inter-operable. Very importantly, DSRC was designed to ensure timely and low-latency communications among hundreds of devices, which cannot be achieved by today's 4G/LTE systems.

Because Bluetooth, wifi and 4G/LTE technologies are mature, they have been deployed quickly and smoothly. However, DSRC is new and needs time to develop. While the technologies are getting mature, no production vehicle today in the US comes with DSRC. General Motors likely will be the first company to do so, with their 2017 Cadillac CTS. The US Department of Transportation has a new Federal Motor Vehicle Safety Standard (FMVSS) 150 under review. If passed, it will require DSRC on all light ground vehicles. In Japan, DSRC is already available under the name of ITS connect, using Japan's standardized ITS frequency

Automated Vehicles

The Roles of Dynamics and Control

of 760 MHz [2]. Some other countries, e.g., China, might push for a cell-phone based vehicle communication system, even though no standard has been defined.

For system and control engineers, the most significant impacts of vehicle connectivity are shown in **Figure 1.** The nature of control changes in three fundamental ways: (i) some of the unknown disturbance inputs become known; (ii) Instead of measuring the position of the lead vehicle, for example, its acceleration or even brake action can be known through communication. In certain cases, future information may also become available; (iii) multiple vehicles can become collaborative or coordinated. These three changes mean different control synthesis methods can be used, and better control performance is possible.

AUTOMATED VEHICLES

Many people use the terms "automated", "autonomous" and "driverless" vehicles interchangeably. However, there are actually 5 levels of automated vehicles defined by SAE International [3]. An automated vehicle (AV) is "driverless" or "autonomous" only when the vehicle (i) controls both steering and acceleration/deceleration, (ii) does not expect the human driver to monitor the driving environment, and (iii) does not rely on the human driver as the fallback for the driving task. The Autopilot system offered by Tesla Motors is a "Level-2" automated vehicle, and is not a driverless or autonomous vehicle. Many companies are already offering "Level-2" automated vehicles, or plan to do so in the near future. On the other hand, driverless vehicles are being actively pursued as the end-game by not only many automotive companies, but also outsiders such as Google, Apple, Intel, and NVidia. The google self-driving car is a "Level-4" automated vehicle and is a driverless car. When an AV can operate at highway speeds, and can operate in day/night, rain/snow, and in all driving scenarios, then it can be said to be a "Level-5" vehicle.

In general, there are five technical challenges for automated vehicles (see **Figure 2**). The complexity and difficulty can grow significantly from low automation levels to higher levels. For example, lane keeping assistance systems only need to focus on lane detection and keeping, and may not have full capability to detect other crash threats, e.g., a slowing lead vehicle, or a cross-path bicycle. A driverless vehicle, on the other hand, needs to detect all objects and understand the driving environment thoroughly to navigate through the traffic safely.

Since the focus of this paper is on dynamics and control, the last two technology challenges (control and validation) will be discussed later and in more depth in this paper. Here we will briefly talk about the first three challenges, i.e., sensing, localization and perception.

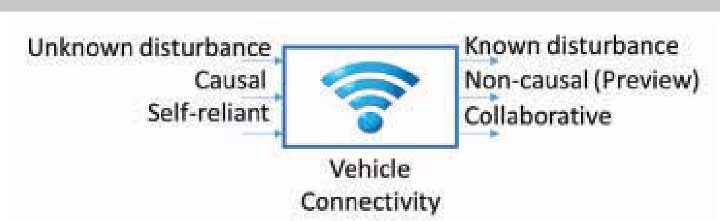

FIGURE 1 Vehicle connectivity fundamentally changes the nature of the control system.

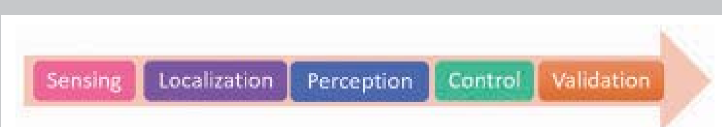

FIGURE 2 Five technical challenges of automated vehicles

Sensing: Camera and radar are the two key types of sensors used in the Tesla Autopilot system. Lidar, on the other hand, is the major sensor used by the Google self-driving car project. Prices of cameras and radars have dropped to the range of hundreds of dollars while lidars are still 1-2 orders of magnitude more expensive. These three sensors all have their relative strengths and weaknesses. Lidars provide the best accuracy in detecting the position and shape of an object and can have 360-degree view, but are expensive, vulnerable to rain and snow, and might be interfered by other laser sources (including other driverless vehicles). While many believed that lidars cannot see the lanes, there were results showing the lanes can be seen by analyzing lane marker reflectivity. A radar sensor can best see through the fog, rain, or snow, and can detect the relative speeds of other vehicles accurately. However, it is not very good at detecting the size and shape of the object, thus is not very useful in understanding what it just saw. This sensing inaccuracy results in a major challenge: radars are not very good at differentiating stationary objects (e.g., a mailbox) and an obstacle with zero speed (e.g., a parked car). Radars are also pretty useless detecting the lanes. Due to these two major limitations, radars cannot be the primary sensor for autonomous driving. But radar can be a backup in inclement weather. Cameras can have adequate resolution and can see color, and stereo cameras can detect the range to the objects. Therefore, cameras have better situation awareness if the images are interpreted correctly. However, their performance is affected by light conditions and adverse weather. Since all the available sensors have limitations, there is significant effort to push down the price of lidars so that all three types of sensors are available on AVs. The test vehicle we recently acquired at the University of Michigan is equipped with 5 lidars, 5 radars and two cameras (see **Figure 3**), which allows researchers to study the synergy of these sensors in autonomous driving.

Localization: The concept of simultaneous localization and mapping (SLAM) was a hot topic in the robotics area [4]-[6]. For AVs, however, because GPS and navigation maps are already widely available, there is little need to solve the mapping problem, and GPS provides a reasonable localization measurement. However, the GPS accuracy can be poor, especially in urban environments, where fewer satellites are in direct line of sight, and significant multi-path problems sometimes exist. The SAE standard J2945/1 [7] defines the recommended vehicle position accuracy in the horizontal direction to be 1.5 meters, so that the vehicle's lane position can be known reliably. If not corrected, standard GPS cannot achieve this accuracy requirement, mainly due to satellite and receiver clock drift, satellite orbit error, conditions in the Ionosphere and Troposphere, and multi-path. Fortunately, there are two characteristics that can be explored: (i) Slow-varyingness: many of these factors change slowly because they accumulate over time or change slowly with air temperature and season; and (ii) Commonality: they affect GPS receivers near each other largely in the same way, except the multi-path and receiver errors. Localization accuracy can be improved through on-board inertial motion sensors, high accuracy maps, and differential mode. The term differential mode means using a base station at a known location to broadcast correction signals for other GPS receivers in the neighborhood. Differential mode with coarser (code phase) correction is known as DGPS, those with real-time finer (carrier phase) correction are known as Real-Time Kinematic (RTK). Recently, time-separation signal processing techniques and choke ring antennae have been developed to reject far- and near-multipath errors, the major source of non-common position inaccuracy.

The benefits of accurate localization are two-fold: (i) It provides accurate measurement of the most important controlled output of the autonomous vehicle: its position; and (ii) If the vehicle location is accurately known and a high-definition navigation map is available, computation load in the perception phase (see next section) can be dramatically reduced. One can imagine that a future high-definition navigation map (HD map) will have not only streets and intersections, but also more details such as traffic signals, signs, and markers of major buildings, which are stationary objects that the perception software can use. As an example, it is much easier to differentiate between an obstacle in front on a flat surface and a hill using an HD map [8]. Another example is that the HD map can be used to improve localization accuracy, especially in adverse weather. In addition, the stationary objects do not need to be the focus of the perception algorithm. The computation power can then be focused on moving objects for faster and more accurate perception.

Perception: Even though both sensing and localization problems are non-trivial, perception has been the weakest link in recent pursuit of autonomous driving. Cameras can produce millions of pixels, and lidars can generate millions of "hits" per second. The large amount of raw data then needs to be processed, clustered, and combined to form the basis for understanding the environment: the lane markers, parked and moving vehicles, pedestrians, cyclists, traffic controls (signals and cops), and special road users such as emergency vehicles. It is important to know not only their current positions, but speeds and accelerations as well. Knowing the obstacle or road user types is important because the knowledge enables using a model to better predict their behavior. In its June 2016 monthly report [9], Google announced significant progress in recognizing cyclists, and understanding their gestures. Cyclists are fast, agile, and vulnerable road users. They obviously should be treated differently from cars. Given the newness of this report from a top self-driving car project, and the fact that Google has not even started to deploy their fleet in cities with significant snow [9], it is fair to say that there is still a

FIGURE 3 University of Michigan automated vehicle test platform.

lot of work to do in perfecting their perception algorithms.

It is necessary to mention that there is significant interest in using the concept of "deep learning", a fancy term for the long-standing field of machine learning, as a way to achieve model-free perception, or to combine the perception and the planning/control step into one stage. There are many deep learning approaches and algorithms [10]-[12]. They typically share two features: (i) multiple layers of nonlinear processing units to extract different features, and (ii) learning of feature representations in each layer and improving, e.g., through value evaluation and policy improvement through Monte Carlo tree search.

An example deep-learning-based autonomous driving system was recently demonstrated by NVIDIA [13]. This system uses a convolutional neural network (CNN), and directly takes raw pixels from a single front-facing camera as the input and generates steering commands as the output. The results are significant in two ways: only tens of hours of driving data are used, and the system achieves perception and control simultaneously. However, there are also significant limitations: the system only achieves steering control and is far away from being a fully autonomous driving system. In addition, it is very hard to validate the performance of the black-box CNN-based driving system and practically impossible to ensure its performance in driving scenarios not used in the training data. The black-box nature of this approach could be a show-stopper for implementation on production vehicles for liability reasons. However, we do believe that CNN can play an important role in the perception process of AV, e.g., multiple CNNs can be trained very successfully for pedestrian detection, cyclist detection, gesture detection, etc.

MOBILITY TRANSFORMATION CENTER

The Mobility Transformation Center (MTC) is a public/private R&D partnership led by the University of Michigan. MTC aims to develop the foundations for a viable ecosystem of CAVs. The major activities of MTC are described below.

Mcity: Mcity (see **Figure 4**) is a 32-acre test facility dedicated to research, development and testing of CAVs. Mcity was designed and developed by MTC, in partnership with the Michigan Department of Transportation (MDOT). The Mcity simulates a broad range of urban and suburban environments. It includes four lane-miles of roads with intersections, traffic signs and signals, simulated buildings, street lights, traffic circles, a railroad crossing, and a simulated underpass. It has been used to develop and test functions such as frontal collision warning, emergency electronic brake light, human factors, vehicle to pedestrian safety, autonomous driving, cybersecurity, etc. A notable recent test conducted at Mcity was the "Snowtonomy" system developed by Ford Motor Company [14]. It was demonstrated that even when the road is heavily covered by snow, the AV can still drive safely using high-resolution 3D maps generated by Lidar before snow. Bicycle and pedestrian safety features have also been demonstrated at Mcity (see **Figure 5**).

Living laboratories: The University of Michigan Transportation Research Institute (UMTRI) was awarded the Safety Pilot Model Deployment grant [15] from the US Department of Transportation in 2012 to instrument 2,800 vehicles and 19 intersections with DSRC equipment. The results were used to understand real-world performance of DSRC, which in turn can be used to predict safety impacts of DSRC in reducing motor vehicle crashes. Under the support of MTC's 60 industrial members, a "connected Ann Arbor" living lab is being built, to instrument 9,000 connected vehicles. When the project is finished, roughly 10% of the vehicles in the city will be equipped with DSRC, the highest penetration-rate of DSRC vehicles anywhere in the world. In addition, 60 of the major intersections of the city will also be DSRC-equipped. The vision is that by 2018, the city of Ann Arbor will be a living laboratory, useful for the development and testing of advanced CAV functions such as pedestrian safety, eco-driving, adaptive traffic signal control, etc. The data collected from the living laboratory is being used to calibrate a macroscopic model [16] that can be used to accurately assess the impact of CAVs on energy consumption and congestion. We will also demonstrate how information collected from DSRC-equipped vehicles can be used to form the basis for a modern traffic control center without relying on traditional sensors such as magnetic loops, cameras and radars. This is possible because it was demonstrated [17] that traffic flow/congestion can be estimated accurately (within 10%) when just 5% of the vehicles' positions and velocities are known (through DSRC).

Another living laboratory concept that just got launched is "Automated Ann Arbor", which aims to deploy driverless vehicles in the city of Ann Arbor as a last-mile enhancement to today's public buses. This project is not only about development of artificial intelligence (AI) for AVs. In addition, the project will also identify and remove the legal, regulatory, liability and insurance roadblocks, and to learn how AVs can be smoothly integrated to become a useful element of the future mobility system.

Research Projects: To develop the talent pool and a strong pipeline for the future workforce, MTC also supports graduate students to work on long-term, pre-competitive research projects. Currently, there are 23 active MTC projects. These projects cover a wide range of CAV topics in engineering, legal issues, human factors, cybersecurity, user behavior, GPS accuracy, machine learning, image processing, accelerated evaluation, etc.

FIGURE 4 Mcity—the world's first test facility specifically designed to test connected and automated vehicles.

CAV RESEARCH CHALLENGES

CAV research challenges in the areas of "Control" and "Validation" are discussed in this section.

Control: There are at least three areas related to the control for CAVs that need further research and development.

(i) External HMI

This somewhat ambiguous term refers to the requirement that an AV should behave like a normal, undistracted human driver, and should communicate its attention and intention with people outside of the vehicle. Some people argue that AVs should (i) follow traffic laws, and (ii) should drive equally or more safely than human drivers. However, satisfying both requirements is far from enough. If an AV drives too conservatively and differently, it may encourage unsafe behavior from other drivers. The driverless cars from Google, Navya and Easymile all have a top speed around 25 miles/hour, and the cruising speed can be lower. In other words, they may be perfect for specific applications (e.g., mobility in a botanical garden or an industrial park), but are not yet ready to share the road with other vehicles in most cities today.

In order to drive "more like a human driver", it is important to collect large quantities of data to understand "driving etiquette". Through the Safety Pilot Model Deployment project, more than 6 million trips, and more than 40 million miles of vehicle data have been collected, which provide vehicle position, speed, acceleration, yaw rate and brake pedal state information. A subset of the trips (400 thousand trips, 3 million miles) also have forward looking video images, headway to the lead vehicle, and lane position collected. We are working on analyzing these data to produce etiquette information for driverless vehicles for the city of Ann Arbor. In addition, mechanisms to replace eye-contact and gestures between the human driver and other road users need to be developed so that the intention of the driverless car can be communicated to people both inside and outside of the vehicle effectively and reliably. One such external HMI example was demonstrated by Mercedes-Benz F 015. Effective and standardized communication symbology must be developed to improve transparency and trust of other road users toward driverless vehicles.

(ii) Correct by construction

The concept of formal methods to ensure "correct by construction" was introduced for software development about three decades ago [18]. Recently, this concept was applied to the synthesis of control algorithms [19]-[21]. The process started with clearly-stated specifications followed by analysis of the behaviors of the dynamic system. If the bounds of exogenous disturbances are known, the invariant set that can be ensured by the bounded control signals can be computed, if the plant dynamics are given. There are two major reasons control algorithm development can be much more challenging than computer software: First, there can be significant exogenous disturbances. Secondly, the plant dynamics to be controlled can be highly uncertain. Nevertheless, there had been some initial successes reported in applying formal methods in the design of automated vehicles [21][22]. In a recent paper [23], a "correct by construction" algorithm based on the barrier function concept was designed to guide a low-speed AV through a busy urban environment with seven pedestrians walking randomly, reaching the destination without any collision in 1,000 simulations. In comparison, traditional navigation methods are either too aggressive and experienced multiple collisions (e.g., potential field method [24]), or are too conservative and took a long time to reach the destination (e.g., the Hamilton-Jacobi method [25]). For safety-critical systems such as driverless cars, it is a good idea to apply formal methods for control synthesis, so that the final design has guaranteed performance and is much easier to validate.

(iii) Preview and coordinated control

When vehicles are connected, information can be communicated. CAVs can be superior to AVs that are not connected because **(a) Connectivity is a better sensor.** DSRC range is about 1,000 feet, much longer than those of the onboard sensors such as camera, radar or lidar. Position and velocity obtained through communication are much more accurate than those measured from the onboard sensors when the target is several hundred feet away. In addition, some of the vehicle states such as yaw rate and acceleration are much harder to measure using camera, radar or lidar, but can be easily obtained from a collaborative CV. Knowing driving conditions from 1,000 feet ahead enables preview or model predictive control for safer, smoother, and more efficient driving. It is also possible to learn what is around a corner and what is behind a bus using communication, both are scenarios challenging for onboard sensors to detect. **(b) Connectivity adds an actuator.** For example, an ambulance can request a traffic signal to change phase, to enable safer driving across intersections. Finally **(c) Connectivity creates a collaborative traffic system**. Automation makes individual vehicles smarter and safer, but connectivity can link them together to form an even safer and more efficient traffic system. A good analogy is that individual PCs can be great, but internet-connected PCs can be much better and more useful. It is also clear that CAVs can apply preview/predictive control algorithms, can achieve collaboration among multiple vehicles, and can communicate intent and state. In comparison, AVs can only infer/guess the states of other vehicles, and has no opportunity to apply coordinated or preview controls. We have heard many argue that AVs do not need to be connected. The question is: if connected vehicle

FIGURE 5 Examples of CAV functions demonstrated and tested at Mcity—Cyclist and pedestrian safety by Honda and Snowtonomy by Ford.

technologies are available and can enhance AV performance, why not use them?

Validation: It is necessary to thoroughly evaluate the safety of AVs before their release and deployment. Approaches for AV evaluation can be divided into three categories. Frequently, vehicles are tested through a "test matrix" approach. Low-level AVs such as automatic emergency braking (AEB) and lane departure warning are already widely available in both Europe and Asia, and their performance has been evaluated through test matrices. For driverless vehicles, this approach may not be appropriate, because the vehicle is intelligent and can be calibrated to excel in the predefined tests, while performance in other driving conditions has little assurance. In addition, driverless cars from different companies might use different sensors, with different challenging scenarios. A pre-defined test matrix may inadvertently bias against one vehicle vs. other vehicles.

A popular alternative to test high-automation-level AVs is the Naturalistic-Field Operational Test (N-FOT). In an N-FOT, a number of equipped vehicles are tested under naturalistic driving conditions over an extended period of time. An obvious problem of the N-FOT approach is the time needed. In the U.S., on average one needs to drive 530 thousand miles to experience a police-reported crash, and 100 million miles for a fatal crash. Based on the Google self-driving car project's July 2016 report [26], they

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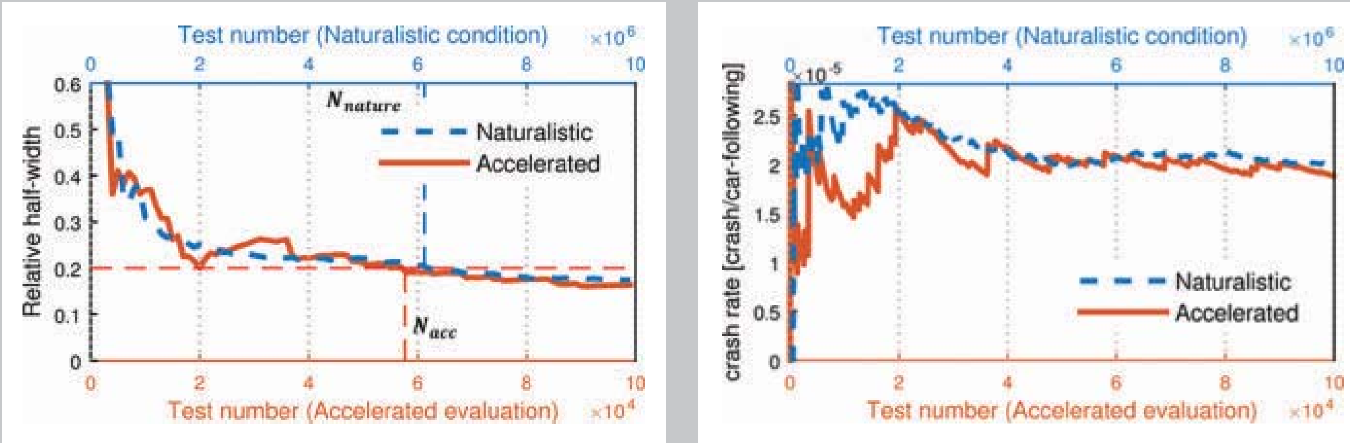

FIGURE 6 In the accelerated evaluation process the vehicle crash rate is estimated accurately compared with the naturalistic simulations while the number of tests needed is reduced significantly.

have tested for more than 1.8 million miles, which is only 2% of the average "miles between fatal crashes". Because of the low exposure to safety-critical events, N-FOT is unlikely to be used in government approval tests.

Researchers have also used Monte Carlo simulations [27]–[28] to emulate N-FOT tests by building stochastic models. Computer simulations can reduce the time and cost compared with field tests. However, low exposure to safety-critical scenarios is still an issue.

Finally, the Worst-Case Scenario Evaluation methodology [29][30] uses model-based optimization techniques to identify worst-case disturbances (e.g., lead vehicle motion) to evaluate control systems. It targets the weakness of a vehicle control system and does not consider the probability of occurrence of the worst-case scenarios. It has three major limitations: (i) high-fidelity vehicle models are needed, (ii) it is computation intensive, and (iii) the results do not relate to the risk in real-world driving.

After reviewing the literature, it becomes obvious that we do not yet have a thorough and efficient way to evaluate driverless cars (e.g., the Google car). Currently, there is no government-defined testing procedure anywhere in the world. If Google asks the National Highway Traffic Safety Administration (NHTSA) to allow it to sell cars, what should NHTSA do? Approve it without an official validation procedure (trust self-certification)? Test the vehicle for a million miles on public roads? Reject it? If the Google car is approved, and another company (with less experience) makes a similar request, what will be the decision then?

Recently, the concept of "accelerated evaluation" was developed and applied to evaluate AVs [31][32]. The first step of this procedure is to collect large quantities of naturalistic driving data. The probability density function that describes the motion of the primary other vehicle (POV) is then manipulated through the importance sampling technique [33]. The modified probability density function emphasizes the risky behavior of the POV and reduces simulation of benign scenarios. It was found that the safety benefit of AVs can be accurately estimated while the simulation time is reduced by 3-4 orders of magnitude (see example in **Figure 6**). While the initial results are encouraging, a lot of work needs to be done before the driverless car can be tested thoroughly and quickly. A knowledge gap exists in several areas: high-fidelity sensor models; large data requirement to build statistics and models for multiple other vehicles in a wide range of scenarios; behavior models for pedestrians and cyclists, and models for adverse weather conditions.

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CONCLUSION

Vehicles over the last two decades have become noticeably more intelligent, with many driver assistance systems becoming widely available. In the near future, connected and automated vehicle technologies are expected to be deployed rapidly. While there has been a lot of research in, and attention to, the field of sensing, localization and perception, this paper aims to point out a few areas related to the field of dynamics and control that offer opportunities for further research. ■

EVALUATING CONNECTED

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Vehicle to vehicle communication (V2V) and vehicle to infrastructure communication (V2I) can enable a new paradigm of vehicle applications. This paradigm shift will have profound impact on passenger and commercial vehicles, including both on-road and off-road vehicles. The connected vehicle applications could significantly improve vehicle safety, mobility, energy savings, and productivity by utilizing real-time vehicle and traffic information [1-2]. To realize this vision, three basic elements are required. First, communication devices and sensors need to be installed on both vehicles and the infrastructure. Second, new algorithms need to be developed to coordinate vehicle operation through V2V and V2I communication. Third, systematic and efficient testing methods are required to evaluate various connected vehicle applications (CVAs) to ensure their safety and effectiveness. This article focuses on the third element: evaluation of connected vehicles (CVs).

VEHICLES AND THEIR APPLICATIONS

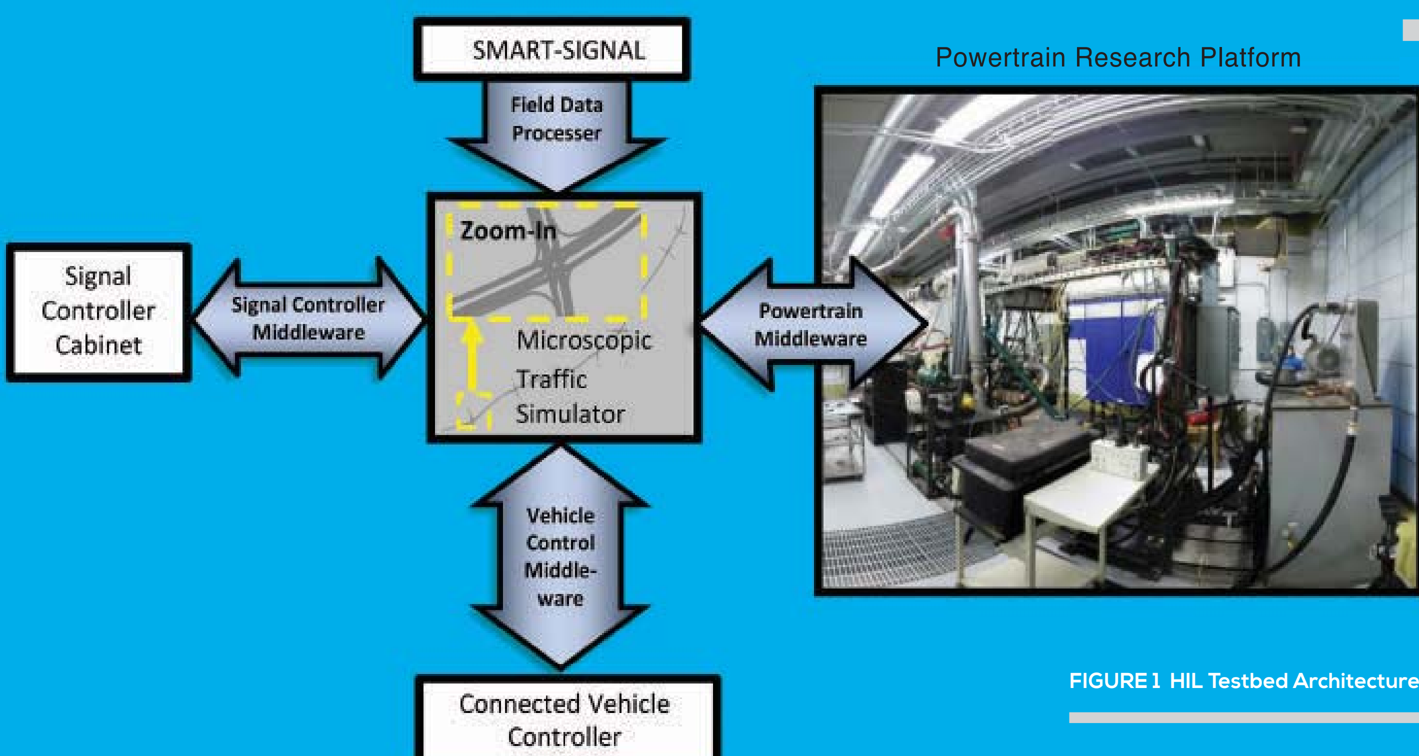

FIGURE 1 HIL Testbed Architecture.

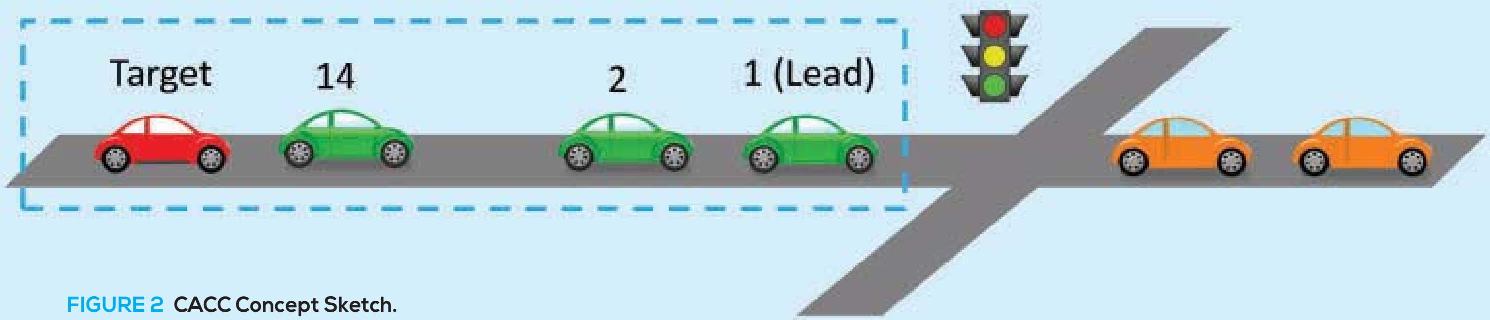

FIGURE 2 CACC Concept Sketch.

The average life span of automobiles in the United States is 15-20 years. This fact indicates that it will take at least 20 years for all vehicles on the road to be equipped with communication devices. Before then, on-road transportation will operate in the so-called "multimodal" mode. Vehicles with or without on-board communication devices need to operate together. Road infrastructure such as roadside equipment (RSE) will also be deployed gradually. This will be coupled with various vehicle automation levels, such as no automation (human operated), partial automation, or fully automated vehicles. The multimodal operation makes the evaluation of connected vehicles challenging, especially considering the safety factors for testing vehicles in real traffic. Given the above challenges, it is crucial to develop systematic, safe, and efficient testing methods for connected vehicles and their applications.

HARDWARE-IN-THE-LOOP TESTBED FOR CVAS

Currently the performance of a vehicle's fuel economy and emissions in real traffic is measured through either simulation or by instrumenting the vehicle with on-board instruments. There are limitations and challenges for either of the existing approaches. First, a simulation-based approach replaces the engine with steady-state fuel-use and emission maps and therefore may not be able to capture the transient behaviors. Secondly, instrumenting vehicles is time consuming and expensive since it requires major modifications of the vehicle. In addition, equipping large precision measurement devices on small passenger vehicles is challenging for testing purposes. One idea to solve this problem is to develop hardware-in-the-loop (HIL) testbeds for evaluating connected vehicles. The HIL system utilizes a real engine for direct fuel and emission measurements. Furthermore, different vehicles can be tested quickly and flexibly by changing the engine and the load settings on the dynamometer. The HIL testbed can also accommodate large precision measurement devices since it is built in a laboratory setting. Testing connected vehicle applications in simulated but realistic traffic is more economical without having to instrument multiple vehicles. It is also safer and bypasses the legal issues that would otherwise hamper the evaluation of connected vehicle applications in real traffic.

In this section, we will present a HIL testbed for evaluating connected vehicles at the University of Minnesota (UMN). The main objective of this testbed is to integrate a powertrain research platform [3] with a real-time traffic simulator (VISSIM) so that we can operate the powertrain research platform as if it is propelling any target vehicle selected from the simulated traffic network. This allows systematic evaluation of connected vehicle mobility and energy savings precisely, safely and efficiently. The architecture of the HIL testbed is shown in **Figure 1**.

VISSIM is a microscopic traffic simulator that allows the user to access traffic simulation states, such as vehicle speed, road conditions, and signal phase and timing, at every simulation time-step. Traffic networks can be set up in VISSIM to simulate real-world traffic scenarios. Field data can be used to calibrate the VISSIM simulation. A signal control cabinet can be connected to VISSIM to control the signal phase and timing in the traffic network. The connected vehicle controller is used to evaluate different vehicle control strategies such as cooperative adaptive cruise control (CACC). The powertrain research platform is used to emulate the powertrain operation of any target vehicle selected in VISSIM. Once the target vehicle speed and acceleration are received in real-time, the vehicle power demand is calculated and the powertrain operation is determined. The laboratory fuel and emissions measurement instruments are used to measure the fuel consumption and emissions in real-time.

The HIL testbed can be further enhanced by a living laboratory. The living laboratory enables the HIL testbed to represent a vehicle that follows the on-road test-vehicle to evaluate the performance of CVAs. To enable real-time communication, a road segment will be equipped with the roadside equipment and a small number of test-vehicles will be instrumented with onboard units (OBU). An OBU collects the test-vehicle data (e.g., location, speed, acceleration, pedal position, etc.) and generates a basic safety message (BSM) to broadcast to the RSE and other test-vehicles. RSE broadcasts traffic control signal phase and timing (SPaT) and MAP data to test vehicles, and forwards BSM and SPaT to the HIL testbed. With the equipped road and test vehicles, vehicle data can therefore be transmitted to the HIL testbed in real time to coordinate the on-road test-vehicles and the HIL testbed.

EXPERIMENTAL RESULTS

In this section, we show an example of using the HIL testbed to evaluate the performance of an emerging connected vehicle application: cooperative adaptive cruise control (CACC) [4]. CACC is intended to form a platoon of vehicles where each vehicle (except the lead vehicle) can automatically follow the preceding vehicle with safe separation distance by using radar or other sensors to measure the distance to the preceding vehicle and a communication device to communicate with other vehicles or the infrastructure. To evaluate the CACC application, as shown in **Figure 1**, the traffic simulator, connected vehicle controller (the CACC controller), and the powertrain research platform are connected in real time with the help of the middleware. Assuming that perfect communication is available between vehicles in a traffic network, the CACC algorithm is able to obtain preceding vehicles' attributes like vehicle speed to derive the velocity of the CACC vehicle for the next time step.

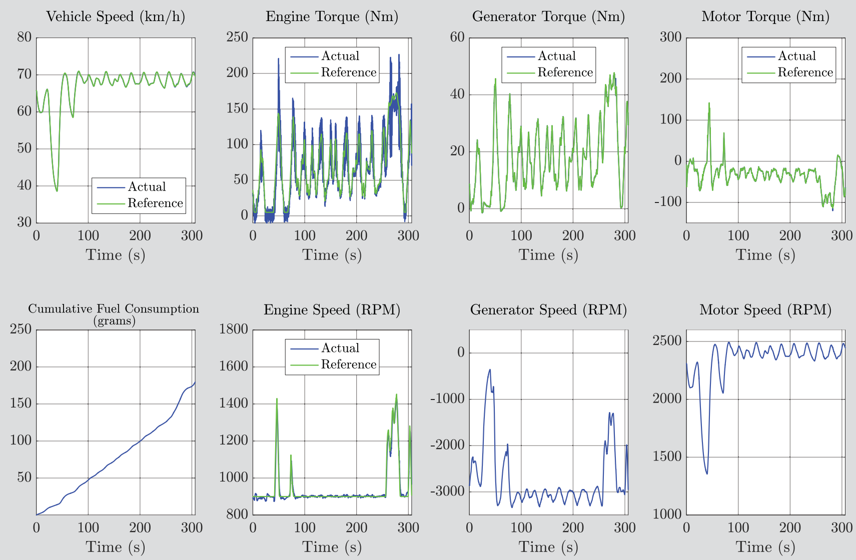

FIGURE 3 Vehicle and Powertrain Dynamics of the CACC Vehicle.

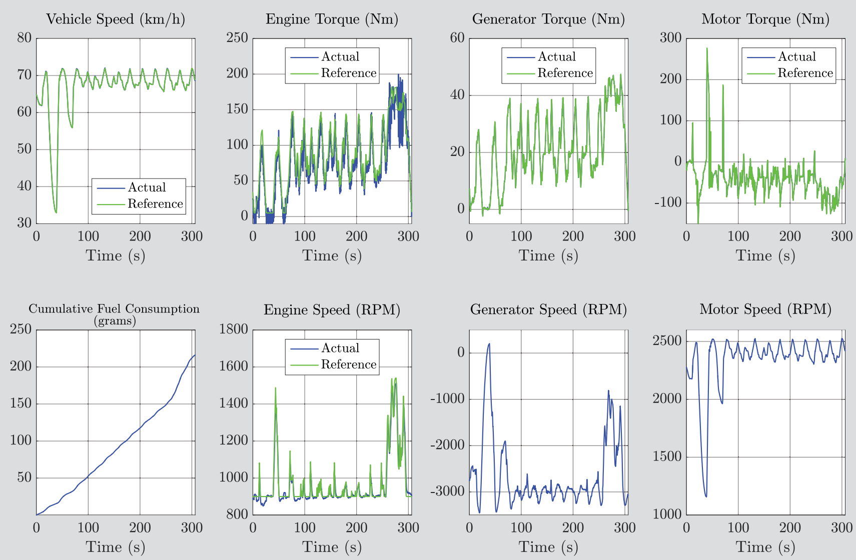

FIGURE 4 Vehicle and Powertrain Dynamics of the Immediate Preceding Vehicle.

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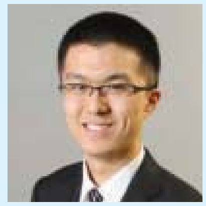

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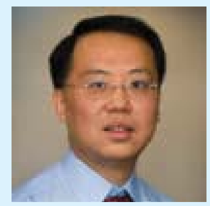

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A platoon of 15 vehicles is simulated in the VISSIM traffic simulator where the 15th vehicle is controlled by the external CACC controller and the other 14 preceding vehicles are controlled by the internal driver model of VISSIM. The platoon of vehicles is simulated on a traffic network that emulates a local highway as shown in **Figure 2**. During every time step of the simulation, the vehicle speed attribute for the 14 preceding vehicles is transmitted to the CACC controller, which then takes the average of these velocities, taking into consideration distance constraints so that the controlled vehicle does not come dangerously close to the immediate preceding vehicle or recede too far away from it. The idea behind taking the average of the velocities of the 14 preceding vehicles is to incorporate the dynamics or the behavior of the preceding vehicles ahead of time in the dynamics of the controlled vehicle. Given that ideal communication is available, taking the average of the velocities of the preceding vehicles allows the CACC controller to determine the future trajectory of the controlled vehicle, which leads to significant fuel benefits and reduction of emissions. For instance, when the lead vehicle in the platoon of vehicles stops at a traffic signal, the decrease in the velocity of this lead vehicle also causes the average of the velocities to decrease, which allows the controlled vehicle to lower its velocity and increase the relative distance between itself and the immediate preceding vehicle. This increase in relative distance gives the controlled vehicle sufficient space to maintain the same velocity instead of abruptly decelerating or accelerating in the case when communication is not available. This behavior over a complete driving cycle tends to smoothen the velocity profile of the controlled vehicle with less fluctuation in its acceleration, which has a direct correlation with fuel consumption. Hence, occurrence of this behavior over a driving cycle leads to significant fuel benefits relative to the immediate preceding vehicle's fuel consumption.

The experimental results were obtained using the HIL testbed. The controlled vehicle is modeled as a power-split hybrid electrical vehicle [1]. A planetary gear set connects the engine to a motor and a generator.

Based on the desired speed determined by the CACC controller, the vehicle power demand is calculated and split between the engine and the battery power. The engine operating point is then calculated and sent to the powertrain research platform in real time. The results below represent the vehicle dynamics, powertrain dynamics, fuel consumption, and emissions of the controlled vehicle as well as the immediate preceding vehicle.

Figures 3 and **4** show the tracking performance of the actual engine in the powertrain research platform for the controlled and the immediate preceding vehicle, respectively. **Figure 5** clearly shows that the emissions for the immediate preceding vehicle are higher for all the gases compared to the CACC controlled vehicle. **Figure 6** strengthens the hypothesis that using preceding vehicles information has potential for fuel benefits by showing that there is approximately 16.9% fuel benefit for the controlled vehicle with respect to the immediate preceding vehicle in a local highway driving condition.

CONCLUSION

In the foreseeable future, connected vehicles need to operate alongside unconnected vehicles. This makes the evaluation of connected vehicles and their applications challenging. The HIL testbed can be used as a tool to evaluate the connected vehicle applications in a safe, efficient and economic fashion. The HIL testbed integrates a traffic simulation network with a powertrain research platform in real time. Any target vehicle in the traffic network can be selected so that the powertrain research platform will be operated as if it is propelling the target vehicle. The HIL testbed can also be connected to a living laboratory where actual on-road vehicles can interact with the powertrain research platform. ■

ACKNOWLEDGEMENT

The authors would like to acknowledge the support by the Federal Highway Administration under grant DTFH6114H00005.

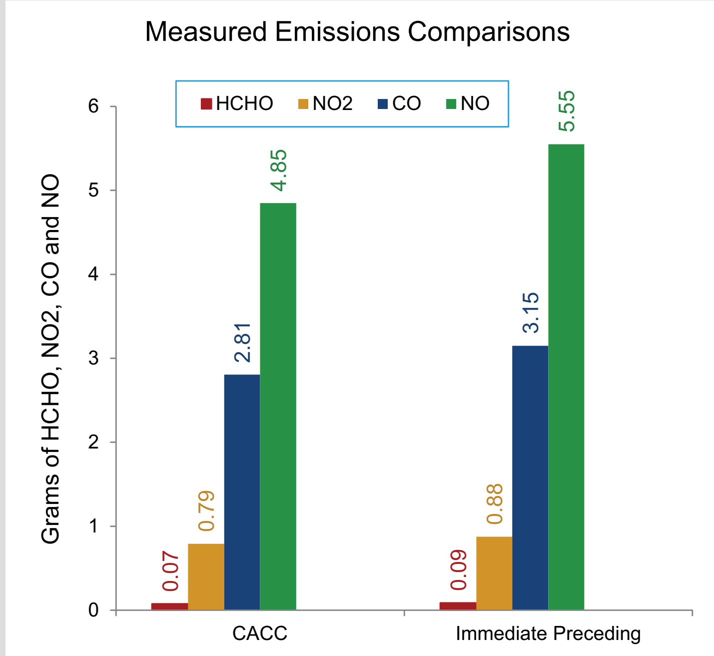

FIGURE 5 Emissions Measurements for the CACC Vehicle and the Immediate Preceding Vehicle.

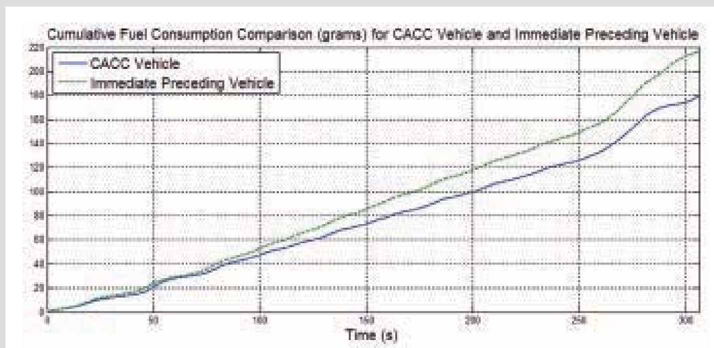

FIGURE 6 Total Fuel Consumption Comparison for the CACC vehicle and the Immediate Preceding Vehicle.

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2017 AMERICAN CONTROL CONFERENCE

Seattle, WA, May 24–26, 2017

The 2017 AMERICAN CONTROL CONFERENCE will be held Wednesday through Friday, May 24-26, at the Sheraton Seattle Hotel in the heart of Seattle, Washington – the most visited city in the Pacific Northwest. The conference venue is near nightlife, restaurants, shopping, and entertainment, just a walk to all of Seattle's known sights such as the Seattle Waterfront, Pike Place Market, Space Needle, Seattle Aquarium, and the Washington State Ferries.

The ACC is the annual conference of the American Automatic Control Council (AACC, the U.S. national member organization of the International Federation for Automatic Control (IFAC)). National and international society co-sponsors of ACC include American Institute of Aeronautics and Astronautics (AIAA), American Institute of Chemical Engineers (AIChE), Applied Probability Society (APS), American Society of Civil Engineering (ASCE), American Society of Mechanical Engineers (ASME), IEEE Control Systems Society (IEEE-CSS), International Society of Automation (ISA), Society for Modeling & Simulation International (SCS), and Society for Industrial & Applied Mathematics (SIAM).

The 2017 ACC technical program will comprise several types of presentations in regular and invited sessions, tutorial sessions, and special sessions along with workshops and exhibits. Submissions are encouraged in all areas of the theory and practice of automatic control.

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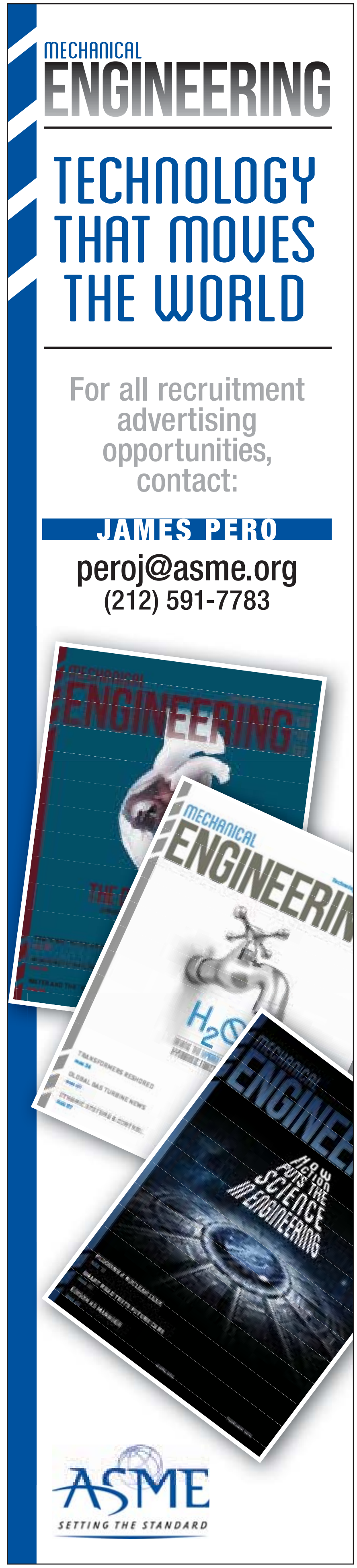

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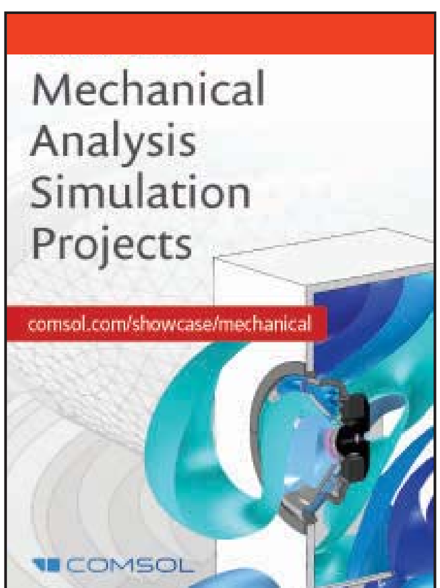

COMSOL

VISUAL COLLABORATION

VIZERRA, SAN FRANCISCO.

Vizerra has released Revizto 4.0, the latest version of its visual-collaboration software suite for the architecture, engineering, and construction industry. Revizto turns BIM models and CAD files into navigable 3-D environments, preserving complex mechanical, electrical, and plumbing information and other object data. In addition to the application's 3-D visualization component, which is built on lightweight gaming technology that makes using the platform approachable for all stakeholders, the new version combines key functionality into a single program, Revizto Viewer, for improved workflow. Revizto 4.0 also offers full support for 2-D PDF documents, which allows firms working with 2-D documents to take advantage of the program's collaborative platform and issue-tracking functionality.

CAD VIEWER

ZWSOFT, GUANGZHOU, CHINA.

CADbro is a 3-D CAD viewer designed to allow users to access, annotate, and analyze engineering data. The application supports more than 20 file formats, including those used in Catia, NX, Creo/ProE, SolidWorks, Parasolid, STEP, DWG/DXF, and STL, which will enable users to access and interact with 3-D CAD data even if they don't have a license for the application that created the file. CADbro has also incorporated smart commands to detect open edges and perform quick healing, and includes flexible editing technologies such as direct edit, curve creating, and shape/part transfer to make it possible for users to tweak CAD models.

GEOMETRIC MODELER

KUBOTEK USA, MARLBOROUGH, MASS.

KeyCreator Direct CAD and KCM Geometric Modeler are applications intended to enable the interoperability of CAD files, real-time collaboration, and an increase in computing speed. The company states that unlike other commonly-used modelers whose thread-safety methods came after the prevalence of multi-core computer processors, its applications using the KCM engine takes advantage of the thread-safety and multi-threading. This change will allow for faster speeds when performing computationally intensive CAD operations. KCM Modeler is designed to work, read or even infer the geometry of a CAD model in a different file format, with the goal of increasing the ability of files to be shared across the entire supply chain.

SOLID MODELLING

VARICAD, LIBEREC, CZECH REPUBLIC.

VariCAD 2016-1.03 brings many new features to the company's 3-D/2-D mechanical CAD system. The new version allows solids to be created by multiple sections lofting or via the connection of contours of two planar surfaces. Changes of circle or arc radii can be done for multiple objects at one step, and users can permanently change solid axes for solids imported from STEP. The new version allows selected line styles to be blocked to enable the automatic detection of hatch area boundaries. Also, 2-D dragging and stretching options are available via the right click button on the mouse, and temporary construction lines may be used for drawing or dragging.

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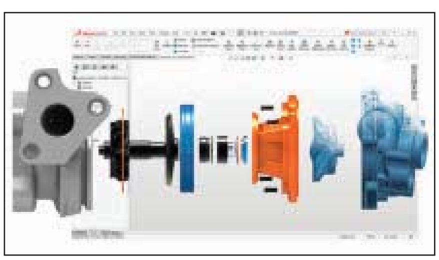
Submit electronic files of new products and images by e-mail to **memag@asme.org**. Use subject line "New Products." *ME* does not test or endorse the products described here.

CAD TO PDF

PROSTEP AG, DARMSTADT, GERMANY.

PDF Generator 3D, version 6.0 (shown above), is designed to provide a range of new features to design enterprises. Among the enhancements is the ability to use a 3-D master model as a medium for the paperless communication of engineering data to other parts of the enterprise, such as sample and prototype construction, manufacturing, and assembly. Version 6.0 enables users to change the color of product and manufacturing information annotations so that they stand out better against the model background, and the ID of topological elements is now retained both when importing models from Catia V5 and Parasolid. The application now supports the conversion of the latest CAD formats, including Catia V5-6 R2015, Inventor 2016, NX 10.0.4, Solid Edge ST8, and SolidWorks 2016.

PETROLEUM PROCESS ANALYSIS



ASPENTECH, BEDFORD, MASS.

The release of aspenONE version 9 is intended to provide integrated, streamlined workflows to firms in the oil, gas, refining, chemicals, engineering, construction, and other process industries. The new distillation column analysis capability enables engineers at refineries to analyze hydraulic performance and test operating parameters, and the improved integration and workflow in the new aspenONE refinery planning model enables process engineers to update planning models directly. A new map monitor improves scheduler visualization with an interactive web-based mapping application, providing real-time, accurate information that streamlines fuel distribution. Another new feature allows process engineers to simplify the incorporation of custom models into the application, reducing time-to-market for specialty chemicals producers, the company says, by speeding up modeling of key processes.

SCAN TO CAD

3D SYSTEMS, ROCK HILL, S.C.

Geomagic for SolidWorks is intended to provide fast, accurate processing of 3-D scan data directly within the SolidWorks environment. The application uses a toolset derived from 3D Systems' experience in 3-D scan software, enabling this new software plug-in works seamlessly inside SolidWorks. It includes features such as scan registration, automated smoothing, instant "wrapping" to polygons, and automated smart selection tools for extracting solid features. Precise deviation analysis enables engineers to accurately compare completed CAD models to original scan data on the fly. According to the company, a solid model of a mold block based on organic 3-D shapes can be created in less than 10 minutes using the application.

3-D PRINT PREPARATION

STRATASYS, MINNEAPOLIS

Stratasys, the 3-D printing and additive manufacturing company, has released GrabCAD Print, an open-architecture "design-to-3-D-print" workflow application. The application resides on the GrabCAD SaaS platform and is supported by a community of designers, engineers, and students. GrabCAD Print is designed to make 3-D printing faster and more reliable by eliminating the requirement to translate and repair computer-aided design files. Instead, product designers, engineers, and 3-D printer operators can now send native CAD files to a Stratasys 3D Printer or service bureau directly from their familiar CAD environments. GrabCAD Print works with a variety of Stratasys FDM and PolyJet 3D Printers and can natively read several popular CAD formats from PTC Creo, Dassault Systèmes' SolidWorks, Siemens PLM Software's NX software, Catia, and Autodesk Inventor.

TRACING TO 2-D

SIEMENS PLM, PLANO, TEXAS

Catchbook is a new drawing and tracing app for tablets and smartphones that converts freehand drawings into accurate 2-D designs. The app gives users the ability to draw freely, or import an image or photograph and sketch over it to add details; Catchbook converts the sketches into accurate 2-D drawings. The drawings are completely editable via simple push and pull—Siemens' D-Cubed software component works behind the scenes as a 2-D geometric constraint solving tool to capture and preserve relationships between geometry. Professional design engineers can quickly capture ideas with Catchbook and collaborate more easily with non-CAD users. The app works with both touch and stylus enabled Android, iOS, and Windows operating system devices.

LASER MICROMACHINING

PHOTOMACHINING, INC., PELHAM, N.H.

The MicroMachine USP III ultra-short pulse laser micromachining workstation uses a 20 W femtosecond laser with three wavelengths—infrared, green, and ultraviolet. The pulse duration is adjustable from 290 fs to 10 ps. The high peak power of the laser permits virtually any material to be micromachined with exceptional quality and resolution. Once the laser processing parameters are determined, the industrial-grade system can migrate directly into a production environment. An optional spindle stage can also be integrated into the system for the manufacture of stents, catheters, and other tubular components. While designed for advanced medical device manufacturing, the company says the system should appeal to any industry researching ways of using lasers in micro-manufacturing.

DIRECT-DRIVE LINEAR MOTOR

MOTICONT, VAN NUYS, CALIF.

Moticont, a manufacturer of motion control products, has released the new SDLM-025-070-01-01 direct drive linear motor, which features a built-in encoder. Inside the motor housing, the linear optical quadrature encoder is directly connected to the shaft for the greatest possible accuracy. The motor is 1 in. (25.4 mm) in diameter and 2.75 in (69.9 mm) long, and offers a stroke length of 0.5 in. (12.7 mm), a continuous force rating of 22.2 oz. (5.9 N), and peak force of 67.2 oz. (18.7 N). By directly coupling the load to the low inertia non-rotating shaft, the motor eliminates backlash and allows for high acceleration/deceleration. The SDLM-025-070-01-01 Direct Drive Linear Actuator is also available as a complete plug-and-play linear motion system with a matching motion controller.

PYROMETER

LUMASENSE TECHNOLOGIES, SANTA CLARA, CALIF.

The new Impac IGA 140/23 pyrometer is suited for low-temperature metal, ceramic, graphite, and other material applications starting at 50 °C. With both low (50-700 °C) and high (150-1,800 °C) temperature ranges, the IGA 140/23 gives manufacturers flexibility in the range of processes covered. The pyrometer is effective in induction, tempering, annealing, heating/cooling, and various other processes that occur at lower temperatures. The product features a simple design with fewer moving parts to reduce maintenance requirements. The pyrometer requires no start-up time and allows for immediate readouts. With a variety of communication options, the IGA 140/23 is capable of interfacing with many production system available in the marketplace.

MOBILE DIAGNOSTICS

HEIDENHAIN, SCHAUMBURG, ILL.

The PWT 100 is a compact standalone device used for checking the function and adjustment of Heidenhain encoders. The device incorporates a 4.3-in. touchscreen used for display and operation, along with supporting multiple serial interfaces such as EnDat 2.2, Fanuc Serial Interface, and Mitsubishi High Speed Interface. Other feedback options, along with incremental signals, will become available in the future through software expansions and firmware updates. The PWT 100 has a simpler performance range with significantly larger measuring tolerances than some other diagnostic devices offered by the company, but can be used to complement the PWM 20 for checking the function of encoders. The company says the PWT 100 is designed for mobile use.

VENTING SYSTEM

BIONOMIC INDUSTRIES, MAHWAH, N.J.

Bionomic Industries, a manufacturer of air pollution abatement technologies, has announced availability of its new ScrubPac VentClean system. The compact packaged system can remove more than 99 percent of storage tank and rail car vent emissions caused by breathing and filling operations. The scrubber system takes advantage of a triple-action scrubbing technology and offers a low pressure scrubber design to avoid potentially damaging over-pressurization of fiberglass and plastic storage tanks. The system features corrosion-resistant construction and is offered in four model sizes to handle gas capacities up to 1,500 acfm. The company suggests the ScrubPac VentClean system is suitable for such applications as HCl recovery and the removal of acid gases, alcohols, formaldehyde, and amines.

NOISE SOURCE

PASTERNACK, IRVINE, CALIF.

Pasternack, a provider of radio frequency, microwave, and millimeter-wave products, has expanded its lines of coaxial packaged noise sources. Thirty models cover frequency bands ranging from 100 kHz to 60 GHz. The new noise sources may be used as a reference source to measure system level noise for test and measurement applications. But other applications could involve system and component level wireless testing, signal simulation, and evaluating analog and DOCSYS CATV systems to improve the dynamic range of analog-to-digital converters by dithering and reducing correlated noise. The company says its portfolio of coaxial noise sources boasts a wide range of output ENR levels from 7 dB to 35 dB, and the amplified models have output power levels ranging from -14 dBm to +10 dBm.

SUMP CLEANER

CECOR, VERONA, WIS.

The new single-phase electric, Sump Shark model SE15-60PL sump cleaner has the same space-saving vertical design as the popular SA5-60PL (air) unit, but can be plugged into any standard electric unit. With a suction lift of 13-in. of mercury (or 177-in. of water) and pumping rate of 60 gallons per minute, the SE15-60PL can suck up an entire sump of metalworking fluid entrained with sludge or chips in minutes. The unit comes complete with hoses, quick-disconnect coupler, suction tools, and filter bags. An optional F23 filter is available, as is a DF4 discharge filter for fine filtering.

VENTED CONNECTOR

KOLLMORGEN, RADFORD, VA.

Kollmorgen has developed a new vented connector for the company's popular AKMH motors. The vented connector assembly is applied to the end of the cable that exits the AKMH motor, allowing the motor to vent at the connection point while maintaining the IP69K rating. (Venting is not required beyond this connection point.) That enables the use of either a wash-down mating cable, if the cable is continuing through a wash-down zone, or a non-wash-down cable if the connection point is placed outside of the wash-down area.

CABINET COOLER

EXAIR, CINCINNATI.

The new Small 316 Stainless Steel Cabinet Cooler system keeps electrical enclosures cool with 20 °F (-7 °C) air while resisting heat and corrosion that could adversely affect the internal components. The wear, corrosion, and oxidation resistance of type 316 stainless steel is intended to promote long life and maintenance free operation. There are no moving parts to wear out. Cooling capacities up to 550 Btu/hr. are ideal for small electrical enclosures and heat loads. Models with higher cooling capacities up to 5600 Btu/hr. for NEMA 12, 4, and 4X enclosures are also available. The company suggests applications such as cooling control panels used in food processing, pharmaceutical, foundries, chemical processing, and other corrosive locations.

SUBMISSIONS

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

SELF-LUBRICATING MATERIALS

METALLIZED CARBON CORP., OSSINING, N.Y.

Metallized Carbon Corp. recommends its Metcar Grade M-595 type materials for aircraft turbine engines and auxiliary power unit main shaft seals due to a chemical added to these grades. The self-lubricating materials are impregnated with proprietary inorganic chemicals that improve their lubricating qualities and oxidation resistance. The materials feature high thermal conductivity, which means they excel at handling and dissipating the high temperatures found in aerospace engines, as well as a low coefficient of friction, a low wear rate at high sliding speed, and resistance to oxidation in high temperature air. The materials are also strong and dimensionally stable.

PRESSURE REDUCING REGULATORS

MARSH BELLOFRAM, NEWELL, W. VA.

The BelGAS division of Marsh Bellofram offers its Type P203 and P203H pressure reducing regulators for industrial, commercial, and utility service applications. The regulators feature cast iron bodies, with aluminum bonnets and diaphragm casings and a durable powder-coated epoxy exterior finish. The regulators are available in a wide range of available flow capacities and pressure control ranges. The company says the P203 and P203H are suitable for medium and large industrial applications where consumption and usage vary greatly. Other applications may be found in large buildings, such as schools, universities, and offices that have multi-floor heating requirements which require constant, high flow demand on the delivery system.

FRICTION TESTER

PAUL N. GARDNER CO., POMPANO BEACH, FLA.

Surface slip is a key factor when printing or filling packaging materials on an automatic line. Gardner's Compact Friction Tester is intended to provide detailed information of the slip characteristics of packaging material, including both static and dynamic coefficients of friction. The CFT features pre-loaded ISO/ASTM/TAPPI test methods, a single-touch button to initiate tests based on defined test parameters, and a graphical representation of forces during test. Static and dynamic COF results displayed on screen immediately after test, and a full statistical analysis of test results can be output to a label printer for easy reporting. The manufacturer says its CFT is suitable for use in either the production floor or a laboratory environment.

COORDINATE MEASURING MACHINE

HEXAGON MANUFACTURING INTELLIGENCE, NORTH KINGSTOWN, R.I.

Hexagon Manufacturing Intelligence has released a new model of its Global EVO coordinate measuring machine designed in collaboration with the design house Pininfarina. Hexagon says the machine is tailored specifically to offer process speed and efficiency to manufacturers requiring accurate tactile scanning and high throughput. The Global EVO features several technologies to improve speed, including a vibration reduction technology called Compass that acts like a suspension system for the CMM, compensating for vibrations caused by its own movements. By reducing vibrations, the system enables higher-speed scanning without degrading accuracy. Global EVO also includes Fly2 Mode, a new trajectory-optimizing technology that generates the most efficient path between points.

EXTRUDED BODY CYLINDERS

AUTOMATIONDIRECT, CUMMING, GA.

AutomationDirect is offering the Nitra Pneumatics H-Series compact extruded body cylinders in bore sizes from 12 mm to 100 mm and stroke lengths from 5 mm to 100 mm. The cylinder bodies and end caps are constructed with hard anodized extruded aluminum and are factory lubricated for optimum performance and long, reliable life. Designed for fittings to be mounted in the top of the cylinder, additional features include a magnetic piston, chrome-plated steel piston rods, and slots for mounting 4 mm square cylinder switches. H-series cylinders are interchangeable with other common brands.

CORELESS BRUSH DC MOTOR

PORTESCAP, WEST CHESTER, PA.

The new 24DCT Athlonix brush dc motor features an energy-efficient coreless design with an optimized self-supporting coil and magnetic circuit to ensure high performance. With torque carrying capabilities reaching up to 14.96 mNm, the 24DCT provides high performance with efficiency reaching up to 90 percent while maintaining a long lifetime. Athlonix 24DCT 24 mm dc motors are available in two variations—precious metal commutation and graphite commutation with a neo magnet inside. The company suggests the motor could be used in battery-driven applications as varied as medical and industrial pumps, drug delivery systems, robotic systems, miniature industrial power tools, tattoo machines, dental tools, and watch winders.

ERGONOMIC LIFTER

J. SCHMALZ GMBH, RALEIGH, N.C.

The new JumboFlex Battery vacuum handling system from Schmalz solves several challenges at once. It grips, lifts, and transports starter batteries of different shapes, sizes, and weights without any physical exertion for the user. The system comprises a lifting unit, operator handle, and gripper, which is equipped with a special sealing gasket and suction resistances. The handle is designed to be operated with one hand, and the lifting unit uses a flexible hose, which provides the required suction flow to securely hold the batteries. The vacuum gasket can enable a user to pick up batteries from above, regardless of the cover geometry of the battery. The system is completed with a responsive aluminum crane such as a jib crane or an overhead crane system.

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The website announcements will provide information on the scope of the proposed standards action, the price of a standard when being proposed for reaffirmation or withdrawal, the deadline for submittal of comments, and the ASME staff contact to whom any comments should be provided. Some proposed standards actions may be available directly from the website; hard copies of any proposed standards action (excluding BPV) may be obtained from:

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ASME maintains approximately 500 codes and standards. A general categorization of the subject matter addressed by ASME codes and standards is as follows:

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Boilers
Certification & Accreditation
Chains
Controls for Boilers
Conveyors
Cranes & Hoists
Cutting, Hand, & Machine Tools
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Elevators & Escalators
Energy Assessment
Energy Storage
Engineering Drawings, Terminology, & Graphic Symbols
Fasteners
Fitness-For-Service
Gauges/Gaging
Geometric Dimensioning & Tolerancing (GD&T)
High-Pressure Vessels Systems
Keys and Keyseats
Limits & Fits
Materials
Measurement of Fluid Flow in Closed Conduits
Metal Products Sizes
Metric System
Metrology & Calibration of Instruments
Nondestructive Evaluation/ Examination
Nuclear
Performance Test Codes
Personnel Certification
Piping & Pipelines
Plumbing Materials & Equipment
Post Construction of Pressure Equipment & Piping
Power Plant Reliability, Availability & Performance
Powered Platforms
Pressure Vessels
Pumps
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The ASME Standards & Certification section is published as submitted to Mechanical Engineering magazine by ASME's Standards & Certification Department.

NEXT MONTH IN MECHANICAL ENGINEERING

HEAT SINK SUNK

By Alan S. Brown

Big data centers draw massive amounts of power, forcing technology companies to find innovative—and unlikely—ways to remove the waste heat.

香港中文大學
The Chinese University of Hong Kong

Applications are invited for:-

Department of Mechanical and Automation Engineering
Professors / Associate Professors / Assistant Professors

(Ref. 160001SC)

The Chinese University of Hong Kong (CUHK) ranks top 50 universities worldwide (QS World University Rankings, 2016/17). CUHK was also ranked the Most Innovative University in Hong Kong (from Thomson Reuters, August 2016). The 2014 Research Assessment Exercise ranked the mechanical engineering discipline of CUHK the first in all universities in Hong Kong in terms of the ratio of world leading research (top category of 4*). Further information about the Department is available at http://www.mae.cuhk.edu.hk.

The Department of Mechanical and Automation (MAE) at CUHK is seeking excellent candidates to fill the above faculty positions in the following areas:

- robotics and automation;
- design and manufacturing, in particular, in areas of 3D printing and CAD;
- energy and environmental engineering, including smart / green building, building automation and control, pollution measurement and monitoring, smart grid, and energy management.

Applicants should have (i) a PhD degree; and (ii) a proven track record or demonstrating potential for teaching and research excellence.

The appointees will (a) teach undergraduate and postgraduate courses; (b) develop an externally funded research programme; and (c) supervise postgraduate students.

All positions are similar to tenure tracked positions at universities in USA; that is, appointments will initially be made on contract basis for up to three years commencing August 2017, which, subject to mutual agreement, may lead to longer-term appointment or substantiation later. Outstanding candidates with substantial experience for Professor rank may be considered for substantive appointment forthwith.

Applications will be accepted until the posts are filled.

Application Procedure

The University only accepts and considers applications submitted online for the post above. For more information and to apply online, please visit http://career.cuhk.edu.hk.

Applicants please upload the full CV, copies of academic credentials, publication list with abstracts of selected published papers, details of courses taught and evaluation results (if available), a research plan, a teaching statement, together with names, addresses and fax numbers / e-mail addresses of three to five referees to whom the applicants' consent has been given for their providing references (unless otherwise specified).

For more information, please contact Ms. YL Kan at ylkan@mae.cuhk.edu.hk or Prof. Jie Huang (MAE Department Chairman) at jhuang@mae.cuhk.edu.hk.

BAYLOR UNIVERSITY

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Two Positions in Mechanical Engineering: (1) Clinical Professor of Practice and (1) Lecturer

The Department of Mechanical Engineering in the School of Engineering and Computer Science seeks dynamic scholars to fill one clinical professor of practice and one lecturer position. Exceptional candidates in all areas of mechanical engineering are encouraged to apply. The two positions are sought to fill specific program areas including (1) mechanics, materials and manufacturing, (2) thermofluid sciences or (3) biomaterials/ biomechanics/ biofluids. Both positions are expected to teach basic mechanics courses and laboratories, a measurements course, and/or engineering design courses. Responsibilities for both positions include teaching and mentoring students, scholarly engagement in engineering education, curriculum development, and professional service. In light of Baylor's strong Christian mission, each successful applicant must have an active Christian faith.

The positions will begin in August 2017. Application materials may be submitted at apply.interfolio.com/38984 and apply.interfolio.com/38902.

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.

School of Engineering
VANDERBILT UNIVERSITY

Faculty Position
Mechanical Engineering Department
Vanderbilt University

The Department of Mechanical Engineering at Vanderbilt University invites applications for a tenure/tenure-track faculty position to begin in the fall of 2017. Applications will be considered for positions at all ranks commensurate with qualifications. Applicants must possess a Ph.D. in Mechanical Engineering or closely related discipline. The Department is particularly interested in candidates with research experience and interests in rehabilitation robotics and/or medical robotics.

The School of Engineering strives for an active culturally and academically diverse faculty of the highest caliber, skilled in scholarship and teaching. The Department of Mechanical Engineering has 15 tenured/tenure-track faculty members with reputations for excellence in research fields including nanoengineering, rehabilitation engineering, and medical robotics, with an annual research expenditure of $7.5 million. The department encourages interdisciplinary research and the faculty is affiliated with 8 cross-campus research centers. The School of Engineering is immediately adjacent to the Vanderbilt University Medical Center, which greatly facilitates collaboration between the schools of engineering and medicine. Successful candidates are expected to (1) teach at the undergraduate and graduate levels, (2) establish vigorous research programs with extramural funds, and (3) contribute to synergistic efforts within the School of Engineering. Applications consisting of a cover letter, a complete curriculum vitae, statements of teaching and research interests, and the addresses of at least three references (include email address) should be submitted on-line at https://academicjobsonline.org/ajo/jobs/8005

Ranked in the top 15 nationally, Vanderbilt University is a private, internationally recognized research university located on 330 park-like acres 1.5 miles from downtown Nashville, Tennessee. Its 10 distinct schools share a single cohesive campus that nurtures interdisciplinary activities. The university has a student body of over 12,500 undergraduate, graduate, and professional students, including over 25% minority students and 1,170 international students from 84 countries. The School of Engineering currently comprises 90 tenured and tenure-track faculty, operates with an annual budget of over $100 million, including $70 million from externally funded research, and serves over 1,400 undergraduate and nearly 500 graduate students. In the 2017 rankings of graduate engineering programs by U.S. News & World Report, the School ranks in the top three among programs with fewer than 100 faculty (behind Caltech and Harvard) and has risen steadily in the rankings over the past decade.

With a metro population of approximately 1.8 million people, Nashville has been named the “It” city by Time magazine, one of the 15 best U.S. cities for work and family by Fortune magazine, was ranked as the #1 most popular U.S. city for corporate relocations by Expansion Management magazine, and was named by Forbes magazine as one of the 25 cities most likely to have the country’s highest job growth over the coming five years. Major industries include tourism, printing and publishing, manufacturing technology, music production, higher education, finance, insurance, automobile production and health care management.

UNIVERSITY of HAWAIʻI®
MĀNOA

Assistant Professor
(Materials: Advanced Materials and Manufacturing), position number 0083251,

University of Hawaii at Manoa (UHM), College of Engineering (COE), Department of Mechanical Engineering, invites applications for a full-time, general funds, tenure track, faculty position, pending position clearance and availability of funds, to begin approximately August 1, 2017.

The University of Hawaiʻi is a Carnegie doctoral/research-extensive university with a strong emphasis on research and graduate education. The Department offers B.S., M.S., and Ph.D. degrees in mechanical engineering, and its undergraduate program is ABET accredited.

For more information on college research themes, please visit our college web site at www.eng.hawaii.edu. The department has active research programs in nanotechnology, composites, smart materials & structures, corrosion, dissimilar materials joining, renewable energy systems & sustainability, biotechnology, biomedical engineering, space and ocean science & exploration, robotics, control systems, dynamical systems, combustion, boiling and two-phase flow, multidisciplinary design and analysis optimization, and high-performance computing.

This faculty can potentially work with UHM School of Ocean and Earth Science and Technology (SOEST) & Institute for Astronomy (IFA) and also contribute to the UH-iLab, Makers, 3D Printers, VIP, and Entrepreneurship programs of the College. This faculty can also contribute to the following COE Research Clusters: Sustainable Materials and Manufacturing Technology, Renewable Energy and Island Sustainability, Autonomous Systems (e.g., UAS, AUV, etc.), Biomedical Engineering, and Robotics.

Duties: Teach and develop undergraduate and graduate courses in Materials, Processing, and Manufacturing. Develop externally funded research program in the area of Advanced Materials Manufacturing or Advanced Processing that results in publications in leading scholarly journals; present research work in leading scholarly conferences; supervise graduate students; teach via various distance delivery modes as required; and serve on departmental, college, and university committees.

Minimum qualifications: An earned Ph.D. (All-But-Dissertation, ABD, cases will be considered) in Mechanical or Materials Engineering, or a closely related field. The candidate should have background and experience in an area of synthesis, processing, or manufacturing of Advanced Materials; or Advanced Processing of materials. Candidates must also show a strong commitment to teaching excellence and mentoring at the undergraduate and graduate levels.

Pay range: Commensurate with qualifications and experience.

To Apply: Only electronic applications are accepted. Applicants should follow the instructions at http://www4.eng.hawaii.edu/apply for submission instructions (The applicants should submit a cover letter specifying the position and the research area; a statement on their research interests, activities, and plans; a statement on their teaching philosophy, interests, and plan; a curriculum vitae detailing research and teaching accomplishments; copies of up to 4 relevant publications; and the names, addresses, e-mail, and telephone numbers of 4 references). For more information on the Department, please visit our website at www.me.hawaii.edu.

Inquiries: Professor Mehrdad N. Ghasemi-Nejhad, Chair, 808-956-7560, nejhad@hawaii.edu.

Review of applications will begin on January 15, 2017 and will continue until the position is filled.

The University of Hawaiʻi is an equal opportunity/affirmative action institution and is committed to a policy of nondiscrimination on the basis of race, sex, gender identity and expression, age, religion, color, national origin, ancestry, citizenship, disability, genetic information, marital status, breastfeeding, income assignment for child support, arrest and court record (except as permissible under State law), sexual orientation, national guard absence, or status as a covered veteran.

Individuals with disabilities who need a reasonable accommodation for the application or hiring process are encouraged to contact the EEO/AA coordinator(s) for the respective campus.

Employment is contingent on satisfying employment eligibility verification requirements of the Immigration Reform and Control Act of 1986; reference checks of previous employers; and for certain positions, criminal history record checks.

In accordance with the Jeanne Clery Disclosure of Campus Security Policy and Campus Crime Statistics Act, annual campus crime statistics for the University of Hawaiʻi may be viewed at: http://ope.ed.gov/security/, or a paper copy may be obtained upon request from the respective UH Public Safety or Administrative Services Office.

UNIVERSITY of HAWAIʻI® MĀNOA

Assistant Professor

(Mechanics: Autonomous Vehicles and Robotic Systems), position number 0083205,

University of Hawaii at Manoa (UHM), College of Engineering (COE), Department of Mechanical Engineering, invites applications for a full-time, general funds, tenure track, faculty position, pending position clearance and availability of funds, to begin approximately August 1, 2017.

The University of Hawai'i is a Carnegie doctoral/research-extensive university with a strong emphasis on research and graduate education. The Department offers B.S., M.S., and Ph.D. degrees in mechanical engineering, and its undergraduate program is ABET accredited.

For more information on college research themes, please visit our college web site at www.eng.hawaii.edu. The department has active research programs in robotics, underwater vehicles, ocean and space science & exploration, control systems, dynamical systems, biomedical engineering, biotechnology, renewable energy systems & sustainability, nanotechnology, corrosion, combustion, boiling and two-phase flow, multidisciplinary design and analysis optimization, and high-performance computing.

This faculty can potentially work with UHM School of Ocean and Earth Science and Technology (SOEST) & Institute for Astronomy (IFA) and also contribute to the UH-iLab, Makers, VIP, and Entrepreneurship programs of the College. This faculty can also contribute to the following COE Research Clusters: Autonomous Systems (e.g., UAS, AUV, etc.) and Robotics, Biomedical Engineering, Renewable Energy and Island Sustainability, and Sustainable Materials and Manufacturing Technology.

Duties: Teach and develop undergraduate and graduate courses in Mechanics, Robotics, and Engineering Design. Develop externally funded research program in the area of Autonomous Vehicles and Robotic Systems that results in publications in leading scholarly journals; present research work in leading scholarly conferences; supervise graduate students; teach via various distance delivery modes as required; and serve on departmental, college, and university committees.

Minimum qualifications: An earned Ph.D. (All-But-Dissertation, ABD, cases will be considered) in Mechanical Engineering or a closely related field. The candidate should have background and experience in Mechanics as well as System Integration, Operation, and Applications of Advanced Autonomous Vehicles and Robotic Systems (including design, analysis, fabrication, system integration, testing, operation, and applications of such systems). Candidates must also show a strong commitment to teaching excellence and mentoring at the undergraduate and graduate levels.

Pay range: Commensurate with qualifications and experience.

To Apply: Only electronic applications are accepted. Applicants should follow the instructions at http://www4.eng.hawaii.edu/apply for submission instructions (The applicants should submit a cover letter specifying the position and the research area; a statement on their research interests, activities, and plans; a statement on their teaching philosophy, interests, and plan; a curriculum vitae detailing research and teaching accomplishments; copies of up to 4 relevant publications; and the names, addresses, e-mail, and telephone numbers of 4 references). For more information on the Department, please visit our website at www.me.hawaii.edu.

Inquiries: Professor Mehrdad N. Ghasemi-Nejhad, Chair, 808-956-7560, nejhad@hawaii.edu.

Review of applications will begin on January 15, 2017 and will continue until the position is filled.

The University of Hawaiʻi is an equal opportunity/affirmative action institution and is committed to a policy of nondiscrimination on the basis of race, sex, gender identity and expression, age, religion, color, national origin, ancestry, citizenship, disability, genetic information, marital status, breastfeeding, income assignment for child support, arrest and court record (except as permissible under State law), sexual orientation, national guard absence, or status as a covered veteran.

Individuals with disabilities who need a reasonable accommodation for the application or hiring process are encouraged to contact the EEO/AA coordinator(s) for the respective campus.

Employment is contingent on satisfying employment eligibility verification requirements of the Immigration Reform and Control Act of 1986; reference checks of previous employers; and for certain positions, criminal history record checks.

In accordance with the Jeanne Clery Disclosure of Campus Security Policy and Campus Crime Statistics Act, annual campus crime statistics for the University of Hawaiʻi may be viewed at: http://ope.ed.gov/security/, or a paper copy may be obtained upon request from the respective UH Public Safety or Administrative Services Office.

LSU

TENURE-TRACK FACULTY POSITIONS

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING
COLLEGE OF ENGINEERING

The Department of Mechanical and Industrial Engineering (MIE) at The Louisiana State University (LSU) continues its significant growth of faculty. The Department is currently seeking excellent applicants to fill two tenure-track positions in Mechanical Engineering.

The College of Engineering (CoE) at LSU is experiencing a period of unprecedented growth, which includes an investment of a $110M in a new engineering complex, a result of a public-private partnership. The CoE actively encourages interdisciplinary research including, but not limited to, Advanced Manufacturing and Materials, Energy, and BioTechnology. Depending on their background, new hires will have the opportunity to leverage the resources and collaborative environments of the CoE, the National Center for Advanced Manufacturing (NCAM - **http://ncam.eng.lsu.edu/**), the recently NSF-funded ($20M over 5 years) Consortium for Innovation in Manufacturing and Materials (CIMM), the Center for Computation and Technology (CCT - **https://www.cct.lsu.edu/**), the Institute for Advanced Materials (IAM), as well as partnerships with IBM and ANSYS.

The MIE Department realizes Mechanical and Industrial Engineering education, research and scholarship. It aspires to advance professional frontiers within a creative, multi-disciplinary and diverse atmosphere that promotes discovery, creativity and innovation. It is the largest of seven departments in the CoE and is currently home to 25 Mechanical Engineering faculty, 8 Industrial Engineering Faculty, and a vibrant undergraduate and graduate student body. The faculty conduct funded research across a broad spectrum of traditional and emerging areas. The Department offers separate B.S., M.S., and Ph.D. degree programs in both Mechanical Engineering and Industrial Engineering. Further information on the Department can be found at: **http://www.mie.lsu.edu/**.

Duties of the positions include undergraduate and graduate level teaching and providing associated service; initiating and sustaining independent, externally-funded research leveraging their specialty area, and supervising graduate students. Successful candidates are expected to develop substantive collaborations across departmental and college boundaries, engage industry and develop activities supporting the State's economic development efforts.

Successful candidates will possess a Ph.D. in Engineering or a related scientific field (ABD candidates will be considered if degree will be obtained by August 2017), with at least one degree in Mechanical Engineering. Please see position descriptions online for additional information regarding qualifications.

General Area: **Composites Manufacturing and Materials** Apply online and view a more detailed ad at: **https://lsu.wd1.myworkdayjobs.com/LSU/job/LSU---Baton-Rouge/Assistant-Professor-of-Composites-Manufacturing-and-Materials--Tenure-Track-_R00000587**. Posting # R00000587.

General Area: **Advanced Manufacturing OR Robotics** Apply online and view a more detailed ad at: **https://lsu.wd1.myworkdayjobs.com/LSU/job/LSU---Baton-Rouge/Assistant-Professor-of-Mechanical-Engineering-in-Advanced-Manufacturing-or-Robotics--Tenure-Track-_R00007021**. Posting # R00007021.

An offer of employment is contingent on a satisfactory pre-employment background check. Applications will be accepted until the positions are filled and those received before February 1, 2017 will be guaranteed full consideration.

LSU IS COMMITTED TO DIVERSITY AND IS AN EQUAL OPPORTUNITY/EQUAL ACCESS EMPLOYER

POSITIONSOPEN

ASSISTANT / ASSOCIATE / FULL PROFESSOR IN ROBOTICS

The Department of Computer Science (CS) and the Department of Mechanical Engineering (ME) at Tufts University invite applications for a tenure-stream faculty appointment at any rank in the area of robotics to begin in September 2017. We are looking for individuals with expertise in research and teaching, and a strong vision who can bridge the research strands in control and navigation in ME and artificial intelligence and human-robot interaction in CS and maintain a high-quality collaborative research program at Tufts.

Candidates may have expertise in any area of AI and robotics, especially but not limited to manipulation, control, and human-robot interaction. Please submit your application online through Interfolio at https://apply.interfolio.com/38832.

For more information, please see the complete text of the position announcement at http://www.cs.tufts.edu/Jobs/employment-opportunities.html. Inquiries should be emailed to jointsearch@cs.tufts.edu. Review of applications will begin January 9, 2017 and will continue until the position is filled.

UNIVERSITY OF MICHIGAN-SHANGHAI JIAO TONG UNIVERSITY JOINT INSTITUTE

The University of Michigan-Shanghai Jiao Tong University (UM-SJTU) Joint Institute invites applications for tenure-track and tenured positions in all emerging fields related to Mechanical Engineering. UM-SJTU Joint Institute is committed to building a world-class research and educational institution based on the US university model. The Mechanical Engineering Program is ABET accredited. The students are among China's best. Successful candidates are expected to establish vigorous research programs, mentor students, participate in the international research community, and teach undergraduate and graduate classes. Salary will be highly competitive and commensurate with qualifications. Applicants should send a CV, statement of research interests, three publications, and contact information for five referees as a single PDF file to: Prof. Xudong Wang, Chair of the Search Committee, wxudong@sjtu.edu.cn . More information is available at http://umji.sjtu.edu.cn/en/.

UBC a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA

Seaspan Chair in Naval Architecture and Marine Engineering

The Naval Architecture and Marine Engineering (NAME) program at The University of British Columbia (Vancouver campus) seeks an outstanding individual for a tenure-track or tenured position at the Assistant, Associate, or Full Professor level, who will occupy a Seaspan Chair. The Seaspan Chairs are part of the $33 billion National Shipbuilding Strategy of the Government of Canada. The Chair will hold an appointment in one or more of the following Departments: Mechanical Engineering, Materials Engineering, and Civil Engineering. The starting date of the appointment will be September 2017, or as soon as possible thereafter.

The new faculty member will complement our existing strength in NAME (http://name.engineering.ubc.ca). We welcome applications from individuals who have expertise in any area relevant to NAME, and particularly encourage specialists in the disciplines of ship design, production, materials, and hydrodynamic and structural analysis.

Candidates should be able to develop an outstanding research program, enhance further existing facilities, and lead a group of graduate students, technicians, and faculty members. Owing to the need for close cooperation with industry and government, a track record of successful industry experience would be a key asset. Applicants must either have demonstrated, or show potential for, excellence in research, teaching, and service. They will hold a Ph.D. degree or equivalent in Naval Architecture and/or Marine Engineering, Civil Engineering, Materials Engineering, Mechanical Engineering, or a closely related field, and will be expected to register as a Professional Engineer in British Columbia. Successful candidates will be required to apply for Natural Sciences and Engineering Research Council (NSERC) grants in partnership with Seaspan.

Further information on the employment environment in the Faculty of Applied Science is available at www.apsc.ubc.ca/prospective-faculty.

Applicants to faculty positions in UBC Applied Science are asked to complete the following equity survey https://survey.ubc.ca/s/Seaspan-Chair/. The survey information will not be used to determine eligibility for employment, but will be collated to provide data that can assist us in understanding the diversity of our applicant pool and identifying potential barriers to the employment of designated equity group members. Your participation in the survey is voluntary and anonymous. You may self-identify in one or more of the designated equity groups. You may also decline to identify in any or all of the questions by choosing "not disclosed".

The University of British Columbia hires on the basis of merit and is strongly committed to equity and diversity within its community. We especially welcome applications from members of visible minority groups, women, Aboriginal persons, persons with disabilities, persons of minority sexual orientations and gender identities, and others with the skills and knowledge to productively engage with diverse communities. All qualified persons are encouraged to apply; however Canadians and permanent residents of Canada will be given priority.

Applicants should submit a curriculum vitae, a statement (1-2 pages) of technical and teaching interests and accomplishments, and names and addresses (fax/e-mail included) of four referees. Applications should be submitted online at http://www.hr.ubc.ca/careers-postings/faculty.php.

The closing date for applications is January 1, 2017. Please do not forward applications by e-mail.

THE UNIVERSITY OF UTAH®

FACULTY POSITIONS IN MECHANICAL ENGINEERING

The Department of Mechanical Engineering at the University of Utah invites applications for **3 tenure track positions at the assistant or associate rank** with a July 1, 2017 starting date. Candidates with exceptional background and experience may be considered at a higher rank. Candidates with interest and expertise in the areas of i) **solid mechanics,** ii) **design and/or manufacturing,** and iii) **thermal sciences** are strongly encouraged to apply. Candidates are expected to develop and maintain an active, externally funded research program that complements existing university research. Collaborations in the Department, College of Engineering, School of Medicine, and elsewhere across campus are highly encouraged. Applicants are expected to have an earned Ph.D. or Sc.D. in mechanical engineering or a closely related field prior to start date. The Department of Mechanical Engineering currently has 38 tenure-line faculty members, over 920 undergraduate and 220 graduate students. The University of Utah is a tier 1 research institution that has ranked in the top 5 nationally for start-up companies in the last 5 years. The campus is situated in Salt Lake City, a diverse, cosmopolitan city with a population of 1M nestled against the backdrop of the beautiful Wasatch Mountains. Salt Lake City residents have unparalleled access to national parks (8 within a few hours drive), skiing/snowboarding (7 resorts within 30 min), hiking, biking, rafting/ kayaking, NBA basketball, MLS soccer, and cultural events including opera, dance, symphony, theatre, and outdoor concerts. Review of applications will begin on December 1, 2016 and continue until positions are filled. Please check the complete position announcements at http://mech.utah.edu/department/open-positions/.

The University of Utah is an Equal Opportunity/Affirmative Action employer and educator. Minorities, women, veterans, and those with disabilities are strongly encouraged to apply. Veterans' preference is extended to qualified veterans. Reasonable disability accommodations will be provided with adequate notice. For additional information about the University's commitment to equal opportunity and access see: http://www.utah.edu/nondiscrimination/.

Faculty Positions (All Ranks)

DEPARTMENT OF MECHANICAL SCIENCE AND ENGINEERING

College of Engineering

University of Illinois at Urbana-Champaign

The Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign invites applications for multiple faculty positions in all ranks. Emphasis is on the areas of (i) manufacturing and (ii) energy and sustainability; however, excellent candidates will be considered in all areas related to mechanical science and engineering.

A doctoral degree is required, and salary is commensurate with qualifications and experience. Applications received by **December 4, 2016,** will receive full consideration. Early applications are encouraged. Interviews may take place before the given date; applications received after that date may be considered until positions are filled. The expected start date of a position offered/accepted through this search is August 16, 2017, but other start dates will be considered.

A full position description and information on how to apply can be found on the University of Illinois Urbana-Champaign online jobsite **http://jobs.illinois.edu**. For further information regarding application procedures, please address questions to: **mechse-facultyrecruiting@illinois.edu**.

The University of Illinois conducts criminal background checks on all job candidates upon acceptance of a contingent offer.

ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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RECRUITMENT

NOMINATING COMMITTEE SEEKING CANDIDATES

Submissions requested for Board of Governors and President

ASME has had strong, dedicated volunteer leadership throughout its 136 years of operation. As the Society moves into an exciting transformational time of determining how new growth goals will be met to help fulfill ASME's mission, it is even more necessary to find "big picture" thinkers who will help bring this new business plan into fruition.

The 2017 Nominating Committee is seeking highly qualified candidates to help lead the Society by serving on the ASME Board of Governors and as ASME President.

Prospective candidates should be innovative and capable of visionary planning into the future five to ten years. Each Board member represents the entire membership of ASME and must commit to putting individual feelings and ties to former ASME units aside, using experiences derived from those former units to help make the best decisions for the good of the Society as a whole.

It is the Board's responsibility to assure that the vision and mission of ASME continues to be met through its strategic leadership, not by involvement within the day-to-day operations of program planning and implementation.

Board membership represents the highest level of service available in ASME. Past members consistently note that it is one of the most rewarding and demanding opportunities they have had in their professional careers.

There is no unique profile for a successful Board member. Having a diverse group of members on the Board is important because it broadens the scope of discussion and leads to proper decision-making. The exchange of differing ideas among the members and the combination of individual skills makes the Board an effective team.

Selection for the open positions will take place at the Annual Meeting of ASME in Newport Beach, California, June 12-13, 2017, through a defined nomination and interview process. Those selected by the ASME Nominating Committee become ambassadors for the mechanical engineering profession and ASME.

Please consider submitting your name for one of the following positions, both of which require a high level of experience in the areas of strategy, fiduciary management, and leadership:

- **President** (1 to be selected)
- **Members-at-Large, Board of Governors** (3 to be selected)

Go to http://go.asme.org/nominate to learn more about these positions and the process.

Contact ASME Staff, RuthAnn Bigley, at bigleyr@asme.org for more information. ME

CHALLENGE WINNERS TOUR SPACE COMPANY

The fourth Future Engineers Challenge, a program developed in collaboration with the ASME Foundation and NASA, recently announced its national winners in two age groups.

Primary and secondary school students were tasked with designing a 3-D printable object that would meet the needs of an astronaut living in microgravity. The object would have to ability to assemble or expand to become larger than the 3-D printer located on the International Space Station.

The contest received submissions from 122 students from 26 states, and one national winner from each age division was chosen by a panel of judges that included retired astronaut Nicole Stott.

Thomas Salverson, a native of Gretna, Neb., who is now a freshman at the University of Alabama in Huntsville, won the grand prize in the teen group (ages 13 to 19) for his Expanding Pod, a set of containers intended to enable astronauts to store small items on the International Space Station. His design is comprised of multiple cylinders that slide and twist to create five sealed stowage compartments that lock into place.

"I enjoyed the difficulty of this challenge since it made me think in terms of 'expanding' an object, which was something I had never considered before when 3-D printing," Salverson said. "It took me many prototypes before I had successfully made my completed design, making it all the more rewarding now that I've been selected as a grand-prize winner."

Emily Takara of Cupertino, Calif., won the grand prize in the junior category (ages 5 to 12) with her Space Anchor. While researching some of the challenges that astronauts face while working in space, Takara discovered that astronauts sometimes have trouble moving easily in large, open spaces. That led Takara to design an extendable arm and grabber set that prevents astronauts from getting stuck while floating in microgravity.

"This challenge taught me to persevere and be creative," Takara said. "It has also inspired me to continue designing, as well as teach others computer-aided design."

Salverson and Takara received a trip to Las Vegas, Nev., for a tour of Bigelow Aerospace. The company developed the Bigelow Expandable Activity Module, the first expandable habitat deployed on the International Space Station.

For additional information on the Future Engineers 3-D Space Challenges and upcoming challenges, visit the Future Engineers website at www.futureengineers.org. For details on ASME's K-12 Engineering Education programs, contact Patti Jo Snyder, Programs and Philanthropy, snyderp@asme.org. ME

This photo from 1962 shows a westbound freight train on the Liverpool & Manchester Railway near Lea Green.

HISTORIC RAILWAY NAMED AN ENGINEERING LANDMARK

The Liverpool and Manchester Railway, the world's first inter-city railroad, was recently designated as a joint International Historic Civil and Mechanical Engineering Landmark by ASME, the American Society of Civil Engineers, and the United Kingdom's Institution of Mechanical Engineers and Institution of Civil Engineers.

The ceremony took place September 14 at the Rainhill Library in Liverpool, England. The library is located near the Rainhill Rail Station, which was the site of the railroad's first locomotive trials in 1829. The site was also designated as an engineering landmark by the four societies.

The L&MR, which began operations in 1830, is widely considered to be one of the most significant developments in transportation history as it was the first public railway to provide scheduled transportation of passengers and freight between remote cities, according to the landmark citation.

A team of engineers led by George Stephenson designed the double-tracked railway, which spanned 35 miles of challenging terrain along its route between Liverpool and Manchester. The railway, which is still in service using its original roadbed and most of its original bridges, instituted the basic layout for nearly all rails and rolling stock that followed.

The landmark designation at Rainhill Library was followed by a presentation from ICE on the Liverpool and Manchester Railway line and a visit to Rainhill Rail Station, the site of the historic Rainhill Trials, where five vehicles—including four steam locomotives—were tested on the railway prior to its launch. The trials were the first known engineered program to evaluate rail vehicles in a real-world environment, according to the four societies.

Stuart Cameron, ASME Board of Governors nominee, and **Larry Lee**, past chair of the ASME History and Heritage Committee, were among the attendees at the event, which also featured a trip to the Museum of Science and Industry in Manchester. A replica of the *Planet*, an early locomotive that ran on the L&MR, is displayed at the museum. ME

FREY ADDED TO D-LAB LEADERSHIP

ASME Fellow **Daniel D. Frey**, professor of mechanical engineering at Massachusetts Institute of Technology, was recently appointed as the new faculty director of the MIT D-Lab, a program at the university that promotes the design and dissemination of technologies that could significantly improve the lives of people living in poverty. Frey has been an advocate for D-Lab since its beginning, having supervised or co-supervised 10 projects and establishing working relationships with its research and program staff, according to Amy Smith, D-Lab's founder.

In addition to his role as D-Lab's faculty director, Frey also serves as co-director of experimental design research in the Singapore University of Technology and Design-MIT International Design Center and as faculty advisor for the Comprehensive Initiative on Technology Evaluation, a consortium of six MIT partners that launched in 2012.

APPLY FOR A 2017-2018 ASME CONGRESSIONAL FELLOWSHIP

Applications are now being accepted for the 2017-2018 ASME Congressional Fellowship through the ASME Federal Government Fellowship Program.

Fellows serve as independent, non-biased advisors in engineering, science and technology, bringing a nonpartisan, pragmatic approach to analysis and input which has a profound impact on the decision-making process. The result is effective and technologically appropriate public policy based on sound engineering principles.

Applicants for the Fellowship must have a strong energy background.

ASME will be accepting applications for the 2017-2018 Congressional Fellowship until Jan. 31, 2017.

This ASME Congressional Fellowship is sponsored by ASME Government Relations, the ASME Foundation and the ASME Petroleum Division.

For more information on this opportunity, visit the ASME Congressional Fellowship page on ASME.org. ME

BUILDING WITH SUSTAINABLE FIBER

Turning coconut waste into an alternative to particleboard

Mae-ling Lokko had a co-op job with a coconut fiber supplier in Accra, the capital of Ghana, a few years ago, when she was struck by how much waste coconuts generated. But all that discarded material sparked an idea.

Lokko, a doctoral candidate at the Center for Architecture Science and Ecology, a collaboration between Rensselaer Polytechnic Institute in Troy, N.Y., and the architecture firm Skidmore, Owings, and Merrill, began making pressed fiberboards and other affordable building materials from the waste byproducts of coconuts.

Last year she launched AMBIS Technologies to develop the boards and market them to emerging "hot-humid" countries as an affordable and sustainable alternative to the wood-based particleboard that dominates the building industry.

But Lokko ran into a problem common to people trying to break into mature markets. The process of creating a mass-produced high-density board from sustainable materials wasn't very sustainable. "Trying to go up against particleboard is a losing battle," she said.

The concept, though, makes sense. Coconuts are grown year-round in 93 countries and generate about 20 million tons of husks annually. Coir fibers extracted from the husk are among the strongest and lightest agricultural materials.

Lokko opted to bind the fibers with a combination of mycelium fungus and soy protein, a non-toxic alternative to the petroleum-based formaldehyde binders used in particleboard.

Unfortunately, this healthier binding created its own headaches, as it tended to settle to the bottom of the fiberboard matrix during the pressing process.

Lokko's boards also ran into other challenges. Procuring and processing coconut fibers cost almost three times more than particleboard materials. Quality control was also an issue. With her company based in upstate New York, she had to source coconuts from different distributors.

"We realized that a coconut from Sri Lanka is not the same as one from Ghana," Lokko said.

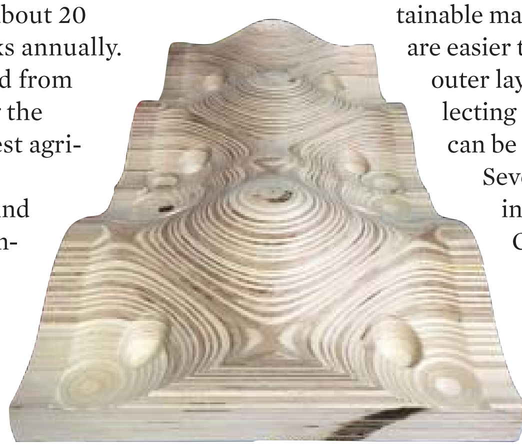
Lokko's research, though, showed the mechanical performance of the fiberboards is equal to particleboards and that they could eventually compete in markets for low- to medium-density materials. And that's where AMBIS is headed.

The company is building acoustic sorption panels for an upscale market. The panels naturally absorb moisture that collects indoors, which helps to reduce load on HVAC systems and lower energy costs.

The square-foot panels include a mat in the middle made from coconut fibers and other sustainable materials like flax and jute, which are easier to source than coconuts. The outer layer includes sensors for collecting air quality information, which can be monitored through an app.

Several hundred panels are now installed in a test house in Ghana.

"There are no regrets," Lokko said. "It's exciting to bring this to both Ghana and New York." ME



Pressed coconut fibers are used to create custom acoustic sorption panels (right) and other building materials.

JEFF O'HEIR