MECHANICAL
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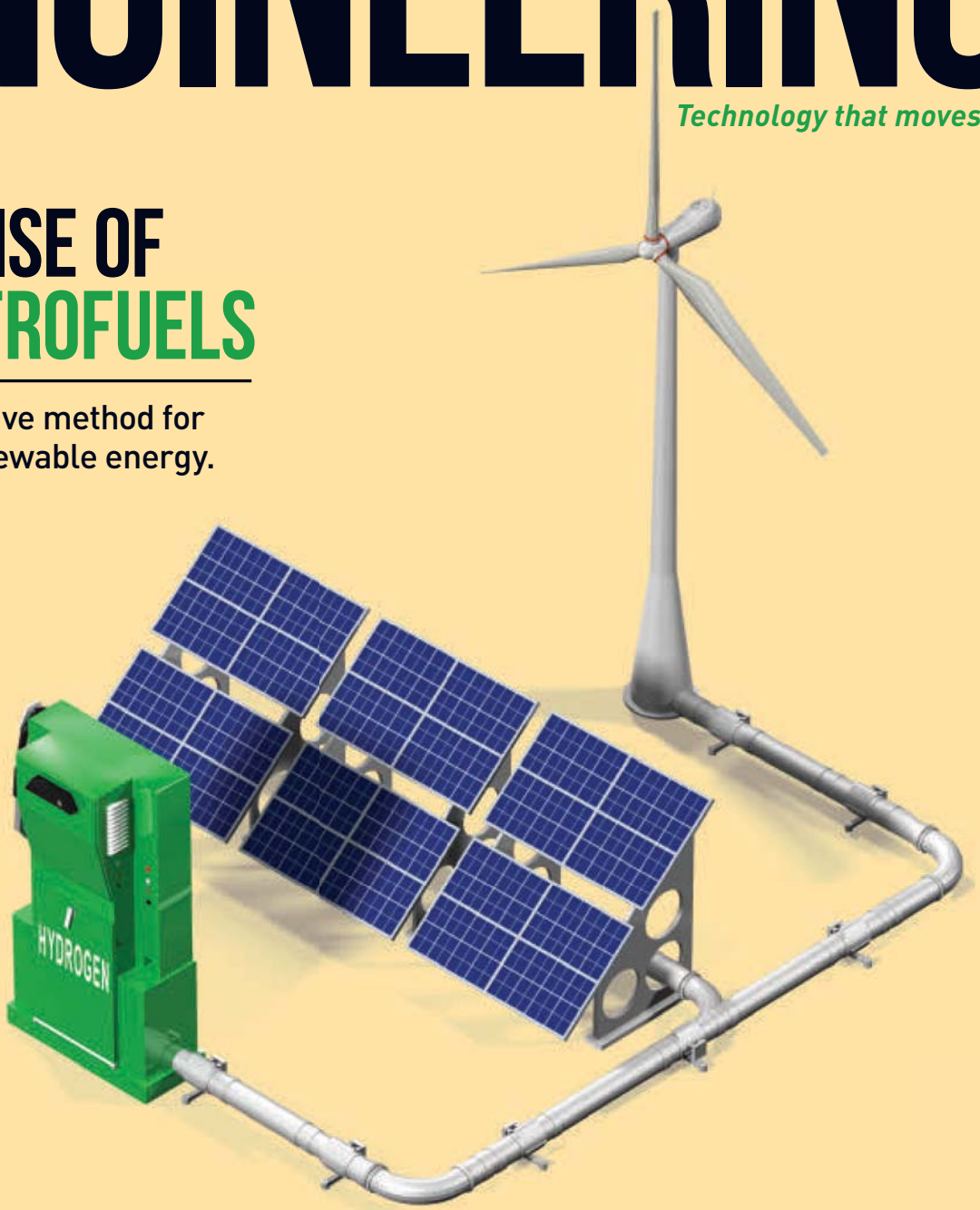
No. 09
139
Technology that moves the world

THE RISE OF ELECTROFUELS

An alternative method for storing renewable energy.



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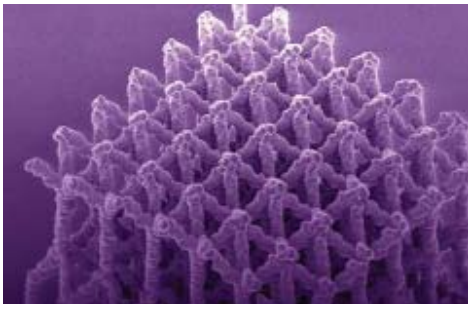
GAME-CHANGING TECHNOLOGY FOR 3-D-PRINTED METAL

IF IT HADN'T BEEN FOR A BIT OF SERENDIPITY, Owen Hildreth may never have thought about solving a problem that has developed into a potentially game-changing 3-D-printing method, promising to overcome a major challenge in producing metal objects. Support material for metals has to be machined or beveled off, a process involving laborious and costly machining techniques. Hildreth's work enables 3-D printing of a metal object and then selectively dissolving the support material after the object is printed with a simple electrochemical etching technique.



3-D PRINTING SCAFFOLDS FOR BONE

ENGINEERS AT WASHINGTON STATE UNIVERSITY have created a 3-D printing method to print structures that can precisely imitate the internal architecture of nature-made materials.

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

THE DROIDS WE'RE LOOKING FOR IN THE CANCER FIGHT

RESEARCHERS AT THE UNIVERSITY OF HOUSTON are creating robots for the war within the body. They've proven that tiny capsules can be guided, with an MRI, through the bloodstream, aligned at a target location, and then fired to attack a cyst or a tumor.

BIOENGINEERING A KEY WEAPON AGAINST CANCER

IMMUNOTHERAPY, OR THE HARNESSING of the human body's natural immune system in order to fight disease, is generating excitement in the continuing race to fight cancer.

A BATHROOM SCALE TO MEASURE BLOOD PRESSURE

RESEARCHERS AND ENGINEERS AT FOUR universities are collaborating on the development of a system for measuring blood pressure using a more convenient approach.

NEXT MONTH ON ASME.ORG

VIRTUAL REALITY ASSISTS 3-D PRINTING OF THE HEART

Take a tour of the human heart using the latest in virtual reality technology with Paul Iaizzo and his team at the University of Minnesota. See how this technology is changing surgery by enabling the printing of personalized 3-D models of any heart.

GENERATIVE DESIGN IN BIOENGINEERING

Francis Bitonti, Studio Bitonti, talks about the ways advanced design software has enabled generative design to flourish in the field of bioengineering in recent years.

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Cover Illustration by Don Foley

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

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Thomas Cheong with Editor-in-Chief John G. Falcioni (right) on Lamma Island.

ONE COUNTRY TWO SYSTEMS

Hong Kong is an international business and technology center—and a place like no other in the world. Under the "one country, two systems" philosophy, the city-state is a special administrative region of the People's Republic of China, but it has been mostly free to pursue its own economic course since Great Britain handed over the territory 20 years ago.

Still, Hong Kong is caught between its past and its future. Not quite part of mainland China, yet by no means independent. For now it's working, and while Hong Kong remains a technology leader, its personality crisis and complicated politics threaten to derail one of the most important infrastructure projects in years, an 85-mile express rail line connecting Hong Kong with the cities of Shenzhen and Guangzhou.

The rub is a plan to lease part of the new Hong Kong terminal to mainland China and allow Chinese officers to enforce mainland law there. When the former British colony returned to Chinese control, mainland China promised it a high degree of autonomy, including the ability to keep its own legal, political and economic systems. Hong Kongers are modest but proud, and the anniversary of the handover on July 1 stirred up a lot of emotions about their big brother to the north, especially as is relates to the rail issue.

Despite the uncomfortable relations with China, Hong Kong remains one of the world's leading financial hubs, rivaling New York and London. Its strong rule of law and support of property rights, combined with tight ties to China, has made it the most significant gateway for exports and imports to and from China. Many rate Hong Kong as the single best place to do business in Asia, and so it is not surprising that Hong Kong is the third largest recipient of direct foreign investment in the world.

But Hong Kong is no longer a manufacturing center. Instead, many factories have migrated to China, and nearby Guangzhou in particular. Still, many engineers have remained in Hong Kong. The Hong Kong Institution of Engineers has more than 30,000 members. There are approximately 3,500 mechanical, marine, and chemical engineers. They and other engineers design or consult on mainland-made products that require sophisticated engineering.

Hong Kong was one of the most stimulating stops on my recent trip to Southeast Asia as part of an ASME delegation. Engineers, particularly those forming ASME's Hong Kong Section, proved to be a tight group. Thomas Cheong, ASME's new Hong Kong Section chair, and I became quick friends after we met—such unexpected human connections are priceless. Cheong is the site manager for the Lamma Power Station and a respected technology leader.

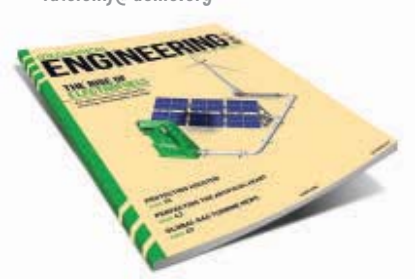
Lamma Island is a half-hour ferry ride from Hong Kong Island but worlds apart from the bustle of the main island. Lamma is peaceful; there are no automobiles and the main drag, Sok Kwu Wan, which until a few decades ago was a mecca for the plastics industry, is now lined with casual seafood restaurants, pubs, and small grocery stores. The north side of the island, in Po Lo Tsui, houses the Lamma Power Station, a coal and gas-fired power station built in 1982 for Hongkong Electric.

These dichotomies are just another example of Hong Kong's contradictions: Both small city and cosmopolitan, both high tech and rural, both Chinese and Western-influenced. As Cheong put it, "Hong Kong is a great place with a wonderful history and a future that should be bright. Engineers will make sure that it remains a center of technology innovation in Asia, and ASME can be part of that." ME

FEEDBACK

How long can two economic and legal systems co-exist in one city-state? Email me.

falcionij@asme.org



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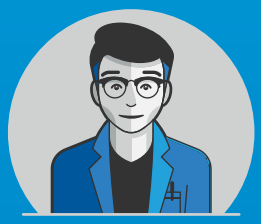

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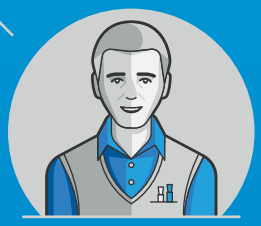

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LETTERS & COMMENTS

JUNE 2017

Reader Gonzalez believes that environmental costs must be considered.

« One reader calls for more long-term thinking, while two more discuss the finer points of evolutionary theory.

LONG-TERM THINKING

To the Editor: Lee S. Langston's June 2017 article ("Running in Place") uses two measures of cost to show us that "gas turbines provide some of the cheapest dispatchable power available" and they are a cost-effective backup for renewable power plants. Such measures take into account short-term environmental costs, including, for instance, those that would not exist without present-day environmental regulation.

However, Langston's article disregards long-term environmental costs, those that extend beyond 50 years from now. This choice is perhaps necessary because economists cannot agree on how to calculate those long-term costs, and psychologists are finding out that humans cannot plan for long terms.

From this standpoint, I have to agree with this analysis, even if shortsighted. However, I find it hard to believe that our children and grandchildren will agree.

Esteban Gonzalez, *Baltimore*

LIKING THE ODDS

To the Editor: In his June 2017 rebuttal of R.P. Siegel's article ("Can 3-D Printing Go Green?" October 2016) Matt Highstreet offers the often-repeated teleological argument while demonstrating a mistaken view of evolution. For those not familiar, the teleological argument states that evidence for intentional design exists in nature and proponents of the argument attribute this to a divine creator. A thorough debunking of this argument is outside the scope of this forum, though it

can be readily discovered online.

Rather, I want to correct Highstreet's misunderstanding of evolution, which has led him to advance the argument from incredulity fallacy. Opponents of evolutionary theory like to say that the process of evolution is entirely random and thus statistically improbable. However, evolution operates through the decidedly nonrandom process of natural selection, which fixes random mutations in genes based on environmental pressures: energy conservation, reproduction, and so on.

Even calling mutations completely random is not without controversy as we continue to develop deeper understanding of the mutation process and how it can be constrained by DNA structural requirements, and the intrinsic conservation of protein function. Suddenly, the odds become much more favorable, particularly when underscored by humanly incomprehensible time-frames.

Scott Rapoport, P.E., *San Diego*

EVOLUTIONARY APPROACHES

To the Editor: In his June 2017 letter, Henry Huse suggests that the effects of NO_X emissions from aircraft have a major and underappreciated effect on climate. But NO and NO_2, typically grouped together as NO_X, are not greenhouse gases. They are transparent to infrared radiation. It is nitrous oxide (N_2O) that is a potent greenhouse gas with 298 times the warming effect of CO_2. Nitrous oxide is created by the breakdown of nitrogenous fertilizer (amongst other routes) and not by combustion.

In the same issue, Matt Highstreet asserts that evolution involves waiting for eons until preposterously implausible events create optimized designs out of thin air. This is not the case for natural evolution (such as the ongoing and concerning development of antibiotic-resistant bacteria), for the human-directed evolution that has given us improved domestic animals and crops, or for evolutionary approaches to computational search and optimization. All three are based on the selection of already successful solutions, their combination into new examples, sometimes better, often not, allied with a small amount of random mutation to introduce novelty into the population.

Anyone with access to Excel can try out the evolutionary feature of the Solver optimizer and see for themselves how quickly such methods find good solutions.

E.R. Jefferys, *Berkhamsted, U.K.*

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.

The Stan system autonomously transports cars from curbside to long-term parking lots.
Image: Stanley Robotics

TAKING THE KEYS

AFTER TEST-DRIVE AT PARIS AIRPORT, SKY'S THE LIMIT FOR VALET PARKING ROBOT.

Parking a car in a large surface lot or multistory garage is a mind-numbing chore. Now, a Paris-based robotics company looks to take the keys from human drivers and put them in the hands of an automated valet parking system.

A successful six-month trial at Charles de Gaulle Airport has Stanley Robotics taking its system, called Stan, on the road to the airport in Lyon, France's second-largest city.

Clément Boussard was in charge of parking self-driving cars as a researcher at Laboratory for Vehicle-Infrastructure-Driver Interactions at the French Institute of Science and Technology in Transport, Development, and Networks in Paris when he founded Stanley Robotics with two others in 2015. Using parking data from de Gaulle, the company tested the system using six cabins and about 30 parking spaces from February to July of this year.

The system enables airport travelers to drop off cars in a cabin near their terminal, grab their luggage, punch in their return flight info, and then take off. Stan carries each car to a parking space and brings it back on the customer's return through management software based on the same concepts used in factory automation to move pallets around. (In spite of being a valet parking system, there's actually no need to leave behind the keys.)

During the prototype testing, the team struggled through design failures. One important adjustment involved the platform that locks the wheels and lifts the vehicle. It took a few iterations to discover the right height for sliding under the front of any car.

The parking test at de Gaulle Airport was mostly a test bed for the user experience. The team at Stanley Robotics, which was named in homage to Stanley Kubrick who created a homicidally perfectionist computer in *2001: A Space Odyssey*, was shocked to discover that the leisure-loving French couldn't care less about the robot behind the curtain.

"We had videos, brochures, and stickers to explain it, but in fact people

didn't care," Boussard said. "They were just really happy to come back and see, 'Wow, my car is here.' " It was the car parking equivalent of an automatic coffee machine, Boussard explained. "When you ask for your coffee, you have a plastic cup coming down, then you have coffee going in, but you don't know what is happening inside the machine."

The technology is a win-win, for both travelers and airports. Since the system knows each user's itinerary, cars can be double-parked until needed, increasing the lot's capacity by 50 percent in an already lucrative sector of the air travel industry.

A new version of the system will launch at Lyon–Saint-Exupéry Airport in 2018 with a plan to increase capacity to handle 10,000 spaces with 100 cabins. Building on $4 million (€3.6 million) in venture capital it received last spring, the company is raising more money to expand into airports in Asia and the United States.

Stan's platforms were engineered to slide under almost every sort of car.
Image: Stanley Robotics

While technologists predict that soon cars will be able to drop off passengers and park themselves automatically, Stan will be able to handle the chore for cars where the driver is still very human. **ME**

MEREDITH NELSON is a writer based in New York City.

CORN IS BETTER FOOD THAN FUEL

Corn's more useful on the cob than in a gas tank, according to a comprehensive study of biofuel corn's economic and environmental metrics.

The efficacy of corn-based ethanol as a motor fuel has long been debated. To try to settle that question, University of Illinois researchers analyzed the agricultural production of corn as food versus fuel in monetary terms. Part of a National Science Foundation project studying the environmental impact of agriculture in the United States, the Illinois group focused on the permeable layer of the landscape near the surface that stretches from the top of the vegetation down to the groundwater, called the critical zone.

The researchers assessed the energy required to prepare and maintain the landscape for the agricultural production of corn and its conversion to biofuel, calculated the environmental benefits and impacts on the critical zone as they affect the atmosphere and water quality, and accounted for corn's societal value, both as food and fuel.

Analyzing the human energy available and expended and inventorying the resources required for corn production and processing, researchers determined the economic and environmental impact of using these resources and converted it to a cost in U.S. dollars.

The researchers found that the costs of using corn as an energy source far outweigh the benefits.

Their results show that the net social and economic worth of food corn in the United States is $1,492 per hectare, versus a $10 per hectare loss for biofuel corn. **ME**

Corn-based biofuel provides a negative economic benefit, according to a recent study.
Image: Getty Images

LIQUID METAL BATTERIES MAY REVOLUTIONIZE ENERGY STORAGE

Battery storage capacity is an increasingly critical factor for reliable and efficient energy transmission and storage—from small personal devices to systems as large as power grids.

This is especially true for aging power grids that are overworked and have problems meeting peak energy demands. Companies are scrambling to develop scalable battery solutions that can stabilize these grids by increasing energy efficiency and storage capacity.

"The market opportunity for grid-scale energy storage is large, growing, and global," said Phil Giudice, CEO and president of Ambri, a startup company in Massachusetts that is developing an innovative battery system that relies on molten metal for storing energy.

The battery is based on research conducted by co-founder Donald Sadoway at the Massachusetts Institute of Technology. The system is different from other storage options on the market because it is the only battery where all three active components are in liquid form when the battery operates. Two liquid electrodes (magnesium and antimony) are separated by a molten salt electrolyte; the liquid layers float on top of each other based on density differences and immiscibility. The system operates at an elevated temperature maintained by self-heating during charging and discharging, resulting in a low-cost and long-lasting storage system.

When a liquid metal battery cell is at operating temperature, potential energy exists between the two electrodes, creating a cell voltage. When discharging the battery, the cell voltage drives electrons from the magnesium electrode and delivers power to the external load, after which the electrons return back into the antimony electrode. Internally, this causes magnesium ions to pass through the salt and attach to the antimony ions, forming a magnesium-antimony alloy. When recharging, power from an external source pushes electrons in the opposite direction, pulling magnesium from the alloy and redepositing it back onto the top layer.

An innovative battery design separates liquid metal electrodes with a molten salt electrolyte.
Image: Getty Images/ iStockphoto

"Liquid electrodes offer a robust alternative to solid electrodes, avoiding common failure mechanisms of conventional batteries, such as electrode particle cracking," Ambri states on its website. "The all-liquid design also avoids cycle-to-cycle capacity fade because the electrodes are reconstituted with each charge."

Extensive laboratory testing on more than 2,500 cells with a cumulative test time of 600,000 hours and 100,000 cycles shows that the all-liquid cell design avoids the main failure mechanisms experienced by solid components in other battery technologies. "This enables our systems to have a projected

"THE MARKET OPPORTUNITY FOR GRID-SCALE ENERGY STORAGE IS LARGE, GROWING, AND GLOBAL."
PHIL GIUDICE, CEO AND PRESIDENT OF AMBRI

continued on p.15 »

REPAIRING ROADS WITH A SMARTPHONE APP

For those of us who don't know what it's like to live at the end of a poorly maintained dirt road in rural Uganda, Kevin Lee has a simple way to put it in perspective: "Imagine knowing how long it will take to get to work in the morning."

Lee is one of the co-founders of Mobilized Construction, a startup that employs a mobile phone application to help fix rural roads in developing countries, some of the hardest to reach places.

When running on a smartphone mounted to a vehicle, the app identifies roads in need of repair. Once the locations are known, local governments can use the app to organize "micro enterprises" of repair crews to fill in the ruts, unclog the drainage ditches, and smooth over the roads. The crews are men with shovels and wheelbarrows, not the traditional bulldozers and excavators commonly deployed for road repair.

The upshot to this lean system is quicker road repair for less money, said Johan Jensen, a co-founder of the startup. By organizing repair crews with hand tools rather than heavy machinery, the cost of repair drops from $10,000 per km to $1000 per km, according to the startup team's estimates.

"What we did was make some software to let local people be involved in the process," Jensen said.

The app engages a phone's accelerometer, GPS, and video camera to identify bumps in a road. Jensen calls it an "accelerator-driven IRI measurement system," referring to the International Roughness Index of roads.

"Equip a car with a smartphone and just drive around collecting data," Jensen said. "The smartphone is heavily mounted in the car, so it basically follows the car's every movements. If there's a major bump in the road, that means the car will bump and the phone will bump. It will trigger the accelerometer and rate it on the index."

A smartphone app measures the jolts inflicted by broken roads on passing vehicles and sends the data to local governments that can organize repairs. *Image: Mobilized Construction*

In a former life Jensen worked on multimillion-dollar road repair contracts in developing countries and felt that they often excluded the out-of-the-way rural roads that can serve the world's most impoverished people. Much of the problem may be logistical, and that's what the app can fix. The app is a means of scaling up rural road repair, Jensen said.

"We're trying to solve the scalability of the project so we can get to the next level. That's why it's all tech-driven and has very little marginal cost in scaling it. We only have the cost of running our database, which is the same regardless of the size of the project," Jensen said.

Access to smooth roads could have a profound effect on a community. Commutes to work become shorter, as does emergency medical response times. Scheduling around hard-to-navigate roads would be a thing of the past. And, with all the new repairs that the app could prompt, it may also help create jobs.

"We looked at the numbers and if you shift into this method of road creation overnight you would be creating 20,000 to 25,000 jobs in Kenya," Jensen said. That is more jobs than is provided by Safaricom, Kenya's leading telecom.

As the app's developers add more features over time, road crews may move beyond repair. They may be able to fortify roads against potential damage.

In the future, the app could integrate weather station data to predict which roads are vulnerable to damage during downpours and floods. Road crews could then clear drainage ditches and buttress the roads against inclement weather, Jensen said.

All of that means more stability and less isolation for the world's underserved communities that live along rural roads. With quick road repair and even preemptive repair of roads that might become impassible in the future, the drive can take a back seat to the destination. ME

ROB GOODIER is managing editor at Engineering for Change. To read more about development engineering, go to Engineeringforchange.org.

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BATTERIES: LIQUID METAL

life span of over 15 years with no degradation in performance," states Ambri.

The liquid-metal battery is a promising approach to solving grid-scale electricity storage problems. Its capabilities allow improved integration of renewable resources into the power grid. In addition, the battery will hopefully improve the overall reliability of an aging grid and offset the need to build additional transmission, generation, and distribution assets.

This is, however, a competitive field. Dozens of startups are targeting utility-scale energy storage with innovative systems that utilize compressed air, iron flow batteries, saltwater batteries, and other electrochemical processes.

Ambri continues to improve the performance and longevity of its batteries—some of its test cells have been running for almost four years without showing any signs of degradation. The company is also exploring other elemental combinations, including calcium, lithium, and lead. Because of the simple design and easy-to-source materials, manufacturing the battery will cost far less than other storage technologies for an equivalent amount of storage.

STARTUPS ARE TARGETING UTILITY-SCALE ENERGY STORAGE THAT USE COMPRESSED AIR, SALTWATER, AND OTHER MEDIA.

"Ultimately," Ambri wrote on its site, "we envision working with global partners to build factories around the world, creating partnerships to serve regional markets." ME

MARK CRAWFORD is an independent writer. For more articles on battery storage visit www.asme.org.

"**IF THREE MILE ISLAND** closes, we'd lose more zero-carbon power than all of the state's renewable resources put together."

Former Pennsylvania environmental secretary John Raymond Hanger, as quoted in The New York Times *on June 13, 2017.*

COMPUTER GAMES ON THE GO

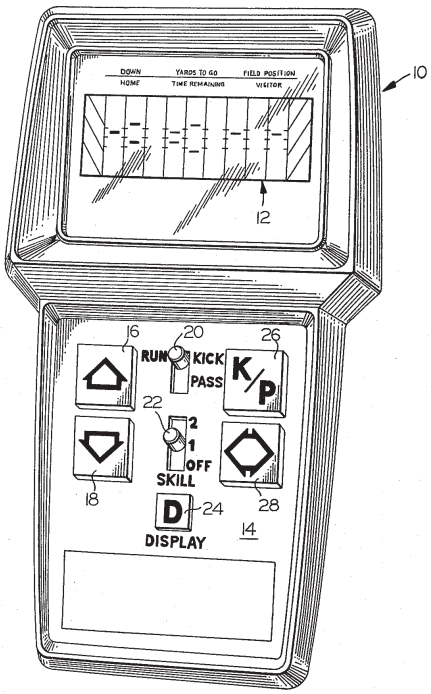
Pokémon Go wasn't the first **video game** that could lead you around.

The strange sight of adults and children walking slowly while staring into their cell phones as they played the game Pokémon Go last year got me thinking about the intellectual property surrounding computer games.

The first reported electronic game was displayed by Westinghouse at the 1939 World's Fair in New York. Patent no. 2,215,544 (1940) disclosed the machine and circuitry that enabled the Nimatron to play the math strategy game Nim.

It wasn't until 1973, however, that the New Hampshire defense contractor Sanders Associates patented the first game-playing console for the home television. Patent No. 3,728,480 (1973) names Ralph Baer as the sole inventor and discloses a "light gun" that could be used in various games. That home video game console patent was licensed to Magnavox, which marketed the game as the Magnavox Odyssey. It is considered to be the first home video game console. A close second is Atari patent no. 3,793,483 (1974) for a less complex, less expensive console.

An early handheld electronic game is shown in patent no. 4,249,735 (1981) for a football game (pictured below). The inventor is Eric Bromley of Coleco Industries, which had some success with video game consoles and later Cabbage Patch Dolls.



The Pokémon Go game appears to be disclosed in patent no. 9,226,106 (2015), which describes a location-based game "requiring players to travel to and/or interact with various virtual elements and/or virtual objects scattered at various virtual locations in the virtual world. A player can travel to these virtual locations by traveling to the corresponding location of the virtual elements or objects in the real world."

But, Microsoft may have been the first to seek a patent for a location-based multiplayer game in patent application no. 2011/0319148 filed in 2010. That application is still pending.

The Pokémon Go patent was filed by Google but is now owned by Niantic, Inc., a Google spinout. Another patent application is still pending. For Pokémon Go, Niantic reportedly teamed up with Nintendo, which owns the Pokémon product franchise.

Interestingly, computer games are a type of product often protected by all three types of intellectual property: patents for the novel technology of the game, copyrights for the computer software underlying the game and for the artwork involved, and trademarks for the name of the game and/or its characters. So, copying the Pokémon Go game could infringe a variety of legal rights.

Finally, video game IP disputes (for example, between Atari and Nintendo) helped define the boundaries of U.S. copyright law applied to computer software.

With the smash success of Pokémon Go, however, it is inevitable that companies will try to copy it as far as the law allows—and beyond. Let the games—and the copycats—begin. ME

KIRK TESKA is the author of *Patent Project Management* and *Patent Savvy for Managers*, is an adjunct law professor at Suffolk University Law School, and is the managing partner of Iandiorio Teska & Coleman, LLP, an intellectual property law firm in Waltham, Mass.

SENSOR IMPROVED WITH TINY HOLES

A disposable, do-it-yourself device for detecting disease markers from breath or airborne environmental hazards is in the works thanks to researchers who found a simple solution to exposing sensors embedded in organic plastic. They realized they could puncture the plastic with minuscule holes.

The thin organic plastic strip developed by Ying Diao, a chemical and biomolecular engineering professor at the University of Illinois, and her team detects danger at levels too low to smell.

Scientists had used organic semiconductors before to sense gas, but the devices weren't acute enough to detect disease markers in breath. Diao's group discovered that the highly reactive sites were not on the surface of the plastic film, but buried inside it. By riddling the film with tiny pores printed onto the surface, the team was able to increase the reactivity by ten times and brought sensitivity to one part per billion.

In its first demonstration, the device was engineered to detect the change in the concentration of ammonia, a biomarker for kidney disease. In clinical settings, physicians currently use bulky, table-sized instruments to find and analyze biomarkers, but the hope is that a kidney function test could be devised using inexpensive disposable sensor chips.

The next challenge is to fine-tune the composition of the sensor for other compounds. To that end the researchers have created an ultrasensitive environmental monitor for formaldehyde, a common indoor pollutant in new or refurbished buildings.

Ultimately the group is working to make sensors with multiple functions to produce a chemical "fingerprint" for a more complete picture of a patient's health.

"It's useful because in disease conditions, multiple markers will usually change concentration at once," Diao said. "By mapping out the chemical fingerprints and how they change, we can more accurately point to signs of potential health issues." ME

Q&A AMY ELLIOTT

A TINKERER AT HEART, mechanical engineer Amy Elliott graduated with a Ph.D. from the Virginia Tech DREAMS Lab, where her studies focused on inkjet-based 3-D printing. After her graduation, she began her career at Oak Ridge National Lab's Manufacturing Demonstration Facility, where she advises the industry on strategic application of 3-D printing. Elliott is also an on-camera expert for Science Channel's *Outrageous Acts of Science* and the cohost for the web series *RoboNation TV*. When not working on random inventions, she enjoys the outdoors and loves to snowboard, kayak, hike, backpack, or anything that seems slightly adventurous.

ME: You studied additive manufacturing when it wasn't popular. How did you decide to pursue it as a career?

A.E: When I started grad school, I studied additive manufacturing, but this was back in 2009. At that time, additive manufacturing and 3-D printing were not popular. So when I graduated, that's when additive became really popular, and I scored this dream job at Oak Ridge National Lab, the world's premier facility for additive manufacturing. And I really just lucked out. It was in the right location, at the right time, and I have been really working with some amazing people and solving some really hard problems in additive manufacturing for the past three years that I've been there.

ME: What do you enjoy the most about your work at ORNL?

A.E: What I enjoy most about my career is having an impact on the world. I can invent an alloy or a technology that is used in a manufacturing process to make a product that someone uses. I can actually make an impact and make someone's life better, and make our nation or world more prosperous.

ME: What obstacles did you face in your engineering career?

A.E: I think the biggest obstacle that I faced in my engineering career and in my engineering education was just the fear of failure. I was not a risk-taker and did not want to fail. But as I look back, I realize how important failure is, and failure happens all along the way, we just don't recognize it. Not being afraid of it and actually embracing it can really make you a powerful engineer. It can really empower you to do amazing things.

ME: You are also the host of science shows on TV and the Internet. What's the purpose of these shows?

A.E: The main goal of all of this TV presence and trying to get kids excited about engineering is so that they want to pursue the careers in these fields. We have a major shortage of people that get into these fields, and there's a reason, right? It's hard. But if we can help them see that it is so valuable and it's so important and it's actually really exciting and fun, once you get past the course work, once you get past math, it's a really rewarding career. We need more kids to pursue those careers so that our nation can continue to be innovative.

ME: How can young students prepare themselves for a career in engineering?

A.E: I think the best thing that a student can do to prepare themselves for a career in engineering is to do hands-on projects, build stuff, learn what it takes to actually make something that works. It's so different from just drawing or theorizing about a machine or a mechanism or a little robot, but actually putting it together and making it work, that's a whole other level. And once you do that, you see how critical engineering is, and it also helps you appreciate your education. ME

CHITRA SETHI

SWIMMING MICROBOTS SCOUR BACTERIA FROM WATER

Microbots kill bacteria with silver nano-particles opposite a magnesium layer.
Image: IBEC

Access to clean water is a global challenge. The World Health Organization reports that 663 million people—one in 10 worldwide—do not have clean water, and newborn babies are especially susceptible to waterborne illnesses.

A team from the Institute for Bioengineering of Catalonia in Barcelona and the Max Planck Institute for Intelligent Systems in Stuttgart hopes to someday remove contamination from dirty water using a flotilla of swimming microbots.

Some strains of waterborne bacteria are now resistant to chlorine, a disinfectant that causes problems for humans in any event. The researchers, led by Samuel Sánchez, wanted to replace the harsh chemical with something more benign. They designed self-motorized spherical particles which they dubbed Janus microbots after the Roman god with two faces.

One side of the tiny round water-cleaning robot is made of magnesium, which reacts with water to produce hydrogen bubbles that propel it. The other face is made out of alternating iron and gold layers sprinkled with silver nanoparticles. Bacteria stick to the gold and are killed by the silver nanoparticles.

In lab tests, the microbots zoomed around in water for 15 to 20 minutes before exhausting the magnesium. They trapped more than 80 percent of *E. coli* in water spiked with a high concentration of the bacteria. The iron layer also holds the potential for remote control of the microrobots via magnetic fields. The iron coating enables users to remove the robots from the water supply after it has been disinfected—just wave a magnet. **ME**

HAND-IN-GLOVE RELIEF FOR CARPAL TUNNEL SYNDROME

A new soft robotic sleeve that gently straightens the wrist could help many of the six million Americans with carpal tunnel syndrome heal faster, and keep them healthy, productive, and pain-free.

One in 20 working Americans suffers from carpal tunnel syndrome, and for them pain-free hands are but a memory. Doctors often recommend a splint, which keeps people from using their hands normally, or, in severe cases, carpal tunnel surgery. This surgery costs more than $5,000, and 500,000 such procedures are performed each year in the United States, with an annual health care cost of $2.6 billion.

Enter the wrist-assist, a soft robotic sleeve that detects when its wearer flexes her wrist awkwardly, and responds by inflating a balloon actuator to nudge the hand to remove the strain.

"The idea was, How do you allow the hand to be mobile when needed and in a neutral position while typing?" said Wade Adams, an undergraduate engineer at Arizona State University's Polytechnic School.

He and Mengjia Zhu, an engineering master's student, and Panagiotis Polygerinos, a mechanical engineer and assistant professor at the university, set out to solve the problem by creating a device that was washable, breathable, and easy to don and doff. They built a sleeve-like apparatus that looks like a long, black, high-tech fingerless glove.

The sleeve uses an inertial measurement unit to measure the angle of the wrist no matter how the user is holding his arm in three-dimensional space. The unit, which contains a magnetometer and an accelerator, sits in the device on the top of the hand.

Meanwhile, pressure sensors detect air pressure in the two balloon actuators.

All three sensors feed data into a microcontroller, which decides whether the wrist is bent more than 5 degrees out of the plane—an angle awkward enough to cause strain. At that point, the controller signals a micro air pump to inflate two thermoplastic balloon actuators, one on top of the wrist and one underneath, to an air pressure of 60 kPa.

"We wanted to help people when typing to keep their wrist in a neutral position," Adams said.

The engineers tested their device by showing it can straighten when a 250-gram weight is attached, and they're initiating tests on human subjects to get feedback. But Adams himself has tried it.

In March, the engineers obtained a provisional patent on their device. The engineers estimate it would cost $76 to build and foresee manufacturing an FDA-regulated device that doctors would prescribe for carpal tunnel rehabilitation, as well as a preventive device for all computer users that they'd sell through retail outlets and to computing centers as an ergonomic accessory to prevent damage.

If they succeed, a few years from now you may be slipping on a pair of ergonomic gloves before you even check your e-mail. ME

DAN FERBER is a science and technology writer. For more articles on biomedical engineering see www.aabme.org

BIG NUMBER

836

MILLION METRIC TONS

WORLD CRUDE STEEL PRODUCTION IN THE FIRST HALF OF 2017

THE HEALTH OF THE GLOBAL economy is often mirrored in its steel production. According to the World Steel Association, an international trade group, global crude steel production in the first six months of 2017 was 4.5 percent higher than it was in the first half of 2016. Production in Asian nations grew fastest—4.8 percent. By contrast, the 6.7 million metric tons of steel produced by the United States in June was down 1.7 percent from June 2016.

An aeroboat, waiting on a sandy flat, can travel inland or across water.

EVERY-TERRAIN VEHICLE UNVEILED

Amphibious vehicles such as duck boats can roll in and out of water, but a new Indo-Russian joint venture has demonstrated an "aeroboat" capable of traveling on land, water, snow, and sand on a cushion of air.

IIAAT Holding, a joint venture between the International Institute for Advanced Aerospace Technologies and Indian firm Millennium Aerodynamics, designed the aeroboat to access difficult terrain, such as flooded or marshy areas. In those places, terrestrial vehicles bog down but traditional boats can't navigate shallow water, portage across dry spots, or plow through vegetation.

The vehicle is propelled by a giant fan, much like the airboats plying the bayous of the American South. But instead of an airboat's flat-bottomed hull, the aeroboat rides on a dynamic air cushion, enabling it to run out of the water and even up steep embankments, negating the need for marine infrastructure. The 20-foot vehicle has room for 10 passengers, the developer says, and is designed to travel as fast as 90 miles per hour.

IIAAT Holding reports having 25 orders for its aeroboat from buyers in India, with an emphasis on uses in disaster relief.

"It's possible to use hovercrafts, but they are very expensive to operate and also have speed limitations," IIAAT Holding's Sukrit Sharan said. "Our amphibious aeroboats can provide high-speed year-round navigation, even when bodies of water are frozen like in Russia." ME

"IF YOU'RE LOOKING FOR overall economic well-being, the path to prosperity is no longer factories."

Lou Glazer, president of the nonpartisan think tank Michigan Future, as quoted in the Los Angeles Times *on June 12, 2017.*

RADOVAN/DREAMSTIME STOCK PHOTOS

FRESH WATER WITHOUT ELECTRICITY

WITHIN EIGHT YEARS, one-quarter of Earth's population will face water scarcity, according to the United Nations. Water problems are especially acute in developing nations. This month, we look at two labs with potentially revolutionary nanotechnologies that pull water from the air and purify seawater—without using any electricity at all.

Evelyn Wang, a professor of mechanical engineering at MIT, did not set out to remove fresh drinking water from humid air. Her original goal was to build a thermal battery to operate HVAC systems without running down batteries in electric cars.

Wang hoped to use water as a refrigerant and went looking for a material that could adsorb and release water efficiently. That led her to Omar Yaghi of UC Berkeley, one of the world's most cited chemists.

Yaghi had developed a class of crystals called metal-organic frameworks, or MOFs. They consist of Tinkertoy-like repeating units of metal hubs linked by organic rods. These frameworks are so open, small molecules pass easily through them.

"MOFs are particularly attractive because they have very steep isotherms," Wang explained. "They can adsorb water as air passes through, and it takes only a small amount of

WATER FROM THE AIR

THE LAB Device Research Lab, Massachusetts Institute of Technology. Evelyn Wang, director.

OBJECTIVE Apply heat transfer techniques to fresh water generation and thermal batteries.

DEVELOPMENT Off-grid technology that pulls fresh water from air with humidity as low as 20 percent.

heat from a low-grade source like the sun to get them to release the water."

Wang and Yaghi worked on the battery for four years, eventually transferring the technology to Ford. Meanwhile, they discussed other ways to use the technology, including water.

"It's the same physics, just a different application," Wang said.

Wang quickly began building a proof-of-concept prototype that consists of MOFs sandwiched between two plates. The MOFs snag water from the air. When she exposes the top layer, painted black to absorb sunlight, it heats the MOFs. They release water as vapor, which condenses on a lower plate held at ambient temperature.

Just 1 kg of MOF collects about 3 liters of fresh water per day from 20 percent humid air (which is drier than the Sahara Desert). Wang believes the team can tweak MOF chemistry to improve performance, and BASF has demonstrated it can produce industrial quantities of some MOFs at competitive prices.

Wang is now focusing on automating water flow through the system and scaling up to larger prototypes. Her Device Research Lab is also continuing to work further on thermal batteries. ME

Rice University's environmental engineering professor Qilin Li was researching water purification when she first read how Naomi Halas had produced steam in an ice bath. Li thought she might apply this behavior to membrane distillation, and walked across the Rice campus to meet Halas.

Unlike conventional distillation, which boils seawater and condenses the vapor into pure water, membrane distillation applies only enough heat to produce vapor. The vapor then moves through a polyvinylidene fluoride (PVDF) membrane which, like waterproof but breathable fabrics, blocks liquid water from entering while letting water vapor escape.

Although membrane distillers are smaller and less costly to build than multistage distillation towers, they use lots of energy to heat water. That's where Halas' nanoparticles came in. They absorbed sunlight and reemitted it as heat. Suspended in icy water, they produced enough localized heating to vaporized nearby water molecules.

Li and Halas decided to see if those nanoparticles could power a membrane distillation system.

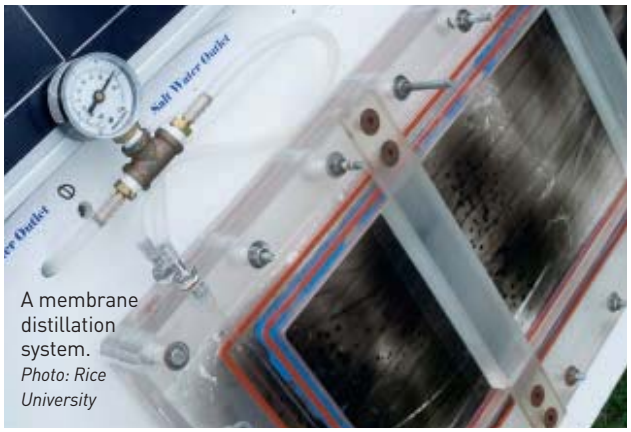
It took two years to develop a prototype. First, they needed more economical nanoparticles. Halas had used gold-coated silicon, but they settled on carbon black. While it did not absorb as much sunlight, it was commercially available and inexpensive.

Halas originally suspended her nanoparticles in water. Li needed to incorporate them into a coating she could apply to a PVDF membrane.

"Any time you add a coating to a membrane, you decrease the ability of the water to move through the membrane," Li said.

She solved the problem by suspending carbon black particles in a porous coating of polyvinyl alcohol (PVA), which readily absorbed water without impeding vapor transport. PVA coatings are often used to prevent fouling, which makes the system easier to clean.

Li is convinced the system will scale well. The embedded nanoparticles keep heating the seawater along the entire length of the membrane, and the slower the water flows, the hotter it becomes. Li hopes to field test a prototype within three months. A similar system for removing industrial and drilling waste from water will eventually follow. ME



A membrane distillation system. *Photo: Rice University*

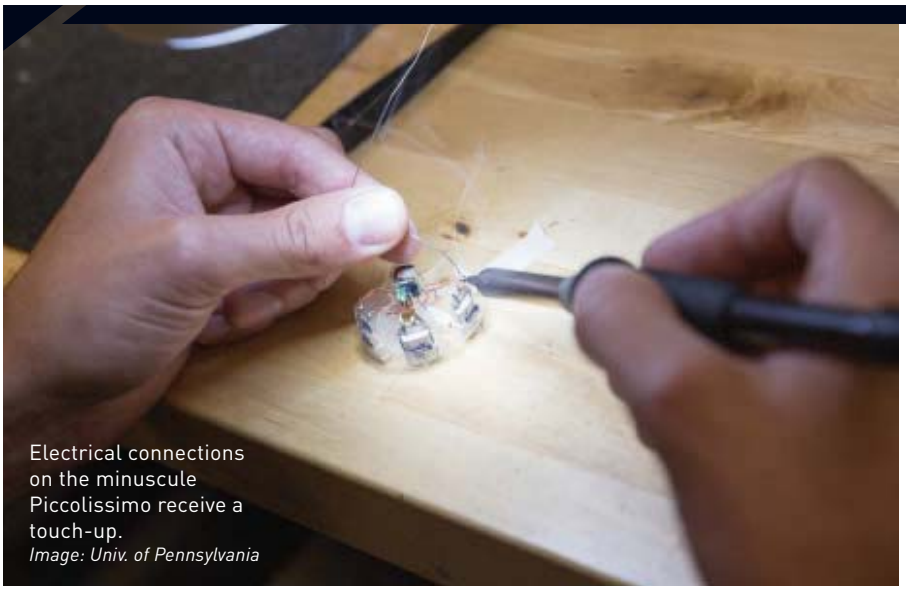
OFF-GRID DESALINATION

THE LAB Center for Nanotechnology Enabled Water Treatment (NEWT), a consortium of Rice University, Arizona State, University of Texas at El Paso, and Yale. Pedro Alvarez, director. Qilin Li, associate director for research.

OBJECTIVE Apply nanotechnology to low-energy desalination, fouling and scaling control, and catalysts and other materials.

DEVELOPMENT Off-grid membrane distillation system that uses solar heat to purify saltwater and industrial waste.

ALAN S. BROWN



Electrical connections on the minuscule Piccolissimo receive a touch-up.
Image: Univ. of Pennsylvania

WORLD'S SMALLEST DRONE NEEDS JUST ONE ACTUATOR

Quadcopters and other drones control their flight by balancing the thrust of several motors, based on feedback from accelerometers and gyroscopes. The world's smallest battery-powered flying robot, the Piccolissimo, needs only one motor and no sensors to do something similar.

Piccolissimo is Italian for "tiny," and a play on the name of inventor Matt Piccoli. The "mini" Piccolissimo is slightly larger than a quarter (28 mm diameter), weighs 2.5 g, and carries three lithium-ion batteries and a chip to control motor speed. A larger, more maneuverable version is 1 cm wider and 2 g heavier.

The secret to Piccolissimo's aerial success is passive stability, the subject of Piccoli's thesis. He is a doctoral candidate in Mark Yim's Modular Robotics Lab at the University of Pennsylvania.

To minimize control actuation, Piccoli builds stability into the device's structure. Both versions of his Piccolissimo start with a single propeller that spins about 800 times per second. Since every action has an opposite and equal reaction, the motor's rotation spins both Piccolissimo bodies 40 times per second in the opposite direction.

The location of the motor is the biggest difference between the two systems. The smallest Piccolissimo uses a center-mounted motor to generate gyroscopic forces. These offset the torque (or thrust) produced by stabilizing blades attached to the body, which act like another set of propellers. Balancing these forces stabilizes the vehicle so it can hover in place.

The larger Piccolissimo's motor is mounted off-center. "Since the propeller is mounted off-center on the vehicle body, the propeller's center, and therefore, the location of its thrust, also spins around 40 times per second," Piccoli said.

Ordinarily, the constantly changing direction of the thrust would cancel itself out. Instead, the motor uses changes in thrust to steer the tiny aircraft.

"If we increase the propeller speed every time the body is facing 6 o'clock and slow down the propeller every time the body faces 12 o'clock, the average torque tries to turn the body towards 12 o'clock," he said.

The larger device can fly for up to three minutes. Piccoli and Yim believe they could use fleets of small, cheap drones like the Piccolissimo to investigate accident sites. The drones could carry small, rotating sensors or line scan cameras and provide 360-degree panoramic views of a site.

"It's common practice to make a simple sensor, then spin it around," Piccoli said. "We get this feature for free." ME

ADVANCED ENERGY PROGRAMS TRANSFORMING AMERICA

The Department of Energy's Advanced Research Projects Agency-Energy is doing its job by jump-starting research into transformative energy technologies, according to a recent report by the National Academy of Sciences.

Congress modeled ARPA-E on DARPA, the Defense Advanced Research Projects Agency, which funded research that made possible the Internet, GPS, stealth aircraft, and drones. In 2009, Congress allocated $400 million for ARPA-E to invest in high-risk, off-the-roadmap technologies that otherwise might not have attracted government or private funding. Since then, its budgets have averaged about $280 million.

THE REPORT LAUDS ARPA-E'S TECHNICAL PROGRESS AND HANDS-ON APPROACH TO FUNDING.

Right from the start, the maverick nature of ARPA-E's mandate to back transformative rather than incremental research made some groups suspicious of its ability to address long-term energy problems. Others attacked it for emphasizing renewable and clean energy at the expense of research into oil, gas, coal, and other conventional technologies.

The National Academies found that ARPA-E is on track to meet its mandate. Half of all funded project teams published papers in peer-reviewed journals, one-quarter received follow-on funding for continued research, and 13 percent obtained patents, a necessary first step in commercializing new products

The report acknowledges that it may take time to assess the full impact of ARPA-E's "tech-to-market" efforts, because energy innovations often take years or even decades to reach commercial fruition. Yet the report generally lauds ARPA-E's technical progress and hands-on approach to funding, including the free rein given managers to scrap underperforming projects. It urged other DOE offices to adopt ARPA-E's best practices.

The report's main criticism of ARPA-E amounts to a publicity problem—the agency needs to do a better of job of demonstrating its value to the public.

The report, *An Assessment of ARPA-E,* is available online at www.nap.edu/catalog/24778. ME

LOOKING BACK

Predicting part failure was as much art as science when this article was first published in September 1987.

NO DISASSEMBLY REQUIRED

BY STAMATIOS N. THANOS, PRESIDENT, ROCKLAND SCIENTIFIC CORPORATION
ROCKLEIGH, N.J.

The author argued that, by using digital analyzers to listen to the frequencies of the noise coming off rotating machines, maintenance schedules could be lengthened greatly.

A common sign of impending failure is abnormal vibrations. For this reason, many plants have instituted programs for monitoring machine vibration, either continuously or periodically. In many cases, a monitoring program involves nothing more than determining whether the overall machine vibration has exceeded a preset level. But since the relationship between overall vibration level and machine health is uncertain, machine monitoring as a rule can only indicate, at best, the possible existence of a problem and the advisability of further investigation. In some cases, vibration may increase drastically but only at one or two discrete frequencies, which fail to affect significantly the overall vibration level. The likelihood that an impending failure will be overlooked in such a situation is the most serious liability of this method.

Predictive maintenance, or machine diagnostics, is an attempt to anticipate failure and determine its probable cause. Thus, it can suggest the magnitude of a problem and give an indication of how much longer the machine can be run before failure will occur. The technique involves the use of a real-time fast Fourier transform (FFT) spectrum analyzer, which measures discrete vibration frequencies to provide a picture of the machine's vibration signature. Studying this signature in the context of the machine's design, and comparing it with the machine's operating history, can provide much of the information necessary for making an intelligent decision regarding maintenance.

Diagnostics can be performed from a central location, but since transmissions of hundreds, or even thousands, of vibration signals from multiple machines are required, on-site diagnostics may be more economical. Today's lightweight, portable spectrum analyzers (in some cases battery powered) not only simplify data collection but also permit instant diagnosis at the machine itself. And since changes in vibration signals are often more significant in diagnostics than absolute readings, it is an asset that past signatures can usually be stored within the instrument.

Although unexpected failure is never desirable, the cost of a regular program to predict machine failure usually can only be justified when a great deal of large, expensive machinery is constantly in use and when interruption would cause significant financial loss. Facilities where this is the case include chemical plants, refineries, pharmaceutical processing plants, paper mills, and power stations. The threat of inconvenience or danger from unexpected failure has also led to the institution of prediction programs for aircraft (especially helicopter) engines and the drive systems of ships, and at nuclear power plants.

Vibration diagnostics are most commonly applied to cases where motion is periodic, such as in rotating machinery. Diagnostics have also been effectively used to identify faults in shafts, bearings, gears, and other rotating members in motors, fans, pumps, turbines, and power transmissions. ME

INSIDE BASEBALL

While Thanos's article was being published, Major League Baseball was gearing up for a first of its kind postseason. Baseball had been played in domed stadiums since the Houston Astrodome opened in 1965, but none of the teams playing indoors had captured a pennant until the 1987 Minnesota Twins, who had begun playing in the Metrodome in Minneapolis in 1982. The fabric roof reflected the sound of the crowd so well that when the Twins reached the World Series in October, their fans greeted the visiting St. Louis Cardinals with a din that exceeded 110 decibels. The raucous home field advantage helped Minnesota win its first World Series.

The sound-reflecting fabric roof of the now-demolished Metrodome. *Photo credit: Wikimedia*

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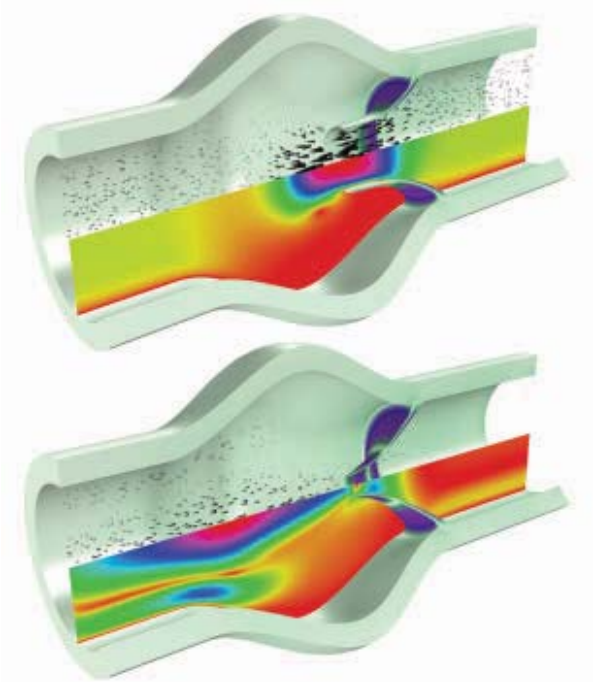

Fluid-structure interaction of a heart valve, including contact modeling.

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KEEPING A LID ON RESOURCE PRICES

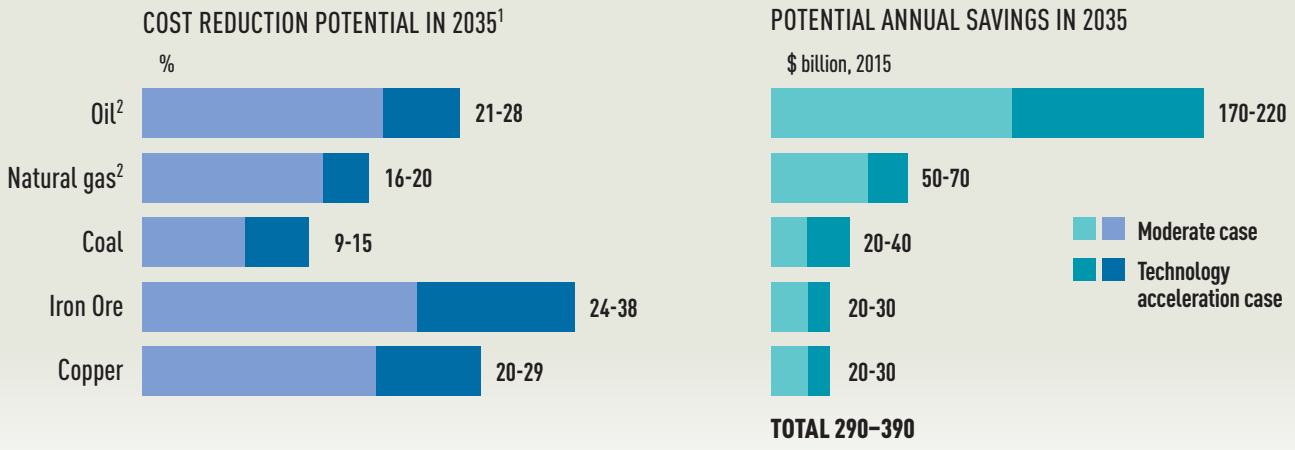
Automation affects more than just manufacturing jobs. Sales of energy and other commodities are being held in check by new technology.

Economies that depend on resource extraction are known for their wild swings. As night follows day, the boom eventually leads to a difficult bust.

Resource-rich countries around the world saw a major run-up in commodity prices starting around 2003, a consequence of China's breakneck industrialization. Unlike past booms that were focused on a specific resource—such as the Texas oil boom of the 1970s—the global commodities supercycle (as it has been called) was broad-based, raising the prices not just of fuels such as oil and coal, but also iron ore, copper, and other economically important materials. That boom survived the Great Recession, but eventually crashed in 2015.

Time for extraction economies to dust themselves off and prepare for a new boom? Not according to a report released earlier this

TECHNOLOGY COULD UNLOCK UP TO $400 BILLION IN ANNUAL VALUE FOR RESOURCE PRODUCERS BY 2035



[1]Difference between total cost per output unit (tonne, barrel) in 2035 and 2015. [2]Only upstream operations considered.

SOURCE: MCKINSEY GLOBAL INSTITUTE ANALYSIS

Note: Numbers may not sum due to rounding.

IMAGE: NOPPARAT ANGCHAKAN/SHUTTERSTOCK.COM

year by the McKinsey Global Institute. The supercycle years masked a number of important technological and economic trends, the report says, and resource-dependent economies may get squeezed in the coming decades.

While the run-up in energy and metals prices during the supercycle boosted profits for resource companies, costs of extraction were also rising. According to MGI, the lifting cost for the major oil companies jumped from $8 a barrel in 2004 to more than $28 in 2014, and mining productivity fell 30 percent over the same period.

Meanwhile, the MGI report, "Beyond the Supercycle: How technology is reshaping resources," says that technological advances will make economies less resource dependent than ever. Analytics and automation will optimize energy and material use in manufacturing, and the widespread adoption of hybrid and electric vehicles will reduce oil consumption. At the same time, solar and wind power are expected to become increasingly cost-competitive with fossil fuels, reducing the need for oil, gas, and coal production.

Eventually, MGI sees resource companies taking advantage of some of the same automation and data technologies that are driving down resource consumption to increase their own productivity, resulting in between $290 billion and $390 billion in annual production cost reductions.

"As a result of lower energy intensity and technological advances that improve efficiency, energy productivity in the global economy could increase by 40 to 70 percent in 2035," the report states.

That increase in economic output won't be distributed evenly. If MGI is right about the effects of new technology, the recent resource crash may leave extraction-based economies bent out of shape for a long time. ME

JEFFREY WINTERS

Electrofuels

One way to store excess renewable electricity is to convert it to **hydrogen, methane, or ammonia**.

By F. Todd Davidson, Kazunori Nagasawa, and Michael E. Webber

In a 1961 speech to Congress, President John F. Kennedy famously dedicated the United States to putting a man on the moon within the decade. In a somewhat less famous address to Congress, President George W. Bush proposed dedicating the nation to perfecting a new fueling paradigm for American automobiles. "With a new national commitment," Bush declared, "our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free."

That child, born in January 2003, is 14 ½ years old and will soon be taking drivers ed. Unless she has access to one of the rare fuel-cell powered vehicles, her first car definitely will not be fueled by hydrogen.

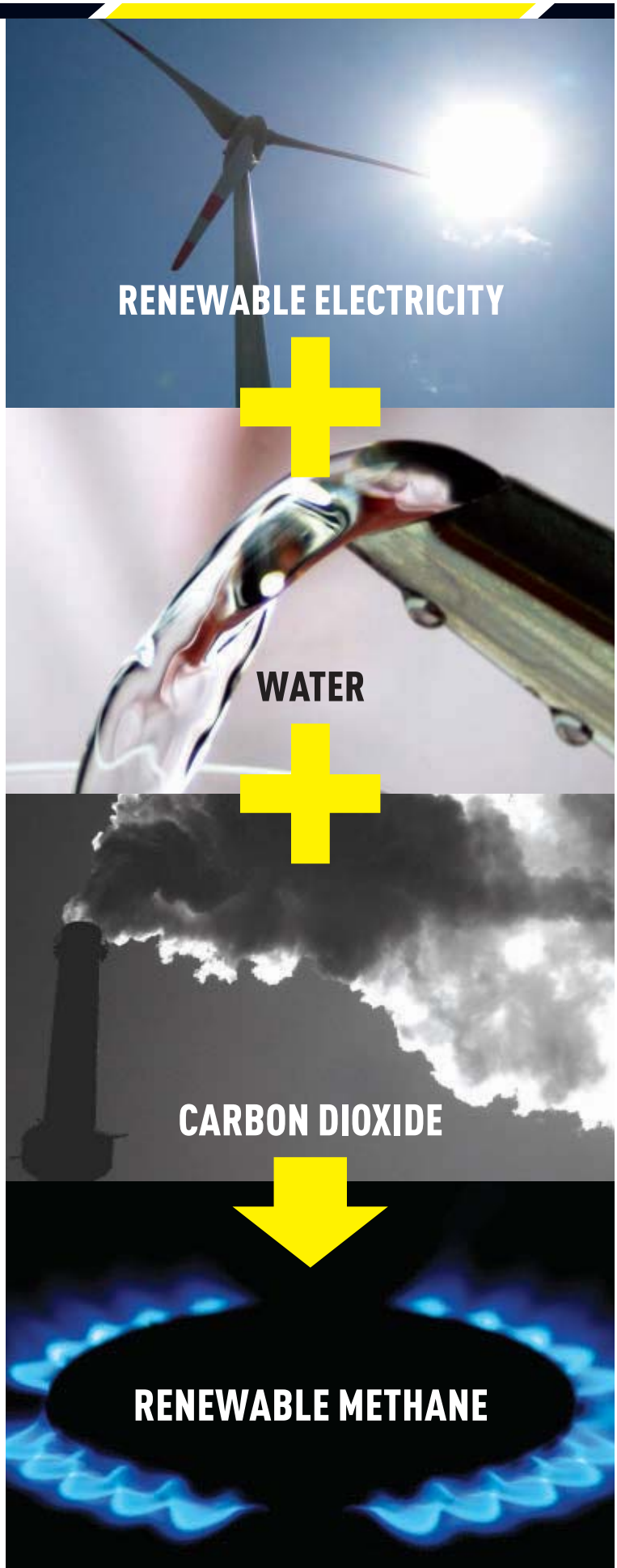
While the idea of a hydrogen-based economy got a lot of attention during the first years of the George W. Bush administration, some important details were left out. For one, even though hydrogen is the simplest and most common element, very little of it is found in nature in the form of hydrogen gas. Instead, hydrogen gas must be extracted from other molecules like water or produced through processes that convert energy from a different form to hydrogen fuel and these have associated losses.

At the same time, while hydrogen was touted as a clean fuel, since water vapor is its only combustion product, critics and energy analysts complained that its production processes were not clean. Almost all the hydrogen produced at that time was made from fossil fuel, either directly as a result of the combination of methane and steam, or indirectly via electrolysis using electricity from natural gas or coal-fired power plants to split water into oxygen and hydrogen. Add to that the difficulty of storing hydrogen gas, and the enthusiasm for the hydrogen economy began to wane.

> We can make fuels from electricity in a way that addresses the problem of intermittency confronting renewable power on the electric grid.

That doesn't mean that hydrogen can't be the means to a cleaner economy, one based on renewable energy. Hydrogen can be produced through electrolysis using electricity from wind turbines, solar cells, geothermal, or hydroelectricity, eliminating carbon emissions entirely at the point of production. The hydrogen can be reacted with other elements to produce synthetic fuels that can be more easily transported and stored. Because these fuels are, in essence, a way of storing the energy content of electricity from renewable sources, they are called *electrofuels*.

These fuels have the potential to reshape the national energy landscape. We have enough renewable power to produce electrofuels at significant volumes, which would displace conventional carbon-emitting fuels from finite sources such as gasoline and diesel. What's more,



making low-carbon, energy-dense fuels from electricity can be done in a way that helps address the problem of intermittency that confronts efforts to increase the amount of renewable power on the electric grid.

When it comes to powering vehicles, the energy density of the fuel or battery is a critical consideration. The perfect energy storage medium would have high volumetric energy density (require little storage space), high gravimetric energy density (would not weigh much), and produce no carbon dioxide when used. By some measures, hydrogen is fantastic: it produces no CO_2 when burned, and its gravimetric energy density, 120 MJ/kg, is the highest of any liquid or gaseous fuel. Unfortunately, hydrogen remains a gas under all but the most extreme conditions, which means it requires a lot of volume to store the fuel. Compressing hydrogen to 69 MPa (10,000 psi) or liquefying it at -253 °C (-424 °F) can improve its volumetric energy density, but at the cost of complicating the handling of the fuel.

To improve volumetric energy density under standard conditions, we need to look to heavier chemical structures that have the advantage of being liquid at standard room temperatures and pressures. Gasoline's chemical structure, for instance, can be approximated with seven carbon atoms and seventeen hydrogen atoms (C_7H_{17}), yielding an energy-dense liquid. A popular car like the Toyota Corolla can travel almost 400 miles on a single tank of gas; the gasoline in that 13-gallon tank weighs only 82 pounds. That is why gasoline and diesel are so

attractive for transportation—and why they are hard to replace with electricity or alternative fuels such as ethanol. For the electric-powered Chevy Bolt to travel the same distance as a fully fueled Corolla, it would need a fully charged battery pack weighing nearly 2,000 pounds and occupying the space of 150 gallons.

Unfortunately, as more and more carbon atoms are included in a chemical chain, the fuel gets heavier and fewer hydrogen atoms are available to combust with oxygen per unit mass of fuel. Instead, the oxygen combines with the carbon atoms, which not only releases much less energy than burning hydrogen, but also produces carbon dioxide. This dynamic can be observed by comparing the volumetric and gravimetric energy density, and the subsequent carbon dioxide emissions of combusting different hydrocarbon fuels. (See chart on page 35.) Methane—with one carbon atom and four hydrogen atoms—has the highest gravimetric energy density and the lowest carbon dioxide emissions per unit of energy released during combustion, but it also has the lowest volumetric energy density due to its gaseous nature at standard conditions. As more carbon atoms are attached to a hydrocarbon chain the volumetric energy density rises but the gravimetric energy density begins to decline and the carbon dioxide emissions begin to rise.

Hydrogen can be mixed directly into existing natural gas pipelines, enabling renewable hydrogen to utilize existing infrastructure.

While no perfect fuel exists, electrofuels made from renewable electricity are a good compromise. They have the lowest emissions of the gaseous and liquid options, and have reasonable energy density.

The simplest electrofuel—hydrogen made from renewable electricity—is based on an old idea. The production of hydrogen from electricity was first posited to a general audience by Jules Verne in his 1874 novel, *Mysterious Island*. Renewable hydrogen suffers from the same volumetric energy density and handling disadvantages as hydrogen made from fossil fuels. However, hydrogen can be mixed directly into existing natural gas pipelines up to a concentration of 10 percent, enabling renewable hydrogen to utilize existing infrastructure for transmission and distribution.

We can start with renewable, carbon-free electricity from wind and solar installations and produce an array of liquid and gaseous fuels.

Even more conveniently, it can also be used as a precursor for manufacturing other fuels. Hydrogen and carbon dioxide can be fed into a reaction chamber where, through the Sabatier process, a catalyst such as nickel can yield water and methane gas fuel. The source of carbon dioxide could either be from the ambient air or from a concentrated source such as carbon capture at the facility where the methane is eventually burned. Either way, this electrofuel—essentially renewable natural gas—produces virtually no net carbon emissions, while being able to tap into the existing natural gas infrastructure. This concept is being piloted at industrial scale in Europe through a scheme marketed as "Power-to-Gas."

Another potential electrofuel is ammonia produced using the Haber-Bosch process, an exothermic reaction of hydrogen and atmospheric nitrogen using a metallic catalyst. The Haber-Bosch process is already widely used in industrial production of nitrogen-based fertilizers, but typically reforms methane with steam to produce sufficient hydrogen for the ammonia reaction. To make ammonia an electrofuel, the hydrogen required for the reaction could be produced via

solar- or wind-powered electrolysis, and the rest of the process could be powered by renewable energy sources, avoiding the need to extract fossil reserves of methane. The production of renewable ammonia provides an effective energy carrier for transporting hydrogen—ammonia can be liquefied at a temperature of -33 °C (-28 °F), significantly warmer and easier to achieve compared to the -253 °C (-423 °F) required to liquefy hydrogen.

These simple chemical pathways allow us to start with renewable, carbon-free electricity from wind and solar installations and produce an array of liquid and gaseous fuels that can be used for future power generation, transportation needs, or industrial processes.

To engineers, it's not enough for a process to work. We must know that it can work at scale. How much electrofuel—renewable hydrogen, renewable methane, and renewable ammonia—could the United States produce in a year?

According to the U.S. Energy Information Administration, the United States produced 609 billion kWh of renewable electricity in 2016. If instead of feeding that electricity to the grid, it was directed to the production of renewable fuels using electrolyzers performing with 75 percent efficiency, then it could produce 12 billion kg of hydrogen. That renewable hydrogen could in turn produce either 19 billion kg of methane or 52 billion kg of ammonia. To put those amounts in perspective, the United States produced approximately 9 billion kg of hydrogen, 600 billion kg of natural gas, and 9 billion kg of ammonia in 2016.

On the basis of energy, the production of 12 billion kg of hydrogen would be the equivalent of 11.5 billion gallons of gasoline, approximately 8 percent of annual gasoline consumption in the United States, a nontrivial amount. As

COMPARISON OF FUEL CHEMICAL REACTION

Fuel	Chemical reaction to form electrofuels	Energy required to form the fuels [kJ of energy per mole of fuel]
RENEWABLE HYDROGEN	$2H_2O + e- \rightarrow 2H_2 + O_2$	285.8
RENEWABLE METHANE	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + heat$	-164.0
RENEWABLE AMMONIA	$N_2 + 3H_2 \rightarrow 2NH_3 + heat$	-45.8

Hydrogen can be produced using renewable electricity (denoted as *e-*) as an input. Hydrogen is both a fuel and an input for the exothermic, catalyst-induced reactions to make methane and ammonia, hence all three are rightly called electrofuels.

renewable power sources continue to grow, the technical potential for production of renewable fuels will continue to rise.

Challenges do exist for utilizing renewable electrofuels. Electrolysis on this scale would require a sustainable supply of purified water. This challenge can be technically overcome with desalination, but the resulting integrated desalination and electrolysis system will require additional capital and supply of renewable energy.

Ammonia also faces challenges with safely storing, transporting, and handling the fuel due to its corrosive and hazardous nature. If the challenges of ammonia are too significant, alternative synthetic fuels could be considered that provide similar hydrogen carrier capability.

Storing excess energy in chemical bonds in the form of hydrogen, methane, or ammonia is an effective way to achieve long-term, grid-scale storage.

While the potential to displace conventional, nonrenewable, carbon-emitting fuels is appealing, the production of electrofuels could also help us manage the grid in the face of more variability. That gives us one more reason to consider them a solution to several problems simultaneously.

The rise of wind and solar has helped reduce emissions and wholesale electricity costs from the power sector. But, because wind and sunshine change according to a mix of climatic, meteorological, and astronomical factors, they introduce a lot of variable supply into the grid. This variability is different than the conventional mindset of dispatchable power plants such as those fueled by nuclear, coal, and natural gas, and is a technical challenge for grid managers. As additional renewable electricity is installed in coming years, countries might face increasing hurdles with integrating these intermittent energy supplies with the grid.

One way to solve the variability challenge is through grid-scale energy storage. Despite significant effort, electrochemical batteries still face technical and economic challenges to achieve grid-scale storage. Pumped hydro storage and compressed air energy storage can provide long duration, large capacity storage but deployment of those systems are dependent on finding the right geography or geology.

Storing excess energy in chemical bonds in the form of hydrogen, methane, or ammonia is an effective way to achieve long-term, grid-scale storage. Instead of storing a surplus of electricity in batteries to be used later, we can convert that electricity into energy-dense liquids and gases. Doing so has the potential to be simpler and

cheaper while also helping to decarbonize the transportation sector. And that means fabricators of the electrofuels can get paid twice: once for stabilizing the electric grid, and again when they sell the fuels.

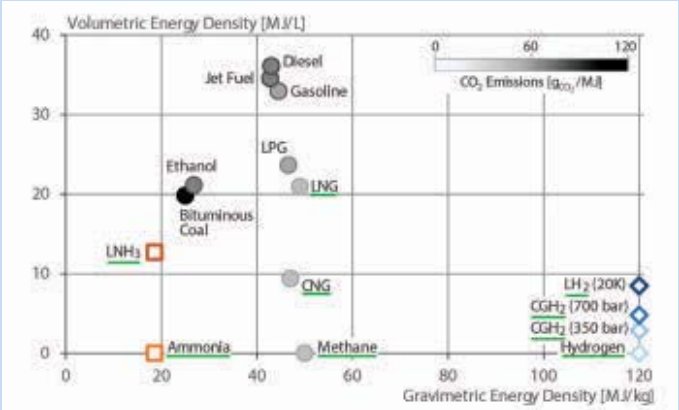
The production of synthetic fuels is an opportunity to make our energy system cleaner and more reliable. This process would solve several problems at once: stabilizing intermittent electricity supply while creating renewable fuels for use in power generation, transportation, and industry.

The large-scale introduction of wind and solar power now makes the production of renewable fuels at least technically feasible. Policymakers should start to give electrofuels the attention they deserve. There are many tax credits or subsidies for renewable or low-carbon sources of electricity such as wind, solar, geothermal, and nuclear, but electrofuels are not yet prominent in the discussion. And, while states like California have mandates for energy storage, stakeholders often ignore the option of electrofuels despite the potential for them to be a more useful and affordable competitor to batteries.

It may be some time before it becomes common for drivers to get behind the wheel of a hydrogen-powered car, as President Bush called for. But electrofuels may provide a unique solution to a number of challenges. And it's time our markets and policies recognize that possibility. **ME**

COMPARISON OF VOLUMETRIC AND GRAVIMETRIC ENERGY DENSITY OF FUELS

A comparison of the volumetric and gravimetric energy density of various fuels (using lower heating value). Hydrocarbon fuels are shown in gray tones corresponding to their carbon emissions from combustion. Candidate electrofuels are underlined. Compressed gases and liquefied fuels are denoted with a prefix of C and L; for instance, compressed gaseous hydrogen is CGH_2 and liquefied ammonia is LNH_3.



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RE-ENGINEERING HOUSTON

A city built for the last century grapples with erecting defenses against the biggest storms of this one.

BY BRIDGET MINTZ TESTA

The Bolivar Peninsula (shown above in a satellite image) was virtually wiped clean by the storm surge of Hurricane Ike in 2008 (inset left). Engineers are now designing barriers that would protect Houston and other cities on Galveston Bay from future storms.
Image: U.S. Army Corps of Engineers

The Bolivar Peninsula stretches across the mouth of Galveston Bay like a forearm raised to ward off a blow. Indeed, that is more or less its function. The peninsula and Galveston Island to the south separate the bay and the low-lying land to the northwest from the warm waters of the Gulf of Mexico and the hurricanes that periodically blow up there.

As storm barriers go, it leaves a bit to be desired—the highest ground on the peninsula rarely breaks 10 feet above sea level—and in September 2008, it was tested. Hurricane Ike made its final landfall between Galveston Island and Bolivar Peninsula as a strong Category 2 storm, with a 15-foot-high surge to the east of the hurricane's center equal to that of a typical Category 3 hurricane. The Bolivar Peninsula, taking the brunt of the storm, was inundated with water between 12 and 16 feet high. Almost every structure on the Peninsula was destroyed by the storm surge; aerial photos in the storm's aftermath showed a landscape stripped down to the sand.

The City of Galveston's south side, which faces the Gulf and has a 17-foot-high, 10-mile-long seawall, suffered minor damage. Yet water surged around the seawall and flooded the north side, which fronts on Galveston Bay and has no seawall or other protection.

The winds from Ike were strong enough to blow out the windows of high-rises in Houston, about 50 miles inland, but the Bolivar Peninsula and Galveston Island blunted the

The Port of Houston is the second-largest in the U.S. and one piece of Houston's nationally important infrastructure.
Photo: Visit Houston

> 60 MILLION TO 90 MILLION GALLONS OF CRUDE OIL AND/OR HAZARDOUS MATERIALS COULD BE RELEASED.
>
> —Jim Blackburn, Rice University

storm surge enough to protect the city's low-lying infrastructure. Experts caution that it wouldn't have taken much in the way of bad luck—a somewhat stronger storm or one that hit slightly further to the west—to have inundated the 52-mile-long Houston Ship Channel (HSC) and several thousand cylindrical storage tanks along the HSC and at the Port of Houston.

Those tanks would be exposed to both lifting forces that could float them off their bases, spilling whatever they contain, and horizontal crushing forces that could split the tanks open.

"If you leave the Houston Ship Channel unprotected, 60 million to 90 million gallons of crude oil and/or hazardous materials could be released," said Jim Blackburn, co-director of the Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) Center, located at the Rice University. It could be the worst environmental crisis in U.S. history, affecting Galveston Bay, other connecting bays in the area, and the Gulf. There's no telling how long recovery would take or if it would even be possible.

Ike showed Houston just how vulnerable it is to a large storm. Leaders of the city and the surrounding area realized they needed to re-engineer the storm defenses, a far-ranging infrastructure project that will ultimately cost billions of dollars. Now, nine years later, they are still debating, exactly, will be done and who, exactly, will pay the bill.

Where to Draw the Line

Houston is the fifth-largest metropolitan area in the United States and has an outsized impact on the U.S. economy. More than 90 percent of U.S. offshore oil and gas production takes place in the Texas Gulf Coast area, and the Houston region contains the largest concentration of energy, petrochemical, and refining industries in the United States. Houston is home to 25 percent of the country's petroleum refining capability, 40 percent of the nation's capacity for downstream chemical production, and the fastest-growing liquefied natural gas industry in the nation.

The region is important beyond energy, too. One-third of the United States seafood harvest is taken from the Texas coast, and the NASA Johnson Space Center—the home of Space Station Mission Control—is located there. The area includes the Port of Houston, which ranks second in the nation, Beaumont's port, which ranks fourth, and Texas City's port, which ranks tenth.

With so much activity in Houston—and with so much of that activity vulnerable to storm surges—regional planners and government officials wanted to know exactly how much of an upgrade the region's coastal defenses needed. That required advanced fluid dynamics models and time on state-of-the-art supercomputers.

"The model utilizes the latitude, longitude, and the elevation of the ground, both above and below the water," said SSPEED Center project manager Larry Dunbar. The model encompasses thousands of square miles of the Gulf of Mexico, Dunbar said, and "there are a couple of million points in the model to represent all the ground."

The model can simulate normal tides based on the phase of the moon and wind direction, showing how the water flows in and out of the complex geography of the bay, both above the surface and below. But when the modelers want to run a storm surge scenario, they start by placing a hurricane-force wind field in the model, along with a storm track, the air pressure in the storm's eye, and the

hurricane's overall size. "The model calculates how high the water gets as a result of a wall of water pushed by the wind and the movement of the storm," Dunbar said.

It just takes a couple of hours to run SSPEED's model on the supercomputer at the University of Texas in Austin, but because there's a queue for supercomputer time, it takes about 24 hours to get results back. Other groups studying Houston's vulnerability to storms are using other models on different supercomputers, and comparing calculation results with each other to ensure they get the same answers from the same data from their respective models.

For each set of starting parameters, the models calculate how high the water gets in Galveston Bay and other locations. When you know how high the water rises, then you know how high a barrier must be built to protect against it. The so-called 100-year storm, which has a 1 percent chance of occurring in any given year, would require barriers as high as 15 feet. Rarer storms would overtop that, however, and expected sea level rise throughout this century would make storm surges relatively higher decades from now.

With those simulation results and the fresh memories of Ike, as well as such storms as Katrina and Sandy, engineers and architects started planning out what would be needed to protect the Houston area from inundation.

The first proposal that attempted to address storm surge, put forth in 2014 by the SSPEED Center, was a levee system with a floodgate at the point where the Houston Ship Channel meets Galveston Bay. This upper-bay gate concept was designed with the sole intent of protecting the HSC, and it quickly became obvious to everyone that while any town inside the project's levees would be protected from storm surge when its floodgate closed, anyone outside the gate would be utterly exposed.

That did not sit well in the many small towns dotting the coast around Galveston Bay. The SSPEED Center still considers the Upper-Bay Gate concept to be feasible for protecting the HSC, but it would be a hard project to build by itself, considering the opposition to it. Estimates of its cost are about $2.8 billion.

The SSPEED Center began expanding its storm surge study and came up with other concepts that would protect more of the region. One would place a barrier and gate across the middle of Galveston Bay—a mid-bay gate concept—and connect to some existing levees. That would protect the northwest part of the bay but still leave many towns exposed. Another concept would build a floodgate across Bolivar Roads, the two-mile gap between Galveston and the Bolivar Peninsula, connecting coastal barriers facing the Gulf itself and protecting the lower bay. The mid-bay gate, like the upper-bay gate, would cost about $2.8 billion, whereas the lower-bay gate's preliminary cost estimate is about $7.6 billion.

"At Bolivar Roads, there is a 2-mile section of open water between the Peninsula and Galveston Island," Dunbar said. "There we would have a navigation gate that is about 850 feet wide—the width of the Ship Channel—and about 60 feet deep that could close off the navigation channel. In addition, there would be a series of vertical environmental gates that can lift up out of the water. When a hurricane comes, you would close all of the gates."

SSPEED now leans toward a multiple barrier system combining the mid-bay and lower-bay gate concepts. The combination plan would provide some protection to the towns along Galveston Bay's coast, while providing additional protection to the HSC and its critical infrastructure, as well

IF THE STORM SURGE GETS INTO GALVESTON BAY, YOU'LL HAVE WINNERS AND LOSERS.

—Bill Merrell,
Texas A&M University at Galveston

The storm surge from Hurricane Ike destroyed almost every structure on the Bolivar Peninsula.
Photo: Jocelyn Augustino/FEMA

as to the heavily developed west side of the bay.

That sort of staged defense system leaves a bad taste in some people's mouths. "If the storm surge gets into Galveston Bay, you'll have winners and losers," said Bill Merrell, professor of marine sciences at the Texas A&M University at Galveston, director of the Center for Texas Beaches and Shores, and chairman and principal scientist of the Institute for Oceans and Coasts.

Merrell has instead proposed a 60-mile barrier system along the entire stretch of the Bolivar Peninsula and Galveston Island. This system would cost $6 billion to $10 billion.

The beaches in the area could be used as foundations, and the barriers that make up the levee system would have hard cores covered with beach sand. The result would be a series of fortified sand dunes—a coastal spine 17-feet high—that keeps the storm surge out of Galveston Bay, protecting not only the high-value infrastructure along the Houston Ship Channel but also the small towns along the bay shore.

The coastal spine would place a swing-type navigation gate across Bolivar Roads, and it would also place environmental gates—smaller, vertical-lift devices—at the smaller San Luis Pass (which is at the southwest tip of Galveston Island). Both the navigation gate and the environmental gates would remain open most of the time to allow water to flow throughout the bay, thus protecting the bay's delicate ecology. When all are closed, the gates would provide a continuous barrier against storm surge getting into the bay. Merrell says that the barrier system could be built using existing, proven technology developed in the Netherlands.

"It shortens and strengthens the coast, and it allows storm surge to be stopped at the coast," Merrell said.

As a nod toward the Dutch, who have built similar extensive coastal barriers, Merrell calls his proposal the "Ike Dike."

Another group, the sprawling Gulf Coast Community Protection and Recovery District, which grew out of a commission studying the aftermath of Hurricane Ike, released a report in June 2016 recommending a coastal spine similar to the Ike Dike protecting Houston and the counties on either side of Galveston Bay, plus a new levee encircling the city of Galveston. For counties further out, the GCCPRD endorsed building new conventional levees.

"We would rework the ends of the new levees to seamlessly join the ends of existing levees," said GCCPRD's Chris Sallese, who was formerly Commander of the U.S. Army Corps of Engineers in Galveston. "When you build a levee, you're keeping water in, but then you have rain that falls from the sky and can't get out, so you have to have pump stations to pump that water out and keep the levees from flooding." The costs, according to Sallese, would be about $111 million for the pump station, and around $816 million for the levees.

How High is High Enough?

While it's hoped that the federal government would help provide funds for Houston's storm surge protection, much as it did for Louisiana after Katrina, it's also expected that local sales taxes would pay for much of the construction. "If you took storm surge protection construction from Houston down to Galveston, that could be five billion to eight billion dollars, and it could be funded by a one-penny sales tax," said Stephen Costello, an expert in Houston's need for storm surge protection. He works for the Houston Mayor's Office. "The only entities in Texas that can levy sales taxes are cities, towns, and the state," Costello said. "Houston's sales tax is already spoken for. We could let the voters decide—we can fund the work with a one-cent state sales tax or let local cities and towns increase their sales taxes by one cent," he added.

Other flood prevention methods put the onus on individual property owners. For instance, buildings on or near the coast in the Houston-Galveston area must be elevated to keep them safe from flooding. No new construction can occur near the coast that doesn't include elevation.

WE CAN FUND THE WORK WITH A ONE-CENT STATE SALES TAX.

—Stephen Costello,
Houston Mayor's Office

In addition to its various floodgate concepts, the SSPEED Center at Rice also has proposed a non-structural alternative or supplement. The Texas Coastal Exchange would involve restoring the native coastal prairie and marsh to withstand hurricane storm surge. The rising water simply remains in the prairie or marsh, and after the storm has passed, the water flows back into Galveston Bay.

The economic concept behind the Exchange is "ecological service," which puts a dollar value on the natural benefits of the land. "We would restore the coastal prairie and develop income for the land owners," said SSPEED's co-director Jim Blackburn. "We must provide enough income to landowners so they don't build on the land."

One concept being looked at is creating a carbon market that would pay landowners for the carbon dioxide that a marsh pulls out of the air and locks in the soil. "It's a partial solution to climate change," Blackburn said. "It's also the commodity most likely to generate significant income for landowners. The projected value of carbon dioxide is $40 to $60 per ton."

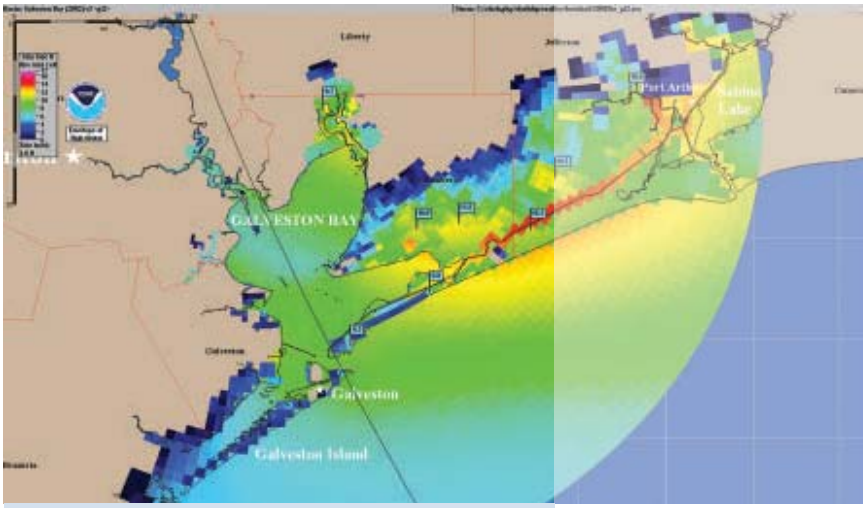
Up to three tons per acre can be removed by landowners, integrating ecology and economy. "We use ecosystems and economics instead of building technological systems for removing carbon. The natural systems do it naturally," Blackburn said.

Using natural ecological systems that pay the landowners addresses several issues: sea level rise, carbon reduction, and climate change. "We would not use regulations; instead, we'd use a market system," Blackburn said. "In many parts of the world, they use regulations. That won't work in Texas. The market system is a much better fit for Texas."

Of course, getting people to pay for soft defenses rather than high walls may be difficult, too. The wall-builders don't even agree among themselves as to how high is high enough.

"The federal government will typically cost-share up to the 100-year point," Sallese said. "It will cost-share for more than the 100-year storm, even up to the 500-year storm, but you have to prove the benefits."

That extra protection is worth it, others say, given the critical infrastructure built along the Houston Ship Channel. "We don't want nuclear plants to flood, so they are designed to be protected from a one in a million event," Dunbar said.



WATER SURGED AROUND THE SEAWALL AND FLOODED THE NORTH SIDE, WHICH FRONTS ON GALVESTON BAY.

The maximum storm surge of Hurricane Ike. Houston and its critical infrastructure are at the top left of the map. A bigger storm tracking a bit to the west would have inundated the Port of Houston.

Image: NOAA

"The industrial complexes at the HSC are generally protected to about 15 feet, which is equivalent to a 100-year storm. But 200-year or 500-year events are not protected by the 15-foot barrier."

SSPEED's mid-bay barrier would place a 25-foot-high barrier and gate across Galveston Bay to protect against the 200-year or even 500-year events.

"It would be ludicrous to build a $10 billion barrier and then have a Category 3 or 4 storm come and destroy the HSC," Dunbar said.

Figuring out which approach is the right one may not even be the right question to ask. "When you include sea level rise, it gets more complicated," Dunbar said. "Think dual barrier system—multiple lines of defense."

That's what the Netherlands does to protect itself from sea level rise and storm surge. Multiple lines of defense would work for Houston and Galveston Bay, too. The hard part is reaching an agreement on where to draw those lines of defense and then finding the money to build them.

The clock is ticking. It's been nine years since Ike, and Houston could face another hurricane at any time. **ME**

BRIDGET MINTZ TESTA is a freelance writer based in Houston.

Billy Cohn helps to break ground on the new Johnson & Johnson Center for Device Innovation Building at the Texas Medical Center in Houston.

REBEL HEART

How Billy Cohn's lifelong obsession with the artificial heart spawned a prolific career as a medical device innovator.

In the video, a team of men in scrubs surround a young, caramel-colored calf as it walks tentatively forward on a treadmill, its attention fixed on a handful of greens just beyond its nose. The calf, sinewy and fit, quickly ups his stride, stretching his mouth toward the tempting treat.

"Just look at that," said Billy Cohn, sketching out the calf's musculature with his finger to emphasize the beast's health, acting more like a seasoned judge of 4-H livestock competitions than the distinguished cardiac surgeon and medical device inventor that he is.

"That's a goddamn healthy looking cow," he said. "You'd never know that's an animal with no heartbeat, no pulse."

Cohn's right—it is a healthy looking animal. Shiny and sleek, with warm, expressive eyes and a strong gait, you might never know that it had its heart replaced with a BiVACOR artificial heart three months earlier.

"Totally normal growth. His hair grew back really fast. No problems whatsoever. And now his cardiac output is 14 liters a minute," Cohn explained. "It's just

BY KAYT SUKEL

"I know it seems like developing a mechanical heart should be really doable. The heart is just a pump, after all. Not much to it."

a pristine animal, put on 72 pounds of lean muscle in the last few months.

"It's just beautiful."

It would be easy to assume that Cohn is ascribing such beauty to the calf, which does indeed look like a serious blue ribbon contender. But Cohn is actually referring to the BiVACOR heart, which he calls the first "practical artificial heart on the planet." A 56-year-old medical doctor with dozens of patents for medical devices under his name, Cohn has a fine appreciation for an exquisite, well-designed machine.

"Magnetically levitated, no mechanical friction or wear, it's the best design we've seen," he said, his voice exhilarated to a tone of boyish wonder. "After decades of work on an artificial heart, we're on the four-yard line and ready to make that touchdown."

He pauses and takes a deep breath. "It's about goddamn time."

MARCHING TO A DIFFERENT BEAT

Cohn distinctly remembers when he heard about the world's first artificial heart.

It was 1969, and today's preeminent cardiac surgeon was a precocious—and often unruly—grade-schooler. His mother, always clipping articles to inspire him and his siblings, showed him a write-up about the mechanical heart that surgeon Denton Cooley had just placed inside Haskell Karp, a man waiting for a heart transplant. As he read the piece, Cohn was transfixed by the description of the bellows-like device made of polyester and polyurethane.

"It absolutely fascinated me. I mean, the idea that you could put a mechanical heart in someone just seemed crazy," he said. "I took that article to school with me, I was so excited. I was showing it to someone when the teacher caught me and took it away. But when she saw what it was, she asked me to get up and say something about it to the class. Which, I, of course, did," Cohn said.

That began Cohn's self-stated "obsession" with the artificial heart. It is an invention that he has followed since childhood—and one he intends to have ready for patients within the next few years.

"I know it seems like developing a mechanical heart should be really doable," he said. "The heart is just a pump, after all. Not much to it. But we just hadn't gotten there with the right design. I was convinced I was born in the wrong era. I figured it would be developed while I was in high school or college and I'd have nothing to do with it."

As it turns out, he could not have been more wrong.

One could argue that Cohn was destined to play a part in the makings of the mechanical heart. When he moved to Houston as a toddler in the early 1960s, the sleepy Texas backwater was transforming itself into a place for progress and innovation. In 1961, NASA selected the city for its manned flight center. Four years later, the very first domed stadium constructed in the United States, the Astrodome, opened to acclaim as the "eighth wonder of the world." Houston was also the domicile of the Texas Medical Center, the largest medical center in the world, where Cooley and Michael DeBakey earned their reputations as the finest cardiac specialists in the world.

"My Mom used to drive me down by the Medical Center," he said. "She'd tell me, 'That's where Dr. DeBakey and Dr. Cooley work.' And it made a huge impression on me. Between the astronauts, the Astrodome, and these heart surgeons, it really seemed like anything was possible."

If anyone asked what he wanted to do when he grew up, Cohn would alternate between heart surgeon and astronaut—though he never thought either was a "remote possibility." Yet

Cohn may feel most at home in his garage workshop, where he glues, solders, bends, and drills new medical device prototypes made from kitchen implements and spare parts.

he kept dreaming of artificial hearts, resolutely incorporating drawings of pneumatic artificial heart valves in the homemade cards he gave to his mother over the years.

Cohn also grew up a tinkerer. Egged on by his older brother, John, now an IBM Fellow, the boys built homemade gadgets, rocket engines, and a variety of incendiary devices in the garage.

"It's amazing we still have our eyes and fingers," Cohn said, a wide smile breaking across his face. "I just love tinkering. I love getting Super Glue all over me, the smell of burning metal chips. There's nothing like it."

Along with his appetite for tinkering, Cohn also cultivated a passion for trombone and bass guitar. By the time he graduated high school, despite the advances being made on the Jarvik artificial heart—the greatest mechanical heart of its time—he decided to study music at Oberlin College. Cohn fell in love with the early punk rock vibe at Oberlin. It spoke to his rebel nature.

Yet Space City and that telltale artificial heart continued to beckon. After two years and a summer job as a hospital orderly, the possibility of becoming a heart surgeon didn't seem quite as remote as before—especially when compared to trying to build a career as a professional musician.

"I loved music—I still love music—it's great fun," he said. "When I grew up, I didn't think that just anybody could decide to be a heart surgeon and just do it.

"But after being in school for a while and talking to doctors, I realized reaching a goal is about following the steps and making the kind of decisions that lead you closer to your goal instead of away from it. Eighty percent of life is showing up, right? I decided I wanted to show

The BiVACOR heart is a rotary pump with a single moving part that consists of two impellers on a magnetically suspended rotor.

up and become a surgeon," he said.

Cohn switched majors, graduated with a bachelor's degree in biology, and returned to Houston to attend Baylor College of Medicine. He was one of the few selected to join the institution's famed heart surgery program, and eventually was chosen as the last chief resident of his childhood idol, Michael DeBakey.

TINKERING WITH PROTOTYPES

As Cohn progressed in his medical career, he never stopped tinkering. He was fast becoming one of the finest heart surgeons in the country, yet he spent his free time in his home workshop, prototyping medical devices to assist his operations. Although he never took an official engineering course, he describes himself as a "frustrated mechanical engineer."

"I get so much satisfaction from working with tools and working with my hands," he said. "I do see it as a form of play and self-entertainment. Heading to Home Depot and picking up a bunch of stuff to build something I have in mind is fun. And if it doesn't work, then figure out what I overlooked and remake it, maybe more than a few times. When I can make something that improves what I use in surgery, that's even better. Because in doing so, I'm not just helping one patient, but lots of other patients down the line."

At current count, Cohn holds an astonishing 90 patents. This includes the 1997 Cohn Cardiac Stabilizer, a device he invented that helps surgeons perform coronary bypass surgeries while a patient's heart is still beating.

Twenty years ago, patients undergoing bypass surgery needed to be hooked up to a heart-lung machine that pumped blood so physicians could still the heart for surgery. However, sometimes the pump caused infections and blood clots.

Johns Hopkins researchers solved that problem with a salad tongs-like device that surgeons inserted into the chest through a small incision. It enabled them to work on a slowed but still beating heart, but Cohn found it challenging to stitch the bypass grafts securely to the heart.

He thought he could do better, and bought out the local supermarket's stock of metal soup ladles. After twisting them into a variety of angles, surfaces, and openings, he created a device that allowed surgeons to press against the diseased artery and stitch the graft into place through a square cutout. Surgeons have used the stabilizer in more than 200,000 operations worldwide.

That was just one of Cohn's many inventions. Some were innovative gadgets designed to make surgery easier. Others improved upon traditional surgical retractors, catheters, and suturing devices. Many started as homemade prototypes and are now used today by surgeons all over the world. When he sees a need, he heads to his workshop to try to answer it.

By the turn of the century, Cohn was working at Harvard Medical School. Although he had a growing reputation as a device innovator, he had not contributed anything to the design of a mechanical heart. Then he began hearing about a local startup, AbioMed, which was preparing its AbioCor heart for human trials. The news rekindled Cohn's childhood obsession.

"It was a brilliant design," he recalled. "It had this internal clockwork system that drove silicone oil from left to right and right to left, compressing a flexible bladder that had in and out valves—entry valve, chamber, exit valve—all molded out of this water-insoluble material that would dump in the blood and then spin it so it

wouldn't accumulate anywhere."

O.H. "Bud" Frazier, a cardiac surgeon who had performed more than 1,000 heart transplants, led the work on AbioCor from the Texas Heart Institute in Houston. Cohn, in Boston, felt left on the sidelines.

Then serendipity stepped in. Frazier and Cohn met at several surgical meetings. Their discussions inevitably turned to new ways to improve upon AbioCor's design. Ultimately, Frazier invited Cohn to return to Houston to work with him on a completely novel approach to artificial heart design—continuous flow.

Conceptually, Cohn explained, it was the difference between the first aspiring aviators, who tried to mimic the flapping wings of birds, and the Wright Brothers, who figured out how to achieve lift with much simpler fixed wings. The AbioCor heart, Cohn said, was the "best heart with flappy wings."

The heart he and Frazier set out to build would replace those metaphorical flappy wings with fixed ones. It would not beat. Instead, it would use two gray metal turbines connected with white tubing and polyester cones sewn onto the heart's atria to pulse blood through the body.

The two designed, iterated, and then tested a prototype. And in 2011, they implanted their Frazier-Cohn heart into a dying 55-year-old man named Craig Lewis. He lived for an additional five weeks following the surgery before dying of liver and kidney failure. The heart continued to pump until it was unplugged. Their first patient taught them new ways to improve upon their first continuous flow prototype.

Meanwhile, an Australian, Daniel Timms, was also working on a continuous flow heart. Half the size of a soda can, his design used magnetic levitation to suspend a small rotor with dual impellers as it spun 2,000 to 3,000 times per minute. Cohn and Frazier loved the design and teamed with Timms.

Surgeons implanted Timms' device in many large animals, including the treadmill-walking calf. The device also provides the right amount of blood flow for a sheep, an animal small enough to serve as an analog for a child. Earlier hearts were too large and powerful for children.

Cohn's excitement for this device is palpable—and human clinical trials are expected to begin within 18 months. "This is the quest for the Holy Grail—and we're closer than we've ever been."

It will take years to fully test and optimize the heart. Meanwhile, Cohn, now BiVACOR's chief medical officer, continues to wear many hats. He is a professor of surgery at Baylor College of Medicine, an adjunct professor of bioengineering at Rice University and the University of Houston, a surgeon at the Texas Heart Institute, and director of Johnson & Johnson Center for Device Innovation. He also serves on the boards of several medical devices companies, including several commercializing the inventions that he created in his garage workshop.

"But it's also satisfying to take the path less traveled and integrate creativity into your daily life. Because deep down, I'm an innovator—I like to create things."

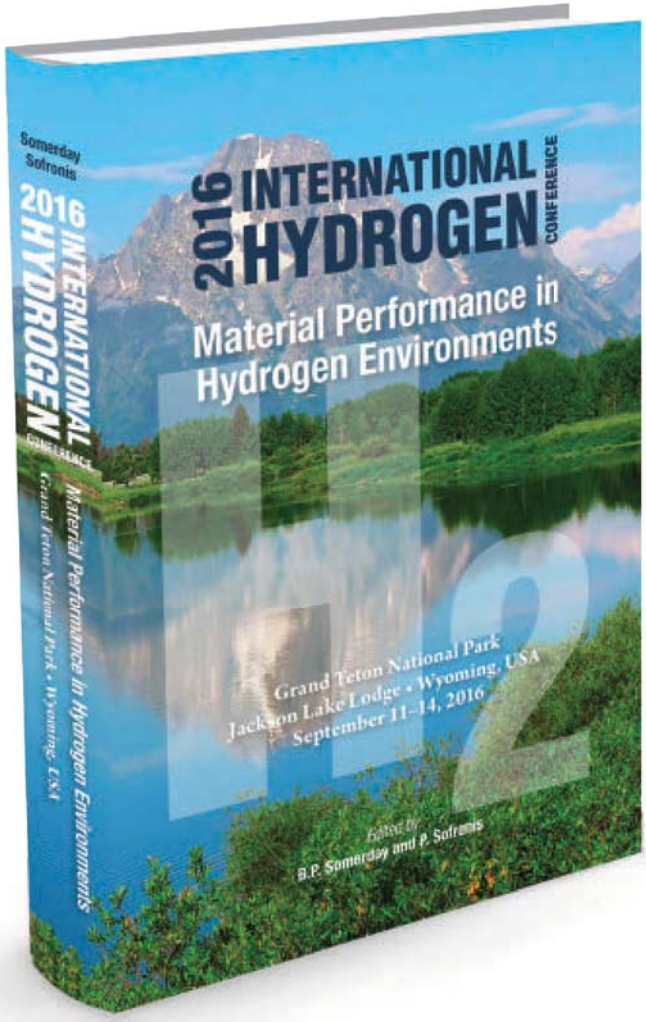
With so many accomplishments, many people would slow down and take a break. Not Cohn. He has too many ideas running around in his mind, demanding to get out and get made.

"There are a lot of people who train to be heart surgeons, who roll up their sleeves and do heart surgery for the rest of their life. And it's a very satisfying way to live your life. I love surgery, I do," he said.

"But it's also satisfying to take the path less traveled and integrate creativity into your daily life. Because deep down, I'm an innovator—I like to create things. And building and iterating and testing and engineering and finding a cool way to solve a problem—that's something that will end up helping a whole lot of people, whether they ever come into my operating room or not.

"What could be better?" **ME**

KAYT SUKEL is a science and technology writer based in Houston.



FEATURED

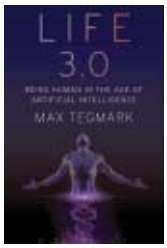
2016 INTERNATIONAL HYDROGEN CONFERENCE: MATERIAL PERFORMANCE IN HYDROGEN ENVIRONMENTS

EDITED BY B.P. SOMERDAY AND P. SOFRONIS

ASME Press Books, Two Park Avenue, New York, NY 10016. 2017.

Last held in 2012, the International Hydrogen Conference is the premier topical meeting on hydrogen effects in materials, a critically important topic given the interest in developing hydrogen as a fuel. The 2016 conference was attended by more than 190 experts and looked at focus areas ranging from basic science to technological impacts. These topic areas included hydrogen-assisted fracture in steels and other structural metals, hydrogen-assisted fatigue, advanced methods for characterizing hydrogen-materials interactions, and hydrogen dissolution, transport, and trapping. The papers from that conference were collected by Brian Somerday of the Southwest Research Institute and Petros Sofronis of the University of Illinois, and provide a snapshot of the state of materials science in combating hydrogen interactions and the challenges remaining.

800 PAGES. $399; ASME MEMBERS, $319. ISBN: 978-0-7918-6138-7



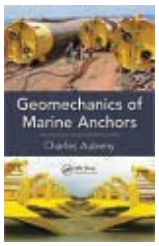
LIFE 3.0: BEING HUMAN IN THE AGE OF ARTIFICIAL INTELLIGENCE

By Max Tegmark

Alfred A. Knopf, 1745 Broadway, New York, NY 10019. 2017.

Tegmark, an MIT professor who has researched how to keep Artificial Intelligence beneficial, explores how the coming AI revolution will affect such human endeavors as war, employment, crime, and justice—even our very sense of self. One question Tegmark digs into is what will people do all day when AI-enabled robots are better employees than humans could ever be? What sort of career advice should we give today's kids—and does the very idea of a career make sense in the face of a deeply automated economy? Rather than impose his views, Tegmark looks instead to open a discussion on the choices we face and the potential implications of what we decide on.

384 PAGES. $28. ISBN: 978-1-1019-4659-6



GEOMECHANICS OF MARINE ANCHORS

By Charles Aubeny

CRC Press, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487. 2017.

Anchoring the moorings of offshore floating structures is a challenge often faced by engineers in the oil and gas industry, but the potential for offshore wind power is creating a demand for solutions in that field as well. Aubeny describes the major types of anchors with respect to their basic design concept, advantages and limitations, appropriate framework for analysis, and observed performance, and he examines the life cycle of the anchors from installation to their ability to hold up under difficult conditions. Several new anchor types have been developed within the last decade, so this book also serves as a compendium of information that up to now existed mostly in journal papers and conference proceedings.

388 PAGES. $159.95. ISBN: 978-1-4987-2877-5

Global Gas Turbine News

Volume 57, No. 3 • September 2017

In This Issue

ASME INTERNATIONAL GAS TURBINE INSTITUTE

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ASME 2017 Turbo Expo Co-locates With Power & Energy and ICOPE

ASME Turbo Expo 2017, in Charlotte, North Carolina, USA, maintained its reputation as the world's premier gathering of over 3,000 turbomachinery professionals. Throughout the week, delegates shared practical experiences, knowledge and ideas on the latest turbine technology trends and challenges. Many expressed their appreciation for the conference, noting that it was an amazing experience, particularly for receiving valuable feedback on research from experts in the field. The moderated keynote panel session was, again, well received as the attendees submitted their questions to the moderators via their smartphones or personal electronic devices.

The audience actively submitted questions, while the moderators collected and asked the panelists for their insight. Bringing their expertise and experience, they made this format a worthwhile part of the conference. Led by Paul Garbett of Siemens Power & Gas Division, and Mark Turner of University of Cincinnati, the opening session featured an exceptional keynote focused on "Disruptive Technologies & Accelerating the Pace of Innovation in Gas Turbines", with panelists Dag Calafell, Karen Florschuetz, and Kevin Murray, followed by the annual awards program of prestigious ASME and IGTI awards.

The plenary panel sessions were well attended with great audience participation. Led by Mark Turner and Dirk Nuernberger, from Siemens, the Tuesday morning plenary session, Multidisciplinary Computations and Optimization in Gas Turbine Design, answered questions about why Computer-Aided Multi-Discipline Optimization (MDO) is important. Panelists Andrew Aggarwala, Ingrid Lepot, Robert Nichols, and Eisaku Ito did a great job presenting and responding. Additive Manufacturing Day, new at Turbo Expo, featured the Wednesday Plenary Session "Disruptive Technologies and Accelerating Innovation in Gas Turbines: The Role of Additive Manufacturing". The session, led by Karen Thole and Rich Dennis, showcased the current activities and future potential on how this rapidly developing technology will impact the gas turbine industry. Panelists Kurt Goodwin, Thomas W. Prete, Markus Seibold, Mike Aller and Rob Gorham answered the questions from the audience via the ASME app. The day was followed by panels sessions featuring the following topics: Processes & Materials for Additive Manufacturing; Design & Performance for Additive Manufacturing; Challenges and Opportunities in Using AM for Turbine Cooling; and Combustor/Fuel Injector applications for Additive Manufacturing. The day ended with AM Posters in the exhibit hall.

The Technical Conference offered five days of almost 2,000 technical paper presentations, including the Scholar Lecture by Dr. Ronald Bunker. After the technical sessions finished for the day, it was nice to wind down with the evening events throughout the week. On Monday evening over 2,000 came out for the welcome reception at the NASCAR Hall of Fame where they enjoyed the car simulator. On Tuesday, Women in Engineering held a networking event featuring a talk from Diane Beagle of GE, sponsor of the event. On Wednesday many students and early career engineers got acquainted with one another at the mixer sponsored by Dresser Rand. During the three-day exposition, delegates met with representatives from premier companies supplying quality turbomachinery products and services. Special recognition during the Closing Ceremony went to MMP Technologies and Vectoflow, as exhibition visitors voted their displays the best. Student Posters were presented on Tuesday and Wednesday afternoon in the exhibition hall, with first place going to Ariane Emmanuelli, second place to Andrew Boulanger, and the People's Choice awarded to Eric Bach.

If turbomachinery is part of your professional life, you cannot afford to miss the annual ASME Turbo Expo! To plan for 2018, see page 60 of this issue and keep informed throughout the year by visiting ASME Turbo Expo online at https://www.asme.org/events/turbo-expo.

See the award winners on page 56

ASME Turbo Expo 2017 Statistics

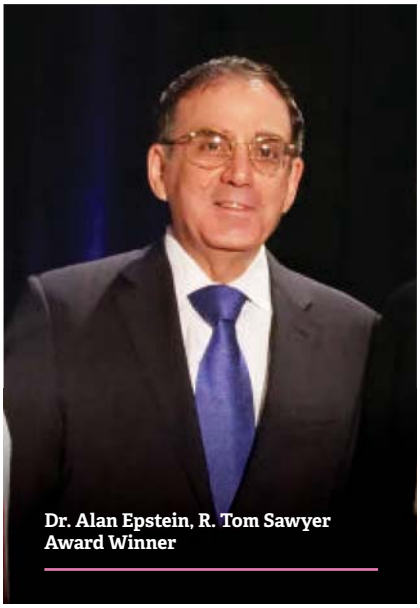
This year at Turbo Expo, attendees represented 56 countries worldwide participating in 333 conference sessions. In these sessions, authors presented 1,098 final papers with 45 tutorial sessions and 24 panel sessions.

Thank you to our volunteers!

- Turbo Expo 2017 Conference Committee
- Turbo Expo 2017 Local Liaison Committee
- Point Contacts & Vanguard Chairs
- Session Chairs & Vice Chairs
- Reviewers
- Authors
- Speakers

Grand Opening: Keynote and Awards Ceremony

Panel Discussion: Moderated, with Audience Q&A



Dr. Alan Epstein, R. Tom Sawyer Award Winner

ASME 2017 PETE Highlights continued on the next page...


TURBO EXPO


TURBO EXPO

ASME 2017 Turbo Expo Conference Highlights

1. Additive Manufacturing Plenary
2. Scholar Lecture with Ron Bunker
3. Congratulations to the 2017 Turbo Expo Student Advisory Committee Travel Award Winners.
4. Congratulations to the 2017 Young Engineer Turbo Expo Participation Award Winners.
5. Dr. Robert J. Miller and Dr. Ho-On To, University of Cambridge 2015 ASME Gas Turbine Award Winers, pictured with Piero Colonna, ASME Gas Turbine Segment Leader
6. Subith Vasu - Dilip R. Ballal Early Career Award Winner, with Piero Colonna, ASME Gas Turbine Segment Leader
7. Michael Dunn, Ohio State University - Aircraft Engine Technology Award Winner, pictured with Keith Boyer and Piero Colonna, ASME Gas Turbine Segment Leader
8. Dr. Eisaku Ito, MHI - Industrial Gas Turbine Technology Award Winner, pictured with Piero Colonna, ASME Gas Turbine Segment Leader
9. The Exhibit Hall was a consistent attraction and forum for companies to meet, network, and present themselves to the industry.
10. Congratulations to MMP Technologies for being selected as the People's Choice for Best Large Booth.
11. Congratulations to Vectoflow for being selected as the People's Choice for Best Small Booth.
12. The Welcome Reception this year was held in the NASCAR Hall of Fame.
13. Student Mixer sponsored by Dresser Rand
14. Women in Engineering Networking Event sponsored by GE

As the Turbine Turns...

#31 September 2017

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

Gears Steer New Engine Designs

The coterie of geared turbofan jet engine companies is growing. Rolls-Royce is now developing a geared turbofan (GTF) for its future engines in the 25,000-110,000 pound-thrust (lbt) range, slated for production in the next decade [1]. This major OEM will join Pratt & Whitney and Honeywell, who both have been designing, developing and producing GTF engines for some years.

Figure 1
Rolls-Royce Epicyclic Planetary Gearbox (4:1 gear ratio 31 inches diameter)

GTF engines have a hub-mounted epicyclic gearbox that drives the front-mounted fan at lower rotational speeds than the engine turbine section that powers the fan. The turbine driving the fan is most efficient at high rotational speeds. The fan operates most efficiently and creates less noise at lower rpm. By lowering fan blade tip speeds by means of gearing, engineers can more easily satisfy fan blade and disk stress limits and avoid the onset of power-robbing supersonic fan blade flows.

The operating gear reduction ratio also permits increasing the engine's bypass ratio with larger fans. Bypass ratios - the mass of fan air bypassed around the engine for every unit mass of air through the engine - can be increased, which improves the propulsion efficiency of the turbofan engine.

The net result is a great reduction in fan generated noise and as much as a double digit reduction in engine fuel consumption. Both of these attributes are causing airlines to demand from airframe companies, new commercial aircraft that mount the GTF engines.

Gear Lore

Gear trains are one of the oldest known machines and none is more closely identified by the general public, with the profession of mechanical engineering. Gears use the principle of the lever to alter the speed and torque carried by shafts, and can be traced back as far as 3000 BC in use in China.

One of the most famous of ancient gear assemblies is the Antikythera Mechanism [2], recovered in 1900 from a shipwreck off the coast of Greece. Possibly constructed in Rhodes in 150-100 BC, the mechanism is an astronomical analog calculator (or orrery) that was probably used as one of the first analog computers to show celestial positions of the sun and moon, the time of solar eclipses and the dates of Olympic and Pan-Hellenic games. The Antikythera Mechanism has some 30 intermeshing gears, which include an epicyclic gear train.

So here we are, two thousand years later using the same type of gear train to improve the performance of modern gas turbines. The name epicycle goes back to Greek astronomy, where planets were believed to move in circular orbits, with the earth as center - a geocentric system. Such orbits could not explain why at times, planets moved backward, relative to the earth-bound observer. Ptolemy (150 AD) explained such retrograde motion by superposing small circles - epicycles - on the original assumed circular orbit.

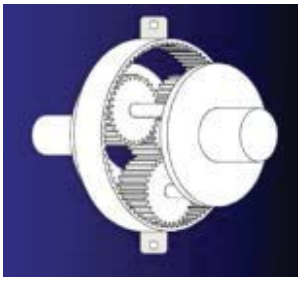


Figure 2a. Planetary Gearbox Sketch.

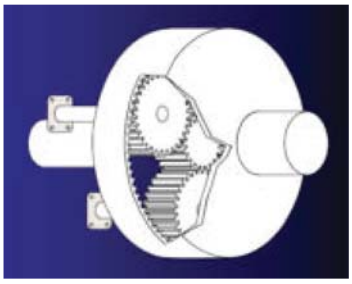


Figure 2b. Star Gearbox Sketch

Currently, a geared fan epicyclic gearbox consists of a center sun gear, mounted on the driving turbine shaft. The sun gear meshes with normatively, five equally-sized surrounding pinion gears, which also mesh with an encompassing annular ring gear. A circular carrier houses the five pinion gear shafts to support and position them.

If the carrier is fixed to the engine casing, the ring gear drives the fan. The pinion gears, now fixed as they transmit motion from sun to ring gear, are now called star gears. If the ring gear is fixed the carrier rotates to drive the fan. The pinion gears now rotate about the sun gear, and are called planet gears. A planetary gearbox can have higher gear ratios than a star gearbox.

Current Production GTFs

Honeywell first started developing geared fans almost 50 years ago [3]. In 1968, then as the Garrett Air Research Phoenix Division, they developed their 3500 lbt TFE731 business jet engine from an existing auxiliary power unit (APU). Given the high rotational speed of the APU low pressure turbine (about 20,000 rpm), to avoid excessive fan tip speeds, Garrett engineers developed a epicyclic gearbox (about 8.5 inches in diameter and with a 1.8:1 gear ratio), which allowed the TFE731 to have a 2.5:1 bypass ratio (high for 1972, when it was certified). Still in production, it has been one of the most successful small gas turbine aircraft engines, with over 13,000 units produced.

Pratt & Whitney is in production of their first generation of GTF engines in the 18,000 - 30,000 lbt range, which power twin engine single-aisle, narrow body 70 - 200 passenger aircraft [4]. As an example, their PW1100-JM is currently powering the Airbus A320neo, with airlines reporting up to 20% in fuel savings. The epicyclic gearbox (about 20 inches in diameter) has journal bearings for its star gears rather than roller element bearings, with transmitted power as high as 30,000 hp. The gear ratio is 3:1, yielding a bypass ratio of 12:1. Even small inefficiencies in its double helical gear teeth and bearings could generate enough heat to "cook" gearbox lubricating oil. Testing has shown that the P&W GTF gearboxes must be at least 99.3% efficient to avoid that problem.

Future Directions

One of my colleagues, Kazem Kazerounian (currently our Dean of Engineering at UConn) who is a gear systems researcher and an early consultant for P&W on gears, has some observations on possible future work on GTF gearboxes:

1. The challenges of light-weight, high-powered epicyclic gear systems include large deflections and vibration induced in the relatively thin ring gears (as the planets/stars pass), and the possibilities of large displacement of the center of the sun gear.

2. New developments include using Herringbone bevel gears (bevel gears of opposite directions to cancel axial thrust) and using spiral bevel gears instead of straight bevels. Additional advantages in smoothness and load carrying capacity might be obtained by phasing the two bevel gears that constitute the Herringbones, so that teeth on both sides do not enter the mesh simultaneously.

3. There is significant room for optimization if designers consider nonstandard, or even non-involute gearing. This is uncharted territory in gear design, that might decide the future leaders in GTF design and manufacturing.

* * *

New technologies evolve based on the chaotic and constant recombining of existing technologies [4]. The GTF combines existing jet engine technology with the well-established mechanical engineering technology of gears.

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2. Jones, Alexander, 2017, A Portable Cosmos, Oxford University Press.

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4. Langston, Lee S., 2013, "Not So Simple Machines", Mechanical Engineering Magazine, January, pp. 46-51.

Recognizing Award Winners

at ASME 2017 Turbo Expo

Congratulations to all award recipients,

and thank you to all ASME IGTI committee award representatives whose work assists the awards and honors chair and the reading committee in the recognition of important gas turbine technological achievements.

IGTI Committees honored more than 100 authors with Best Paper Awards for papers presented. Thank you to Thomas Sattelmayer for serving as the IGTI Honors and Awards Committee Chair, John Gülen as Industrial Gas Turbine Technology Award Committee Chair, and Keith Boyer as the Industrial Gas Turbine Technology Award Committee Chair.

2017 ASME R. Tom Sawyer Award
Dr. Alan H. Epstein, Pratt & Whitney

2015 ASME Gas Turbine Award
Dr. Robert J. Miller, University of Cambridge
Dr. Ho-On To, University of Cambridge

2015 John P. Davis Award
Rakesh Bhargava, Innovative Turbomachinery Technologies Corp. Lisa Branchini, Michele Bianchi, Andrea Depascale, Valentina Orlandini, University of Bologna

2017 Dilip R. Ballal Early Career Award
Subith Vasu, University of Central Florida

2017 Scholar Award
Dr. Ronald Bunker, Retired from GE Aviation

2017 Aircraft Engine Technology Award
Michael Dunn, Ohio State University

2017 Industrial Gas Turbine Technology Award
Dr. Eisaku Ito, MHI

ASME Dedicated Service Award
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TURBOMACHINERY	PAT CARGILL
WIND ENERGY	KEN VAN TREUREN

2017 Student Best Poster Winners

First Place: *Indirect combustion noise in a stator row: 2D modelling and CAA study* - Ariane Emmanuelli
Second Place: *Experimental Investigation of Sand Deposits on Hastelloy-X from 1000 ˚C to 1100 ˚C Using Particle Tracking* - Andrew Boulanger
People's Choice: *Study of the Thermoacoustic Properties of an Autoignition Stabilized Liquid Fuel Flame Using a Newly Designed Atmospheric Reheat Combustion Test Rig* – Eric Bach

Young Engineer ASME Turbo Expo Participation Award Winners

Alessio Abrassi
Valeria Andreoli
Myeonggeun Choi
Arifur Chowdhury
Ward De Paepe
Adam Feneley
Seyed M. Ghoreyshi
David Holst
Seongpil Joo
Julia Ling
Anandkumar Makwana
Georg Atta Mensah
Alom Mohammed Nur
Aravin Daas Naidu
Stefano Puggelli
Janith Samarasinghe
Prashant Singh
Natalie R. Smith
Adam Gabor Vermes
Sheng Wei

Student Advisory Committee Travel Award Winners

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James Braun
Bogdan Cezar Cernat
Theofilos Efstathiadis
Masha Folk
Chiara Gastaldi
Simone Giorgetti
David Gonzalez Cuadrado
Niclas Hanraths
Shane Haydt
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Maria Rinaldi
Deepanshu Singh
Cori Watson
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Lisa Zander

Call for Papers

ASME 2018 Turbo Expo in Lillestrøm, Norway (close to Oslo)

You are invited to offer a paper for publication at the ASME 2018 Turbo Expo Turbomachinery Technical Conference, June 11-15, 2018 in Lillestrøm, Norway

Prepare your abstract and submit it to the list of track topics for which ASME IGTI Technical Committees are seeking papers. Abstracts are due by August 28, 2017 and must be submitted online (plain text, 400 word limit) via the ASME Turbo Expo Conference Website at asme.org/events/turbo-expo.

ASME IGTI Journals
If warranted by review, papers may also be recommended for publication in the Journal of Engineering for Gas Turbines and Power or the Journal of Turbomachinery.

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Publication Schedule:

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August 28, 2017

Author Notification of Abstract Acceptance
September 18, 2017

Submission of Full-Length Draft Paper for Review
October 30, 2017

Notification of Paper Acceptance
January 3, 2018

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January 3, 2018

Submission of Revised Paper for Review
January 29, 2018

Notification of Acceptance of Revised Paper
February 12, 2018

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The Experts in Turbomachinery

Using Splitters to Control Secondary Flow

C.Clark and G.Pullan, Whittle Laboratory, University of Cambridge

Aerodynamic Opportunity

Turbine design involves many engineering disciplines. The final product is a compromise between aerodynamic performance and constraints arising from mechanical, structural or material requirements. As turbine efficiency increases, engineers must revisit the performance penalties associated with these compromises and develop new ideas to improve the design. In this article, we describe one such concept: splitter vanes.

An example of an aerodynamic challenge created by a mechanical requirement is the use of turbine stators to encase components that pass through the main gas path. These components could be part of the engine structure or pipes carrying oil or air. Engineers have used two approaches to tackle this problem. In the first approach, an additional row of non-turning faired struts is added to house the components. This increases machine length, weight and wetted surface area, all reducing performance. In the second, an existing stator row is adapted to accommodate the components. In this case the machine length remains almost constant. However, the modified stators are thick, have a low aspect ratio, and secondary flows dominate.

Secondary Flow

Secondary flow is defined as fluid with a velocity component in a direction normal to the average flow. Secondary flow is typically characterised by vortices such as those that dig away at the riverbed upstream of a bridge buttress.

"Secondary flow vortices are formed by the rotation of vorticity filaments, located in the endwall boundary layers, as the filaments move through the passage. Around each stator leading edge the inlet boundary layer rolls up into a vortex tube. A vortex "leg" enters the passage on each side of the stator. The leg next to the pressure surface at the leading edge (PS leg) sweeps across the passage, entraining more vorticity as it does so, to produce the dominant flow structure known as the "passage vortex". The leg formed at the suction side (SS leg) remains close to the suction surface forming the counter vortex, a much smaller flow feature.

A simple equation for the production of secondary flow was proposed by Squire and Winter [1],

$$w_{sec} = -2\varepsilon \frac{\partial U}{\partial z}$$

This model predicts that the secondary vorticity (w_{sec}) at row exit is a function of inlet velocity gradient ($\frac{\partial U}{\partial z}$) and row turning only and thus, for a fixed inlet boundary layer profile and stator turning, the secondary vorticity will be constant.

Secondary Losses

Although the secondary vorticity is of interest, the designer is principally concerned with the associated aerodynamic loss. The primary loss contribution is the dissipation of the secondary kinetic energy (SKE) as the vortices mix out. The SKE of a vortex is proportional to the square of its circulation. In turn, the circulation is proportional to the width of the passage (the reciprocal of the stator count). Thus, summing the secondary kinetic energy across every stator, we find an inverse dependence with stator count. Therefore, when low stator counts are used, as is common in current designs, SKE is a large contributor to aerodynamic loss.

The effect of increasing the number of stators is to produce a higher number of smaller passage vortices and a net reduction in secondary kinetic energy.

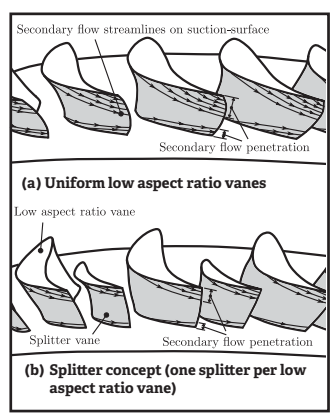


Fig1. Schematic showing both conventional (top) and splitter (bottom) designs, both featuring streamlines due to secondary flows.

Splitter Vanes

The connection between the number of stators and the secondary kinetic energy suggests that the only way to significantly reduce the mixing loss is to increase the number of blades in the row. However, the large thickness needed to pass the structural or pipe components means that the stator count is limited.

The solution requires challenging one of the most common features of a turbomachine – that all blades in a row are the same. Once the possibility of a "non-uniform" stator row with thick blades shielding components and thinner "splitter vanes" to reduce the secondary flow is considered, the design space is greatly expanded.

It was found that both the stators and splitter vanes must be designed simultaneously to achieve peak performance. This increases not only the design possibilities but also the complexity of any numerical simulations performed. The designs evaluated in the current work were produced with fast turn-around computational fluid dynamics (10 minutes per solution) and automated optimization techniques.

The Horseshoe Vortex Jump

During the design process a critical flow feature, only found in non-uniform blade rows, was identified. If the leg of the horseshoe vortex of the thick stator passes upstream of the splitter vane leading edge the vorticity that the designer intended for the first passage is now diverted to the second. This results in a single large passage vortex rather than two smaller ones. In this situation the primary benefit from including splitter vanes is not achieved. Through careful profile design, it was possible to avoid the horseshoe vortex jump and hence successfully reduce the secondary flow strength, improving stage performance.

Experimental tests showed that the underlying theory was correct and that by increasing vane count the secondary kinetic energy was reduced by up to 80%. This in turn lead to increases in stage efficiency of almost 1%, representing a significant fuel saving [2].

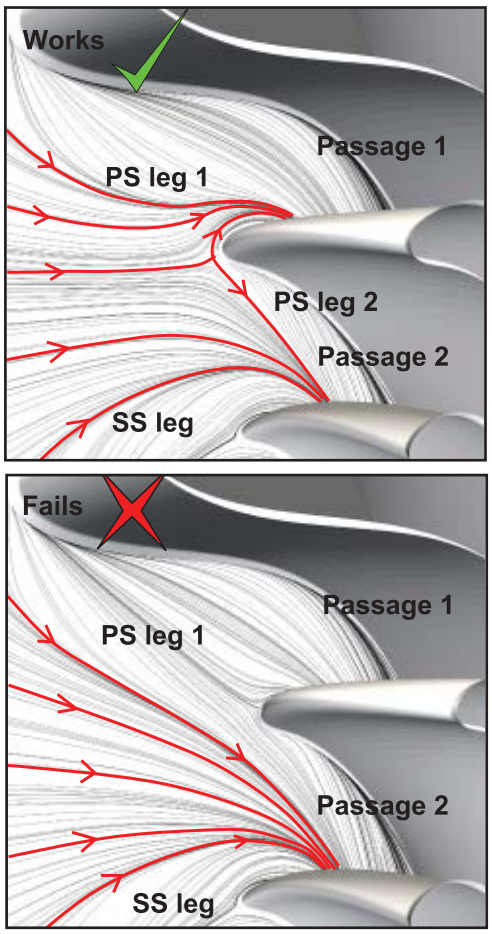
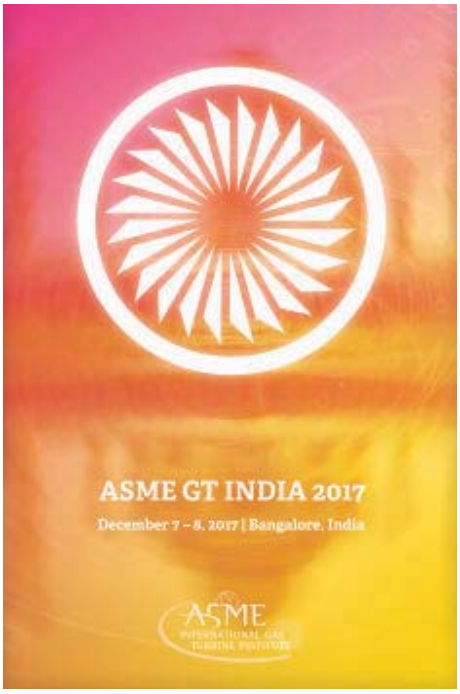


Fig2. Computational endwall streamlines demonstrating a horseshoe vortex jump caused by slight design differences.



References

1. Squire, HB and Winter, KG, 1951 "The Secondary Flow in a Cascade of Airfoils in a Nonuniform Stream". Journal of the Aeronautical Sciences, April 1951

2. "Secondary Flow Control in Low Aspect Ratio Vanes Using Splitters, J. Turbomach 139 (Apr 11, 2017) (11 pages) Paper No: TURBO-16-1304; doi: 10.1115/1.4036190"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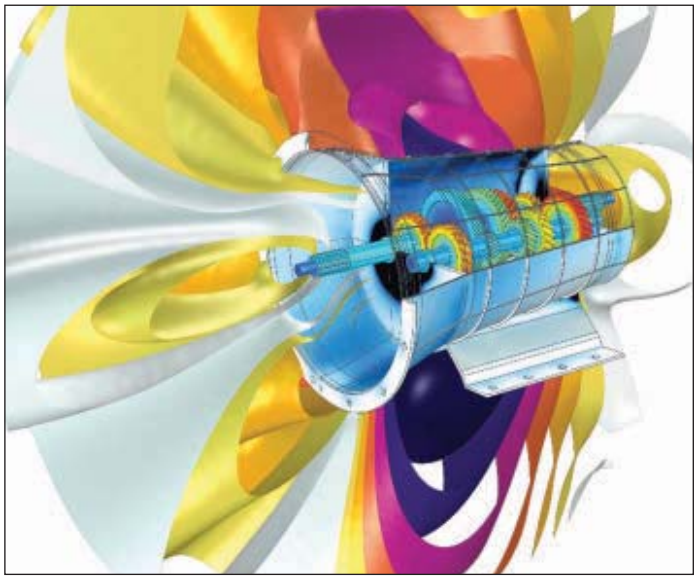
MULTIPHYSICS MODELING, SIMULATION

COMSOL, BURLINGTON, MASS.

COMSOL'S 5.3 VERSION of its multiphysics and server software was created to provide simulation specialists with notable performance improvements and powerful app design and deployment capabilities through new modeling and development tools, solvers, and user-driven features. In many cases, the company promises, users will experience a speedup of 10 times or more in software responsiveness, such as in preprocessing tasks for handling models with several thousand boundaries and domains. With version 5.3, the boundary element method (BEM) is available for modeling electrostatics and corrosion effects so users can easily combine boundary element and finite element methods for greater flexibility in their multiphysics simulations. The projected area is calculated to estimate the clamping forces for molded parts.



3-D SCANNING, DATA PROCESSING

ARTEC 3D, PALO ALTO, CALIF.

Artec Studio 12, intelligence-based software for professional 3-D scanning and data processing, follows in the footsteps of the next generation AI-based 3-D scanner, boasting enhanced speed, an improved user interface, and automated features that minimize the time needed for scanning and processing. Tackling one of the most awkward steps in post-processing, base removal, its Smart Base Removal tool distinguishes between a platform an object is sitting on and the object being scanned, and can even recognize and remove base surfaces, which are not flat. At the same time, all data beneath this surface is also automatically removed.

CONSTRUCTION VERIFICATION

CLEAREDGE3D, MANASSAS, VA.

Verity 1.0 verifies the accuracy of new construction against design/fabrication models, giving general contractors insight into their construction projects. The software analyzes laser-scan-point cloud data of the as-built construction against the design/fabrication models, identifying variances, missing elements, or other potentially costly construction errors. The variance data and corrected model can be exported to Navisworks for as-built clash detection and further analysis. Verity was developed to dramatically reduce the financial impact of poorly constructed and out-of-tolerance work by flagging problems early in the construction process so they can be remedied or eliminated before they effect schedules or future work.

REALITY MODELING

BENTLEY SYSTEMS, EXTON, PA.

ContextCapture for reality modeling increases joint opportunities in surveying and engineering with capabilities that include cloud-processing services, a mobile app, and photo planning for Bentley's applications. ContextShare extends Bentley's ProjectWise connected data environment to securely manage, share, and stream reality meshes, and their input sources, across project teams and applications. Navigator Web is a new web application that delivers high-performance streaming of very large reality meshes through the browser to desktop or mobile devices. For infrastructure project delivery, reality modeling captures the actual context of infrastructure projects through photos and/or scans, creating engineering-ready reality meshes for design modeling, analytical modeling, and construction modeling.

KEYNOTE MANAGEMENT

CHALKLINE, PORTLAND, MAINE.

The company's Keynote Manager integration tool for VisiSpecs enables users to comprehensively coordinate construction drawings and specifications. Not only does it provide coordination and verification but also saves hours on each project by eliminating the need to manually filter master keynote lists to project-specific lists. Users can import their existing master keynote list instead of creating a new list for each project, while having complete control over the keynotes, including adding, deleting, editing, sorting, and commenting, with all modifications tracked by date and user. With the click of a button, all keynotes linked to specification sections may be included, with others filtered out. ME

Penn Engineering

The School of Engineering and Applied Science at the University of Pennsylvania is growing its faculty by 33% over a five year period. As part of this, the **Department of Mechanical Engineering and Applied Mechanics** is engaged in an aggressive, multi-year hiring effort for multiple tenure-track positions.

We seek applicants with exceptional research achievements and future promise, a commitment to excellence in education, and dedication to service and collegiality. Candidates should couple with the department's core strengths in mechanical systems, mechanics of materials, fluid mechanics and thermal sciences. The specific areas for this search, and a link to submit applications, can be found at: http://www.me.upenn.edu/faculty-staff/

The Department has strong collaborations with all other engineering departments as well as Penn's other Schools and multiple research centers. We seek candidates who can add to these relationships. Successful candidates will conduct leading research benefiting from Penn's interdisciplinary tradition and new facilities such as the Singh Center for Nanotechnology. We encourage applicants whose research aligns with the School's new strategic plan (http://www.seas.upenn.edu/PennEngineering2020). Candidates who enrich Penn's diversity are strongly encouraged to apply.

The University of Pennsylvania is an affirmative action/equal opportunity employer. All qualified applicants will receive consideration for employment and will not be discriminated against on the basis of race, color, religion, sex, sexual orientation, gender identity, creed, national or ethnic origin, citizenship status, disability, veteran status, or any other characteristic protected by law.

University of Illinois at Chicago

Department of Mechanical and Industrial Engineering

Assistant/Associate/Full Professor Mechanical Engineering

The Department of Mechanical and Industrial Engineering at the University of Illinois at Chicago invites applications for several tenure-track faculty positions in various areas of Mechanical Engineering. Individuals will also be considered at associate or full professor rank if they possess outstanding qualifications commensurate with the rank. Successful applicants are required to have an earned PhD in Mechanical Engineering or a related field, and are expected to develop and maintain an active, externally-funded research program as well as teach courses at both the undergraduate and graduate levels.

The Department offers BS, MS, and PhD degrees in Mechanical Engineering, and Industrial Engineering and Operations Research; and currently has an undergraduate enrollment of about 770 and a graduate enrollment of about 500. More information about the Department can be found at **http://www.mie.uic.edu**. Applicants are required to send a letter of application indicating their qualifications, an up-to-date CV including the names and contact information of three references, and separate one-page statements outlining their future teaching and research plans.

For fullest consideration, applications must be submitted online at **http://jobs.uic.edu/job-board/job-details?jobID=82503** by **December 1, 2017**. Applications will be accepted until the positions are filled. Expected starting date is August 2018.

The University of Illinois at Chicago is an affirmative action, equal opportunity employer, dedicated to the goal of building a culturally diverse and pluralistic faculty and staff committed to teaching and working in a multicultural environment. We strongly encourage applications from women, minorities, individuals with disabilities and covered veterans.

The University of Illinois conducts background checks on all job candidates upon acceptance of contingent offer of employment. Background checks will be performed in compliance with the Fair Credit Reporting Act.

MECHANICAL AND INDUSTRIAL ENGINEERING
COLLEGE OF ENGINEERING
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San Diego State University
Mechanical Engineering

FACULTY POSITION IN MULTISCALE MODELING OF MULTIPHASE FLOWS

The Department of Mechanical Engineering seeks to fill a tenure-track position at the **Assistant Professor** level in the area of computational multiscale modeling of multiphase flows and transport starting Fall 2018. Candidates with expertise in applications to porous media flows, energy recovery, and biological applications are especially invited to apply. Mechanical Engineering is one of the four departments in the College of Engineering at San Diego State University. It offers an EAC ABET-accredited B.S. degree program, as well as M.S. and joint Ph.D. programs. The department has internationally recognized programs in energy and thermofluids, bioengineering, material science and processing, mechanics, MEMS, NEMS, sensors, robotics, dynamic systems and control. It is anticipated that the person will develop synergies with areas of existing research strength and exploit emerging areas of research by developing a vigorous externally funded research program in the general area of multiscale modeling of multiphase flows and transport. A demonstrated ability to collaborate across disciplinary boundaries is essential. The department shares with the College of Engineering and the University a strong commitment to excellence in undergraduate and graduate education. The successful hire is expected to supervise teams of undergraduate as well as graduate students. Applicants must have a demonstrated ability to teach undergraduate and graduate level classes in fluid and thermal sciences, and other related areas of mechanical engineering.

For more information about the department, college and university, please visit: http://mechanical.sdsu.edu, http://engineering.sdsu.edu, and http://www.sdsu.edu.

Applicants must have an earned Ph.D. degree in mechanical engineering or a closely related discipline. Applications must be received by November 1, 2017 to receive full consideration; the position will remain open until filled. Candidates must apply via Interfolio at http://apply.interfolio.com/42863. Questions may be directed to the Search Committee Chair at MMMFsearch@engineering.sdsu.edu.

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PennState College of Engineering | MECHANICAL AND NUCLEAR ENGINEERING

NEW FACULTY SEARCHES IN MECHANICAL ENGINEERING

The Department of Mechanical and Nuclear Engineering at The Pennsylvania State University is pleased to invite applications for tenure-track positions anticipated in mechanical engineering at the **Assistant or Associate Professor** levels. The Department will consider all areas pertinent to the mechanical engineering discipline.

The Department is home to more than 60 faculty, 300 graduate students, and 1300 undergraduate students. The faculty conduct in excess of $25M per year of funded research across a broad spectrum of traditional and emerging areas. Penn State actively encourages and provides resources for interdisciplinary research collaboration through university-level institutes primarily focused on materials, health, and energy. The Department offers separate B.S., M.S., and Ph.D. degree programs in both mechanical engineering and nuclear engineering, including online graduate programs in mechanical engineering, nuclear engineering, and advanced manufacturing and design. Further information on the Department can be found at: http://www.mne.psu.edu/.

Successful applicants will have demonstrated outstanding scholarly research and will have expressed strong interests in engineering education. Qualifications for these positions include a doctorate in engineering or a related field. The successful candidates will be expected to teach courses at both undergraduate and graduate levels, to develop an internationally-recognized, externally-funded research program, and to contribute to the operation and promotion of the department, college, university, and profession through service.

Nominations and applications will be considered until the positions are filled. Screening of applicants will begin on October 1st, 2017. Applicants should submit a cover letter, a statement on teaching and research, a curriculum vitae, and the names and addresses of four professional references who are academics at the rank of Professor. Please submit these four items in one pdf file electronically to job 72158 at https://psu.jobs/job/72158.

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

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

SAN DIEGO STATE UNIVERSITY
Mechanical Engineering

FACULTY POSITION IN ENERGY STORAGE

The Department of Mechanical Engineering seeks to fill a tenure-track position at the **Assistant Professor** level in the area of thermal and electrochemical energy storage starting Fall 2018. Candidates with expertise in hybrid storage systems and system level integration are especially encouraged to apply, but demonstrated strength in one or more core areas of mechanical engineering is essential. Mechanical Engineering is one of the four departments in the College of Engineering at San Diego State University. It offers an EAC ABET-accredited B.S. degree program, as well as M.S. and joint Ph.D. programs. The department has internationally recognized programs in energy and thermofluids, material science and processing, bioengineering, mechanics, MEMS, NEMS, sensors, robotics, dynamic systems and control. It is anticipated that the person will develop synergies with areas of existing research strength and exploit emerging areas of research by developing a vigorous externally funded research program in the general area of energy storage. A demonstrated ability to collaborate across disciplinary boundaries is essential. The department shares with the College of Engineering and the University a strong commitment to excellence in undergraduate and graduate education. He or she is expected to supervise teams of undergraduate as well as graduate students. Applicants must have a demonstrated ability to teach undergraduate and graduate level classes in one or more core areas of mechanical engineering.

For more information about the department, college and university, please visit: http://mechanical.sdsu.edu, http://engineering.sdsu.edu, and http://www.sdsu.edu.

Applicants must have an earned Ph.D. degree in mechanical engineering or a closely related discipline. Applications must be received by November 1, 2017 to receive full consideration; the position will remain open until filled. Candidates must apply via Interfolio at http://apply.interfolio.com/42865. Questions may be directed to the Search Committee Chair at TEESsearch@engineering.sdsu.edu.

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MICHIGAN ENGINEERING
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

MECHANICAL ENGINEERING FACULTY POSITIONS: 2017-2018

The Department of Mechanical Engineering (ME), University of Michigan (U-M), Ann Arbor, seeks outstanding applicants for multiple full-time tenured or tenure-track faculty positions. The positions are open to candidates at all ranks, including junior- and senior-level appointments. Those who have strong backgrounds relevant to mechanical engineering are welcome to apply. Areas of special interest include: dynamics and dynamical systems, computational science, fluid mechanics, and solid mechanics and materials. We are especially interested in individuals who can contribute to the excellence and diversity of our academic community. Underrepresented minorities and women are strongly encouraged to apply.

The U-M Mechanical Engineering Department is a vibrant and collegial community. It is home to 68 tenured/tenure-track faculty, 21 research faculty, over 450 graduate students (including over 250 Ph.D. students), and 800 undergraduate students. We are well known for our leadership in core mechanical engineering disciplines, as well as in interdisciplinary and emerging areas. The Department is consistently ranked among the top mechanical engineering programs nationally and internationally by the QS World Rankings, U.S. News & World Report, National Research Council Ph.D. Program Assessments, and others. More information about the Department can be found at: http://me.engin.umich.edu/.

The University of Michigan has a long and distinguished history. It was founded in 1817, 20 years before the territory became a state, and was one of the first public universities in the nation. Throughout its 200-year history, U-M has maintained the highest levels of education, scholarship, and research. Ann Arbor is a very attractive city, regularly rated as one of the best places to live in the nation.

Applicants should have a Ph.D. degree in mechanical engineering or an appropriate field. We seek scholars who will provide inspiration, leadership, and impact in research, teaching, and service. To ensure full consideration, candidates are encouraged to apply now and certainly before November 1, 2017, as applications will be reviewed immediately upon receipt.

All applicants should submit, in PDF format: (1) a detailed resume, (2) a statement of research and teaching interests, (3) up to three representative publications, and (4) the names and contact information of at least three references. Applications must be submitted electronically at http://me.engin.umich.edu/facultysearch.

The University of Michigan is a non-discriminatory/affirmative action employer and is responsive to the needs of dual-career families.

UBC THE UNIVERSITY OF BRITISH COLUMBIA

MECHANICAL ENGINEERING FACULTY POSITION MECHATRONICS

The Department of Mechanical Engineering at the University of British Columbia (Vancouver Campus) is accepting applications for one tenure-track, Assistant Professor positions in mechatronics. Applicants should hold a Ph.D. degree or equivalent in Mechanical Engineering, Electrical Engineering, or a closely related field. Candidates with research expertise in one or more areas including instrumentation, optics, micro/nano-positioning, precision engineering, and sensors and actuators are especially encouraged to apply. Previous industrial experience is an asset. The starting date will be July 2018, or as soon as possible thereafter.

The mission of the Department of Mechanical Engineering is to serve society through innovation and excellence in teaching and research. Accordingly, candidates must demonstrate a commitment to students, teaching and learning. All members of the Department are expected to provide service within the Department, at the University, and to both the academic and broader community. The successful applicant will be expected to register as a Professional Engineer in British Columbia.

The ideal candidate will be eager to join an engaged and welcoming academic community, and will complement our existing research strengths. With the support of their colleagues, the successful candidate is expected to develop an internationally-recognized, externally-funded research program, and will be encouraged to seek collaborative research opportunities in diverse application areas.

The University of British Columbia consistently ranks among the top twenty public universities in the world. Current strategic priorities include: student learning, research excellence, international engagement, sustainability, and creating an outstanding work environment. Please see http://mech.ubc.ca for more information on the Department, and http://apsc.ubc.ca/careers for more information on employment in the Faculty of Applied Science.

Equity and diversity are essential to academic excellence. An open and diverse community fosters the inclusion of voices that have been underrepresented or discouraged. We encourage applications from members of groups that have been marginalized on any grounds enumerated under the B.C. Human Rights Code, including sex, sexual orientation, gender identity or expression, racialization, disability, political belief, religion, marital or family status, age, and/or status as a First Nation, Metis, Inuit, or Indigenous person All qualified candidates are encouraged to apply; however Canadians and permanent residents of Canada will be given priority for the position. The position is subject to final budgetary approval.

Applicants are asked to complete the following equity survey: https://survey.ubc.ca/s/MECH-Mechatronics/. 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. This survey takes only a minute to complete. 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”.

Applicants should submit a curriculum vitae, a statement of research interests and a research plan (4 pages or less), a statement of teaching interests and accomplishments (1 page), and names and contact information for four referees. Applications are accepted only through http://hr.ubc.ca/careers-postings/faculty.php, and must be submitted by October 15, 2017.

THE UNIVERSITY OF BRITISH COLUMBIA

THE UNIVERSITY OF BRITISH COLUMBIA SEASPAN CHAIR/PROFESSORSHIP

The Faculty of Applied Science 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 named position in association with Seaspan (https://www.seaspan.com/). The successful applicant will hold an appointment in one or more of the following Departments: Mechanical Engineering, Materials Engineering, and Civil Engineering. We welcome applications from individuals who have expertise in any of the following areas: marine systems engineering, mechatronics, design, additive manufacturing, clean energy, and autonomous vehicles. The starting date of the appointment will be July 2018, or as soon as possible thereafter.

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 an asset. The successful candidate will be expected to conduct research in collaboration with the marine industry. 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, Mechanical Engineering, Civil Engineering, Materials 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 the marine industry.

The mission of the Faculty is to serve society through innovation and excellence in teaching and research. Accordingly, candidates must demonstrate a commitment to students, teaching and learning.

The ideal candidate will be eager to join an engaged and welcoming academic community, and will complement our existing research strengths. With the support of their colleagues, the successful candidate is expected to develop an internationally-recognized, externally-funded research program, and will be encouraged to seek collaborative research opportunities in diverse application areas.

The University of British Columbia consistently ranks among the top twenty public universities in the world. Current strategic priorities include: student learning, research excellence, international engagement, sustainability, and creating an outstanding work environment. Please see http://apsc.ubc.ca/careers for more information on employment in the Faculty of Applied Science.

Equity and diversity are essential to academic excellence. An open and diverse community fosters the inclusion of voices that have been underrepresented or discouraged. We encourage applications from members of groups that have been marginalized on any grounds enumerated under the B.C. Human Rights Code, including sex, sexual orientation, gender identity or expression, racialization, disability, political belief, religion, marital or family status, age, and/or status as a First Nation, Metis, Inuit, or Indigenous person All qualified candidates are encouraged to apply; however Canadians and permanent residents of Canada will be given priority for the position. The position is subject to final budgetary approval.

Applicants are asked to complete the following equity survey: https://survey.ubc.ca/s/Seaspan/. 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. This survey takes only a minute to complete. 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". Canadians and permanent residents of Canada will be given priority for the position. The position is subject to final budgetary approval.

Applicants should submit a curriculum vitae, a (4 pages or less) statement of research interests and a research plan, part of which should be a plan for engagement with the marine industry, a (1-2 page) statement of teaching interests and accomplishments, and names and contact information for four referees. Applications are accepted only through http://hr.ubc.ca/careers-postings/faculty.php, and must be submitted by October 15, 2017.

SAN DIEGO STATE UNIVERSITY
Mechanical Engineering

FACULTY POSITION IN BIOMEDICAL SENSORS AND NANOTECHNOLOGY

The Department of Mechanical Engineering seeks to fill a tenure-track position at the **Assistant or Associate Professor** level in the area of biomedical sensors and nanotechnology starting Fall 2018. Mechanical Engineering is one of the four departments in the College of Engineering at San Diego State University. It offers an EAC ABET-accredited B.S. degree program in Mechanical Engineering, as well as M.S. and Ph.D. programs in Mechanical and Bioengineering. This faculty member will work collaboratively on research projects with engineering, science, and rehabilitation faculty in the Smart Health (sHealth) Institute, a newly established Area of Excellence at San Diego State University. The ideal candidate will have strengths working with and building relationships with and collaborations among engineering, science and biomedical research faculty. This faculty member would spearhead and support translational research with biomedical sensor technologies. The research program would ideally focus on medical, biological and environmental nanosensors or micro/nanofabrication technology. The department shares with the College of Engineering and the University a strong commitment to excellence in undergraduate and graduate education. He or she is expected to supervise teams of undergraduate as well as graduate students in our M.S. and Ph.D. programs. Applicants must have a demonstrated ability to teach undergraduate and graduate level classes in the department.

For more information about the department, college and university, please visit: http://mechanical.sdsu.edu, http://engineering.sdsu.edu, and http://www.sdsu.edu.

Applicants must have an earned Ph.D. degree in mechanical engineering or a closely related discipline. Applications must be received by November 1, 2017 to receive full consideration; the position will remain open until filled. Candidates must apply via Interfolio at http://apply.interfolio.com/42870. Questions may be directed to the Search Committee Chair at MESHsearch@engineering.sdsu.edu.

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University of Illinois at Chicago

Department of Mechanical and Industrial Engineering

Assistant/Associate/Full Professor Industrial Engineering

The Department of Mechanical and Industrial Engineering at the University of Illinois at Chicago (UIC) invites applications for a tenure-track faculty position in Industrial Engineering. Individuals will also be considered at associate or full professor rank if they possess outstanding qualifications commensurate with the rank. Successful applicants are required to have an earned PhD in Industrial Engineering or a related field, and are expected to develop and maintain an active, externally-funded research program as well as teach courses at both the undergraduate and graduate levels.

The Department offers BS, MS, and PhD degrees in Mechanical Engineering, and Industrial Engineering and Operations Research, and currently has an undergraduate enrollment of about 770 and a graduate enrollment of about 500. More information about the Department can be found at **http://www.mie.uic.edu**. Applicants are required to send a letter of application indicating their qualifications, an up-to-date CV including the names and contact information of three references, and separate one-page statements outlining their future teaching and research plans.

For fullest consideration, applications must be submitted online at **http://jobs.uic.edu/job-board/job-details?jobID=82505** by **December 1, 2017**. Applications will be accepted until the position is filled. Expected starting date is August 2018.

UIC is deeply committed to a community of excellence, equity, and diversity and welcomes applications from women, underrepresented minorities, persons with disabilities, sexual minority groups, and other candidates who will contribute to the diversification and enrichment of ideas and perspectives. An AA/EO employer.

The University of Illinois conducts background checks on all job candidates upon acceptance of contingent offer of employment. Background checks will be performed in compliance with the Fair Credit Reporting Act.

MECHANICAL AND INDUSTRIAL ENGINEERING
COLLEGE OF ENGINEERING
UIC

POSITIONSOPEN

Loyola Marymount University (LMU) in Los Angeles seeks an Assistant Professor in Mechanical Engineering in all areas. Candidates should have a Ph.D. in mechanical engineering or a closely related field and ideally a BS in mechanical engineering. Successful candidates will be dedicated to excellent teaching and mentoring, developing a thriving research program, service, and supporting the mission of our institution. Apply online at https://jobs.lmu.edu/. LMU is an equal opportunity institution.

Director, TEES Turbomachinery Laboratory, NOV#E09FY17 **The Texas A&M Engineering Experiment Station** invites applications for the Director of the Turbomachinery Laboratory. Applicants will be able to develop, direct and implement TL's R&D, Work Force Development, and technology commercialization objectives and initiatives. Ensure that TL's activities will establish, maintain and increase the center's competitive position and sustainability. Foster collaboration and opportunity between faculty, researchers and centers. Collaborate with the head of the Mechanical Engineering Department to align goals and outcomes and must hold credentials that allow appointment to the engineering faculty. Maintain current sponsor relationships as well as develop new relationships in new market areas. Expected to foster and provide leadership in expanding the R&D portfolio, workforce development, and technology commercialization activities of TL. A wide degree of creativity and latitude is expected. Expected to supervise the organization of symposia and continuing-education activities as well as chair and support major industrial advisory committees both for organizing symposia and for research. Qualifications: Required Education: Bachelor's in applicable field or equivalent combination of education and experience. Required Experience: Ten years of related experience. Preferred Education and Experience: PhD in Engineering or related field and 10 years of combined experience in industry and academia. Progressive, successful experience and demonstrable accomplishments in R&D, WFD and/or technology commercialization leadership, execution and management. Experience as the director of an R&D organization or agency in industry, government or academia. Service on industry, government, or academic R&D, WFD, and/or technology commercialization planning or steering committees. Service on turbomachinery-related professional committees, societies, and organizations. For additional information and to apply, please go to www.tamengineeringjobs.com The members of Texas A&M Engineering are all Equal Opportunity/Affirmative Action/Veterans/Disability employers committed to diversity.

Faculty Positions in Mechanical and Energy Engineering at the Southern University of Science and Technology (SUSTech), China

The Department of Mechanical and Energy Engineering at the Southern University of Science and Technology (SUSTech), China (http://www.sustc.edu.cn/en) invite applications for tenure-track or tenured faculty positions at all ranks (Assistant Professors, Associate Professors, Professors and Chair Professors). The Department is established with three broad subjects, i.e., Robotics and Automation, Innovative Design and Advanced Manufacturing, as well as Energy Engineering. There are extraordinary opportunities to develop own careers together with the rapid development of the Department in these three major subjects

Established in 2012, SUSTech is a public institution funded by the municipal of Shenzhen City, a special economic zone in southern China. Shenzhen is a major city located in Southern China, situated immediately north of Hong Kong. As one of China's major gateways to the world, Shenzhen is the country's fast-growing city in the past two decades. The city is the high-tech and manufacturing hub of southern China. As a state-level innovative city, Shenzhen has chosen independent innovation as the dominant strategy for its development.

SUSTech is a pioneer in higher education reform in China. The mission of the University is to become a globally recognized institution which emphasizes academic excellence and promotes innovation, creativity and entrepreneurship.

Successful candidates are expected to establish vigorous teaching and research programs in the three broad subjects and related interdisciplinary areas. Candidates should possess doctoral degrees in relevant subjects and demonstrate research accomplishment and/or potential. Senior candidates are expected to play leadership role of teaching and research. Globally competitive salaries and start-up packages will be provided. Those interested are invited to apply through the job website at http://talent.sustc.edu.cn/en/enindex.aspx, with submission of the following material electronically to rongym@sustc.edu.cn:

1) Curriculum Vitae (with a complete list of publications).
2) Statement of teaching philosophy.
3) Statement of research interests.
4) Selected reprints of three recent papers, to represent your research.
5) Names and contact details of five references.

THE UNIVERSITY OF ARIZONA
COLLEGE OF ENGINEERING
Aerospace & Mechanical Engineering

DEPARTMENT HEAD
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We seek an engaging and articulate leader to guide this successful department as it secures additional faculty appointments and expands and enhances its undergraduate and graduate programs, research impact and visibility, and industrial partnerships.

The successful candidate will have a proven record of transparent, collaborative and effective strategic planning, communication and resource management. A distinguished record of achievement in scholarship, research and/or professional practice commensurate with an appointment at the rank of professor with tenure is required. Full posting (#F20856) and application instructions are at https://uacareers.com/postings/16156.

The department is dedicated to innovative interdisciplinary research and teaching in both aerospace and mechanical engineering. The department's research specialties include active flow control, aerospace guidance navigation and control, astrodynamics, biomechanics, computational and experimental fluid and solid mechanics, mechatronics, multibody dynamics, nanotechnology and renewable energy.

Research at the University of Arizona is strongly multidisciplinary and the department works extensively with, among others, the UA Department of Planetary Sciences, Arizona Health Sciences Center, BIO5 Institute for Collaborative Bioresearch, College of Optical Sciences and the Program in Applied Mathematics, all of which enjoy international recognition as centers for world-class academic programs and research.

The University of Arizona is located in Tucson, which has a vibrant, multicultural community – in 2016 UNESCO named it a World City of Gastronomy – and is home to a thriving industrial sector that includes Raytheon, Rincon Research, Paragon Space Development and Vector Space Systems.

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ASME President Charla Wise became the 136th president of the Society during the ASME Annual Meeting in Newport Beach, Calif., held in June.

NEW ASME PRESIDENT CHARLA WISE HIGHLIGHTS ASME'S MISSION & VISION

During her inaugural address at the President's Dinner at the ASME Annual Meeting, ASME's new president, **Charla K. Wise**, discussed the Society's mission and vision, as well as her hopes for ASME's future as it continues with its strategic plan for becoming the go-to organization for addressing key technology-related issues.

Given her history with ASME, Wise is naturally familiar with—and committed to—the Society's mission: to serve diverse global communities by advancing, disseminating, and applying engineering knowledge for improving the quality of life and communicating the excitement of engineering.

Touching on the mission's last point, Wise said, "As quickly as our world is changing and advancing, we need to stimulate and inspire the minds and capture the hearts and souls of our existing engineers and technical professionals, as well as those of future generations of engineers to join us in accomplishing our mission to impact the world positively, through our solutions and technology."

Wise also discussed ASME's vision of being the essential resource for mechanical engineers and other technical professionals throughout the world for solutions that benefit humankind, noting that she shared this vision for the Society as well.

"Last year, when I ran for president, I told the Nominating Committee that my theme for this year would be 'Continuity, As We Move Forward, Together.' And that's the beauty of the strategy that ASME's Board of Governors has been working on over the past several years. It brings us continuity as we look to the future, especially over the next 10 years. It helps us move forward toward achieving our mission by having clear goals. It brings us all together—we all have a common vision—what I call a 'North Star' for the Society."

Much like the North Star, which has been used throughout the ages as a navigational tool because it remains nearly immovable in the sky, the Society's vision "holds steady in front of all of us," Wise said. "We all can keep our eye on the North Star (our vision) as we move forward on our ASME paths as individuals, as sectors, as groups. We all see how our paths may be somewhat separate, yet we are connected and integrated, helping each other, and doing our part to lead us towards success."

As her speech drew to a close, Wise, addressing her fellow ASME colleagues in the room, said, "We are the leaders to make our vision a reality. We are members of such an incredible team. I am always impressed and energized when I look at the credentials, the commitment, the energy and the dedication of this team. You are, and we have on our team 'the best of the best'—and we can make it happen." ME

ANNUAL MEETING MEMBERSHIP ASSEMBLY ADDRESSES ASME AND THE NEXT GENERATION OF ENGINEERS

A special Membership Assembly at the ASME Annual Meeting in Newport Beach, Calif., provided ASME members attending the conference with an update on ASME's recently launched strategic plan and its implications for the future of the Society.

Following an introduction by Executive Director Thomas Loughlin, ASME President **Keith Roe** presented the first portion of the program, "ASME Strategy—How We Got Here," in which he discussed the development of the Society's new strategic plan for establishing ASME as the go-to organization for addressing key technology-related challenges in the public interest. Subsequent steps have included the Board of Governors approving five core technologies—robotics, manufacturing, clean energy, bioengineering, and pressure technology—that will be the basis of the Society's products and services portfolio going forward, and the formulation of an Integrated Operating Plan to provide guidance as the Society develops that portfolio and strives to meet a set of 10-year, three-year, and one-year goals.

During the next section of the program, ASME President-Elect Charla Wise discussed the five Presidential Task Forces that the BOG formed to address issues facing ASME in several critical areas: The five Task Forces presented their recommendations to the BOG during the Annual Meeting for possible inclusion in the Integrated Operating Plan.

The Membership Assembly continued with a panel discussion focusing on ASME's E-Fests—a successful new program of regional three-day events for engineering students that combine learning opportunities revolving around design, advanced manufacturing, and robotics with social activities and entertainment. ME

LORD OF THE RINGS

Image: Kaynemaile

Today's soldiers don't tend to wear chainmail. If you want see the stuff, you'll have to go to a museum—or the movies. The Lord of the Rings, specifically. The series had hundreds of actors that needed to be clad in the linked armor. Of course, the armor on the set didn't need to be the strong and heavy stuff of yore. So special effects maestro and weapons designer Kayne Horsham decided to make it out of silver-plated polypropylene plumbing tubing.

Though the material was lighter and cheaper than iron or steel, Horsham was still assembling the mail the old-fashioned way: breaking the rings so they could be linked together and assembling them by hand. He had 20 to 30 people working on suits of armor of 80,000 rings each. But the assemblers weren't done when a suit was done. Because each ring had been weakened, the armor would break after a day on an actor, and they would work all night repairing them.

However painstaking the process, the material was a big hit before it was coated in silver. "People showed a level of joy when it was in that raw state," Horsham said. "It was warm to the touch, nice and tactile." He began wondering if, after he was done with Lord of the Rings, he might make the chained fabric for the fashion industry.

So he created a machine that would automate the ring assembly. "While I was struggling to debug this machine, I said, why on earth am I doing what people have done for 2,000 years—rejoining them. Why not make them already rejoined," he said. "I had a eureka moment: surely I could use injection molding." He learned CAD and started putting together a model.

Engineers he talked to weren't so sure. He went from one to another, showing them a pink plasticine prototype he'd cobbled together, but couldn't get anyone to take it seriously.

Months later, the first engineer he had talked to decided to help him—on the condition that his name not be associated with the project. In short, Horsham created a liquid state assembly hot runner system capable of injecting material to 50 different points at exactly the right time.

The result is an incredibly strong material with seemingly miraculous properties. Kaynemaile, as the material was dubbed by The Lord of the Rings triology star Viggo Mortensen, can be found wrapped around buildings 16 stories high. No metal mail would survive that height without deformation and breakage. It's also been featured in an installation in Times Square as part of the NYCxDesign show.

Kaynemaile may soon have some non-decorative applications. The material easily separates oil from water, and allows the oil to be reused. Horsham hopes that oil companies will begin to use it to help clean up spills. It also has the potential to make a superior fish-containment net. Today's nets last just a few years and when they break they float randomly through the ocean ensnaring fish and other animals. Kaynemaile has the promise to outperform them.

Whether it's for a catwalk, a hotel lobby, or an oil spill, the material is completely reusable, as it's made of a polycarbonate. "My approach means harvesting the material for reuse—it's just a no-brainer, but commercially people have different motivations," Horsham said. "But I think there needs to be more responsibility for what people design and build."

With Kaynemaile, we may get to that more sustainable future, one link at a time. ME

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


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