MECHANICAL ENGINEERING

Technology that moves the world

THE MAGAZINE OF ASME

No. 03
137

TAKING THE HYDRO OUT OF HYDRAULIC FRACTURING

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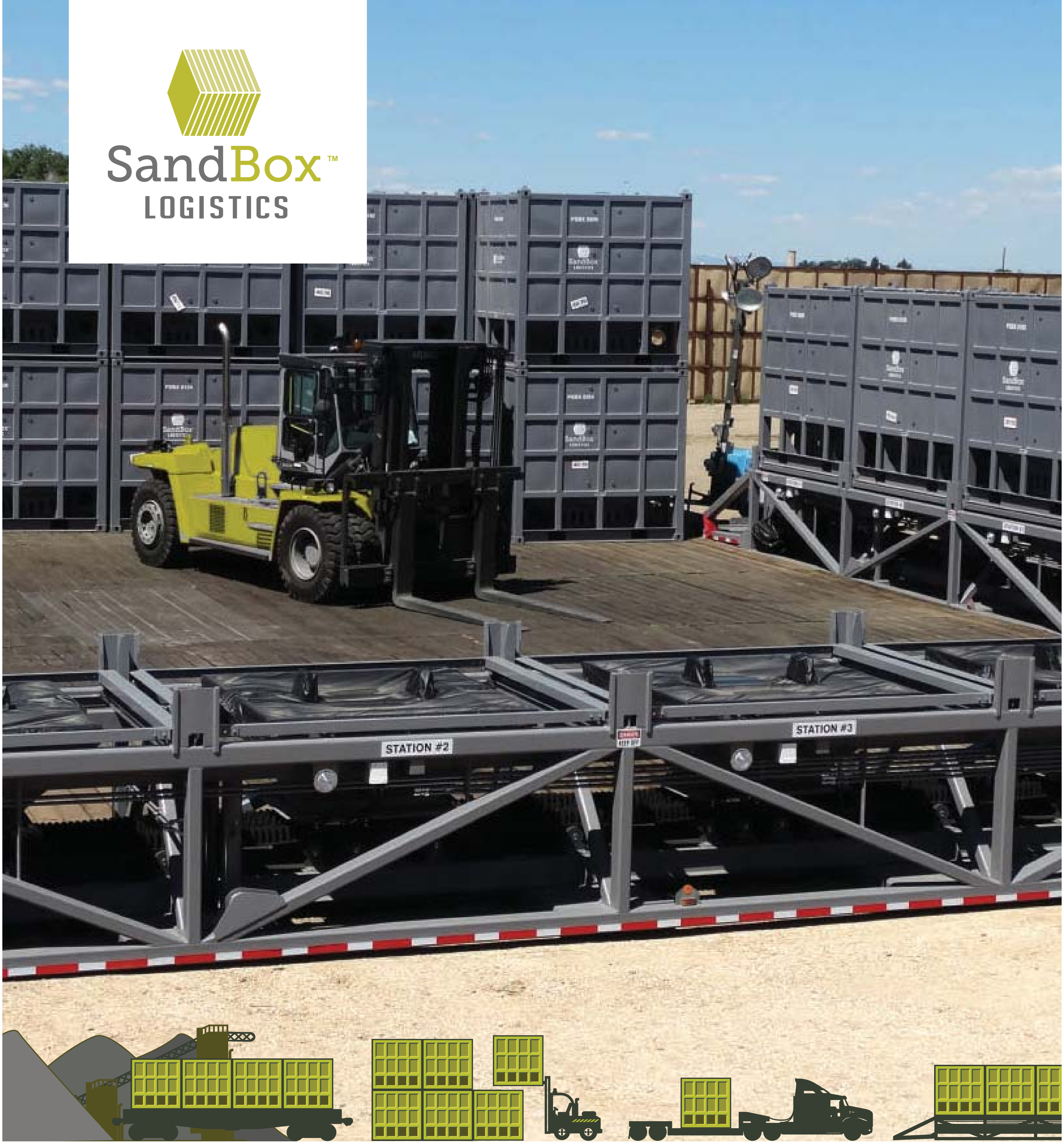

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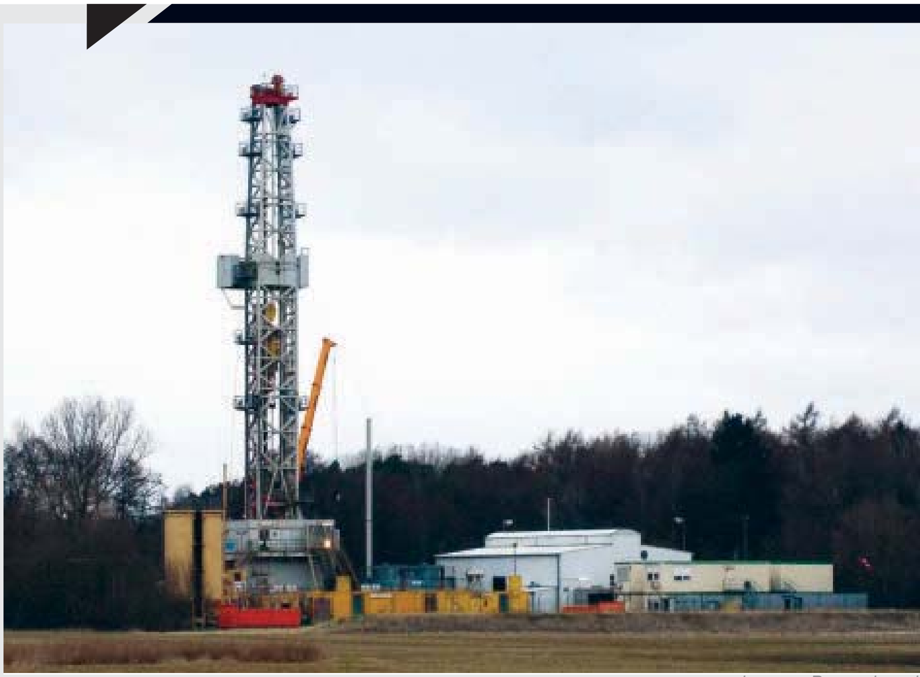

Image: Battenbrook

FRACTURING WITH LESS WATER

HYDRAULIC FRACTURING is a booming success story and has boosted U.S energy production to levels not seen in decades. It is a thirsty process, each well consuming between three million and six million gallons of water, most of which becomes unusable and must be trucked for disposal, generally in deep injection wells. An online article, which reflects many of the issues addressed by this month's cover feature that begins on page 30, looks at researchers working on ways to reduce the volume of water needed for hydraulic fracturing.

LITHIUM ION IN THE AIR

WHILE A HANDFUL of companies have been refining electric planes, one man has been making battery powered aircraft for anyone hoping to experience silent, birdlike flight.

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

ENGINEERING MEETS ART

ENGINEERS ARE APPLYING the principles of origami to develop innovative products and structures that meet a variety of challenging design situations.

VIDEO: IMPROVING LIVES WITH PROFITABLE BUSINESSES

WINDHORSE INTERNATIONAL founder Paul Polak shares his unique perspective on how best to serve the developing world. **ME**

NEXT MONTH ON ASME.ORG

PODCAST: INDUSTRIALIZATION CHALLENGES IN ADDITIVE MANUFACTURING

An interview with Prabhjot Singh, manager of the Additive Manufacturing Lab at GE Global Research, who will be speaking at the 2015 ASME Additive Manufacturing+3D Printing Conference in India.

VIDEO: ENERGY EFFICIENCY AND GAS TURBINE DEVELOPMENT

ASME.org editor Dave Walsh talks with Brian Nolan of Rolls Royce Canada about the technologies that are making gas turbines greener and more efficient in the 21st century.

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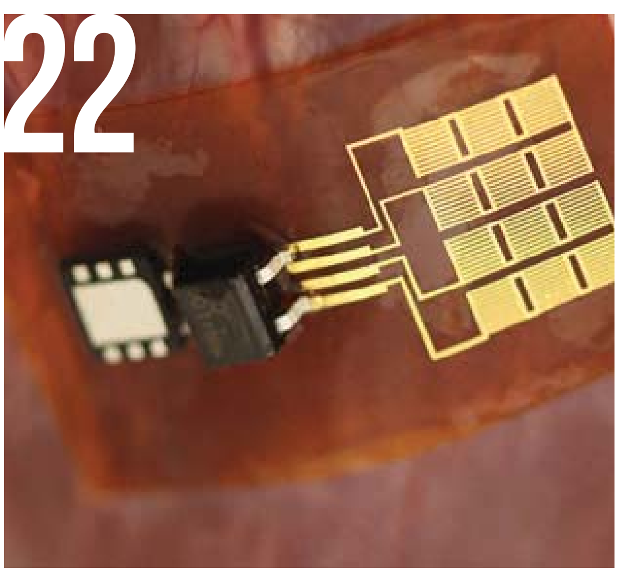

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TRANSFORMERS RESHORED

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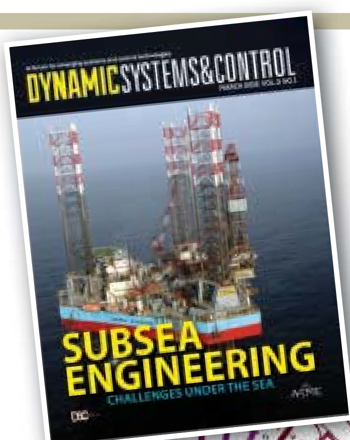

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DYNAMIC SYSTEMS & CONTROL

This issue of the ASME technical division's magazine examines the challenges of deepwater oil production.

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GLOBAL GAS TURBINE NEWS

IGTI's quarterly supplement explores gas turbine cooling flows and celebrates 60 years of Turbo Expo.

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

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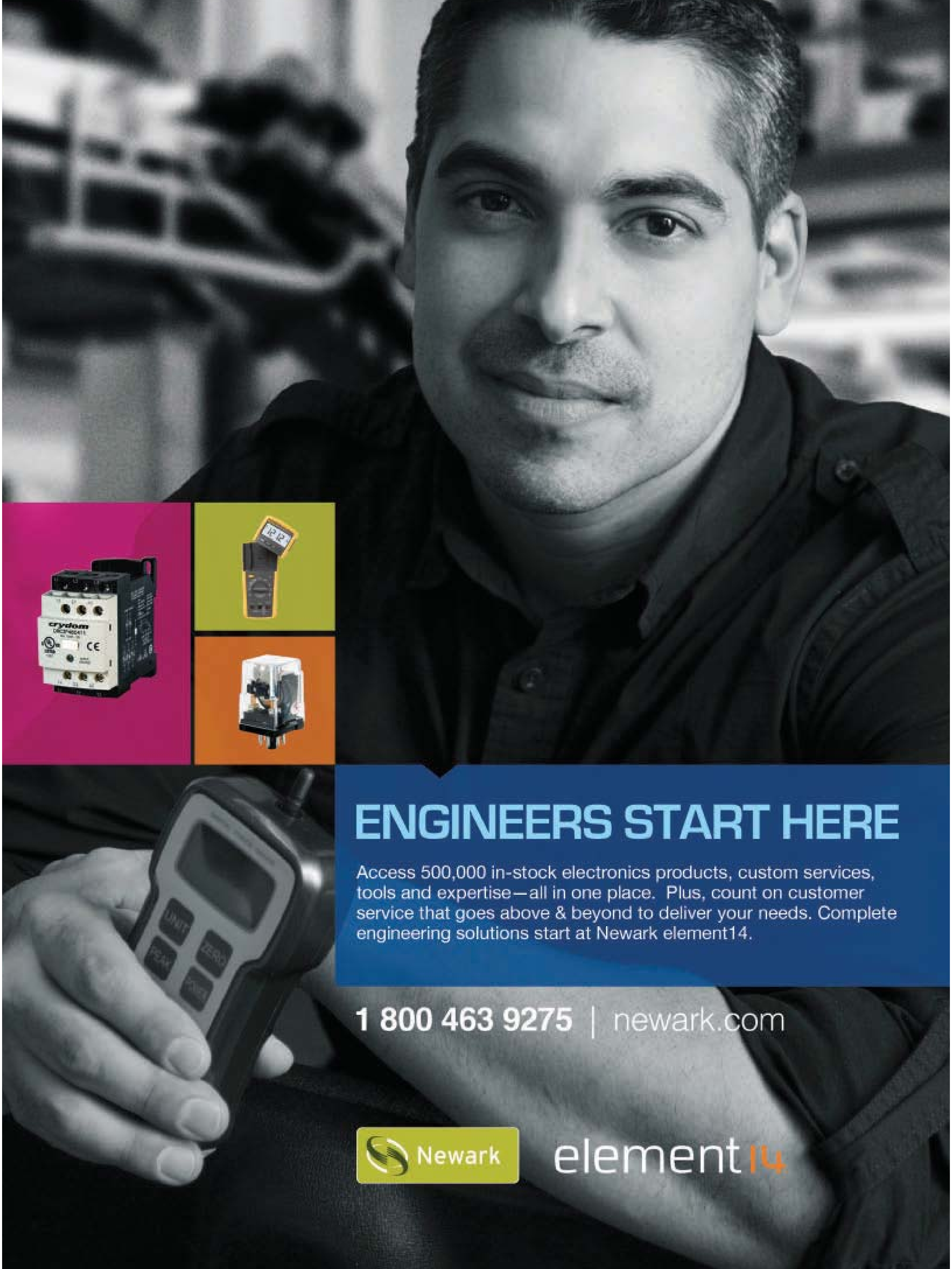
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John G. Falcioni
Editor-in-Chief

NEW WAYS TO SKIN A CAT

With apologies to cat lovers everywhere, time and again we see proof that there is more than one way to skin a cat. One example is in the innovative way new technologies have redefined oil production and the entire industry.

Until recently, the price of oil was controlled by the Organization of Petroleum Exporting Countries, which gave a handful of oil-producing nations geopolitical leverage over the rest of the world. But several new occurrences, including the shale oil revolution in the United States, have dramatically altered the global energy landscape. For now, there is a "new oil order" spurred by technologies that have proven to be transformational. Horizontal drilling and hydraulic fracturing have pushed U.S. oil output to its highest level since the 1980s.

OPEC now is afraid that demand for its crude will keep falling as North American supply grows and makes its way to the global markets as U.S. export barriers fall.

Hydraulic fracturing is one reason for the shift—and some of the leading experts on the technology will convene at ASME's Hydraulic Fracturing 2015 conference in Houston this month (visit asme.org for details)—but the process of extracting oil this way has not been met with universal endorsement.

Critics mostly worry about water. Contributor Mark Crawford points out in this month's cover story, beginning on page 30, that a typical hydraulic fracturing job requires between 2 million and 5 million gallons of water per well. The problem that emerges from this is twofold. First there's the issue of depleting groundwater resources, and then there is the fear that the chemical alchemy that is poured into the water to reduce friction and the growth of bacteria and corrosion will pollute local aquifers.

A solution may be in sight as some companies have found ways to "frack" with less water or no water at all. But Crawford reports that less than 3 percent of the fracturing jobs in the U.S. are waterless. That could change if U.S. companies take a page out of Canada's playbook, where about 25 percent of the fracturing jobs use waterless processes.

Technologies such as hydraulic fracturing are evolving as engineers continue to search for better ways to extract oil, build up supply, and reduce reliance on OPEC. To me that's an example of using technology innovation to re-skin a time-worn economic model.

A sad note...

Robert E. Nickell, the long-time chair of the *Mechanical Engineering* Magazine Editorial Advisory Board, an ASME past president, a devoted and engaged volunteer of the Society, and a friend, passed away due to complications related to a recent battle with cancer.

Nickell's contributions to ASME and to global safety standards cannot be overstated. He was a man whose intellect was matched only by his leadership, his wisdom, and his passions. He was passionate about his family and his friends, as well as his beloved profession and ASME.

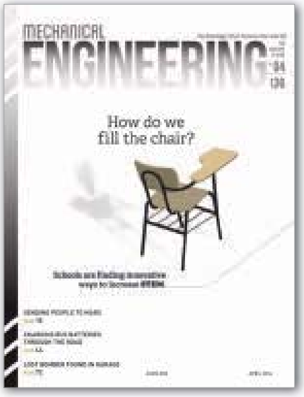
It is often a cliché to say that one individual truly touched many lives. In the case of Bob Nickell, the statement could not be more fitting. Those of us who knew him feel a deep personal loss. To read more about Bob visit asme.org. ME

FEEDBACK

Tell me what you think about hydraulic fracturing. Email me.

falcionij@asme.org

LETTERS & COMMENTS



APRIL 2014

Reader Cameron questions the value of solar power.

« One reader raises questions about global warming. Another extols the virtue of clear writing. And Disney is praised.

DISNEY'S CAROUSEL

To the Editor: I loved the reference to Walt Disney's Carousel of Progress in your December 2014 editorial. My wife and I were on it (again) recently at Walt Disney World.

We have loved Disney for decades, and the old attractions still provide a lot of pleasure. I still marvel at the science and engineering of the technologies shown in the Carousel of Progress, as well as the engineering that went into Disneyland and Walt Disney World.

Brad Buecker, *Lawrence, Kans.*

THANKS FOR THE INFORMATION

To the Editor: I have to thank you and *Mechanical Engineering* magazine for the quantity and quality of the articles I have been reading and saving related to electric energy generation, high temperature materials, QA/QC inspections, and of course gas turbines/jet engines over the last few years.

Even though I am semi-retired the last two years (only work 20-25 hours per week!), I still greatly enjoy all the new things I am learning from *ME* magazine.

Keep up the good and enlightening effort.

Ron Natole, *Houston, Texas*

NO TRUST IN EXPERTS

To the Editor: Congratulations to Tom Parrish (Letters & Comments, August 2014) for pointing out important points in the ongoing argument over "climate change."

First, it is indeed interesting that the supporters of this issue have quietly renamed it from the intimidating "global warming" to the more palatable "climate change." The name changes but the crusaders stay the same.

I am prepared to accept whichever side of the argument turns out to be correct—based on convincing scientific evidence. So far I have yet to see anything that rises above the level of "trust me, I'm a trained expert."

The problem is not whether the earth is warming up, cooling down, melting down, or drying up. Any and all may be possible and one may even be happening as I speak.

The problem is that we really do not know. The problem is too big to be amenable to reliable modeling and prediction. It took a comedian on the Blue Collar Network just this week to make the point. He said that you can identify scientific statements because they invariably contain words like "probably" or "likely." Real science is modest in its claims.

Bill Bryson's account of the history of science, cited by Mr. Parrish, is full of examples of the scientific establishment, meaning the college of self-appointed "experts," being wrong and a minority, or even a solitary heretic, turning out to be right. Can you say Galileo? The fact is that science is not a majority vote and 97 percent of voices in support of a position do not make it true.

A study was conducted some years ago to test the reliability of alleged pundits and experts. These are people in the public eye who gain reputations by predicting future events that are too massive to evaluate in their entirety, and therefore rely on healthy doses of interpretation to fill in the gaps.

More than 8,000 predictions that had been given time to mature, made by about 280 of these individuals, were examined. The success rate was less than 50 percent.

As yet "climate change" advocates simply don't know enough to be so sure, and their certainty is a pointer to how wrong they might be. The truth is that they don't know.

Douglas L. Marriott, *South Lebanon, Ohio*

CONCENTRATING ON COSTS

To the Editor: Thank you for the concise presentation on CSP in "By the Numbers: Concentrated Solar Power Makes a Comeback" (Trending, April 2014). However, I am "confused" by "the numbers."

CSP was listed as somewhere between 1.9 and 3.7 times more expensive than the other technologies, although "[the] industry claims that the newest CSP plants produce power for as little as 13 cents/kWh.," or only 1.4 to 1.9 times more expensive than the other non-solar technologies.

The variable in the equation that I completely don't understand is whether the costs quoted already include the value of the last statement in the article: "if subsidies for CSP continue."

Maybe we could even pay them for all the electricity with enough subsidies. If we taxpayers offer enough subsidies for the technology, will they reach 0¢/kWh?

What is the wean-off timeline for the subsidies for solar (PV & CSP)? How are the subsidies comparable for fossil fuel scrubbing costs and advanced fossil technologies such as coal liquefaction? How are the subsidies comparable for nuclear programs to burn the spent fuel on-site at the plant rather than trucking it thousands of miles to throw it in a hole?

I am completely in favor of researching new technologies and I believe that many renewable technologies, including CSP, may prove viable and should be subsidized through its research phase until it is matured enough for commercial release.

Jay Cameron, P.E. *Agawam, Mass.*

COMMUNICATING VALUE

To the Editor: The letters "Basic Foundation" by Marion Leithead and "Language Challenge" by William Vanek in the November 2014 issue struck several chords, or notes at least, and refreshed my concerns based on some anecdotal evidence from my past.

I have three degrees in mechanical engineering and have been regarded by colleagues over the years as a pretty good engineer. For years, however, many people who do not know my background have questioned whether I really am an engineer. Why? Because I am able to communicate and talk about things other than engineering (I minored in history). And I am able to write reasonably well.

When I suggest corrections to other people's work, however, I am frequently met with the same reactions that Mr. Vanek has received. Not from my children, however. They frequently asked for my help in polishing their writing throughout their school years, including graduate school, because I was adding value to the skills they learned in school.

In another career, as a lecturer in mechanics at the university level, I have encountered a number of students whose basic geometry and trigonometry skills were woefully inadequate because they had been rushed through those courses in high school so that they could "move on" to calculus. This university has high entrance standards; the entering students tend to be at the top of their secondary school classes, yet they lacked functional math skills.

When one has to recommend the purchase of books such as *Trigonometry for Dummies* and *Geometry for Dummies* (no disparagement of those books is intended) to acquire those skills in the middle of studying college level engineering, I feel that something is terribly wrong with our educational system.

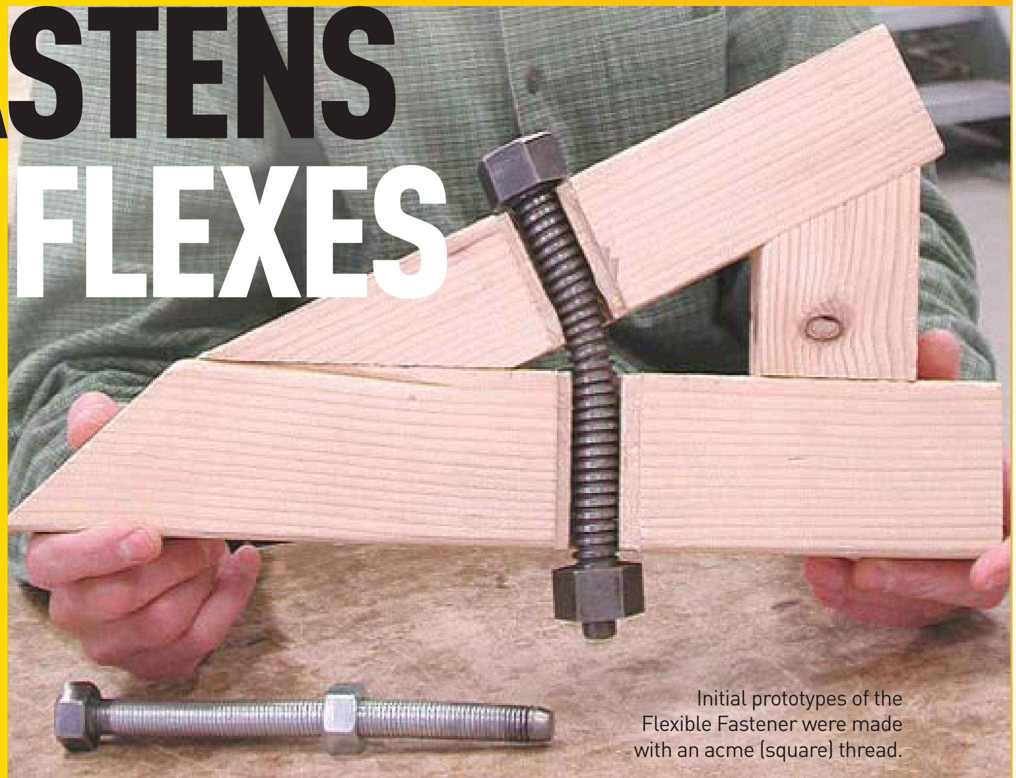
We need both sets of abilities, language and science, to succeed and our educational systems need to realize both of those skills in our students to the best of their ability. And our students need to understand why both are important.

As I tell my engineering classes, if you can't communicate the results of your work effectively, it has lost a great deal of its value. Poorly written material is a real turnoff and tends to diminish the perceived value of the content. As Mr. Vanek says, "We can do better."

Charles Innis, Life Member, *Paxton, Mass.*

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.

IT FASTENS AND FLEXES



Initial prototypes of the Flexible Fastener were made with an acme (square) thread.

Image: Dennis Steers/Cal Poly College of Engineering

IN THE WORLD OF NUTS AND BOLTS and other mechanical fasteners, things are usually flat, parallel, perpendicular, and rigid, just the way engineers like it. But a professor at Cal Poly in San Luis Obispo has disrupted that notion.

Saeed Niku, a professor of mechanical engineering at California Polytechnic State University, working with students in one of his classes, has developed the Flexible Fastener, a bolt designed to bend.

At the heart of the fastener is a shank made of a strong, yet flexible material such as Kevlar, nylon, steel cable, or wire rope. Threads made of steel coiled like a spring wrap around the core and are bonded to it along the length and at each end, along with a head at one end.

The fastener is "axially rigid but laterally compliant," Niku said. "You can tighten the screw like any screw, but it can also move sideways." It can carry axial loads yet is flexible enough to connect non-parallel surfaces, go through mismatched or misaligned holes, or handle machine applications where small lateral movements are required.

The idea for the Flexible Fastener came from a project in Niku's Philosophy of Design class in 2000. Three students were working on a project where there was a question about putting screws into the wooden frame of California houses for earthquake protection. They wanted to bolt the houses to the foundation. Niku came up with the idea for a flexible bolt, and the students took it and made samples.

After the class ended, Niku took over the project and refined the design. The National Collegiate Innovators and Inventors Alliance and the Lemelson Foundation Initially funded the effort.

The Flexible Fastener can be made in many different sizes, from as small as 3/16 inch in diameter to as large as desired. According to Jim Dunning, program manager in Cal Poly's Office of Research and Economic Development, which engages industry through the California Central Coast Research Partnership, the fastener can be manufactured to various degrees of rigidity.

Niku said the fastener can be used with "anything basically that is not parallel or aligned or needs to move sideways." In construction, it can attach parts with non-parallel surfaces without a need for countersinks, as in a truss. It can be used in repairing and refurbishing products and structures where holes do not line up or are misplaced. You can actually just bend a screw into the non-parallel surfaces and attach them.

It can also be used in robotics applications where simultaneous lateral compliance and axial stiffness is desired, as in attaching a fixture to the robot that can move sideways for assembly. Similarly, the fastener can be used in medical applications such as in artificial knees, where bending is desired between different parts while they remain attached or where you need to move sideways because the holes don't match. And Dunning adds, "An application I always have in mind is a seismic retrofit project." The bolt's lateral flexibility allows whole structures to flex to better withstand the jolt of an earthquake.

Niku received a patent on the Flexible Fastener in 2005, and now the Research Partnership, known as C3RP, is attempting to license it. "We seek a partner willing to invest the time and tooling to find out exactly what the optimum manufacturing would be," Dunning said. **ME**

TOM GIBSON, P.E. is a consulting mechanical engineer specializing in machine design and green building, and a freelance writer. He publishes Progressive Engineer, an online magazine (www.ProgressiveEngineer.com).

RENEWABLES COMPETE WITH FOSSILS

RENEWABLE POWER GENERATION HAS LONG BEEN confronted with detractors, who assert that solar, wind, geothermal, and other carbon-free power sources are impractical, intermittent, and expensive. Better to stick with coal-fired plants, they say, than to risk having the lights go out.

Recent advances have not eliminated calm days or brought sunshine to the dead of night, but one concern is being addressed: Most forms of renewable power generation are now cost-competitive with fossil-fuel burning power plants, and those that are still too expensive have costs that are falling fast.

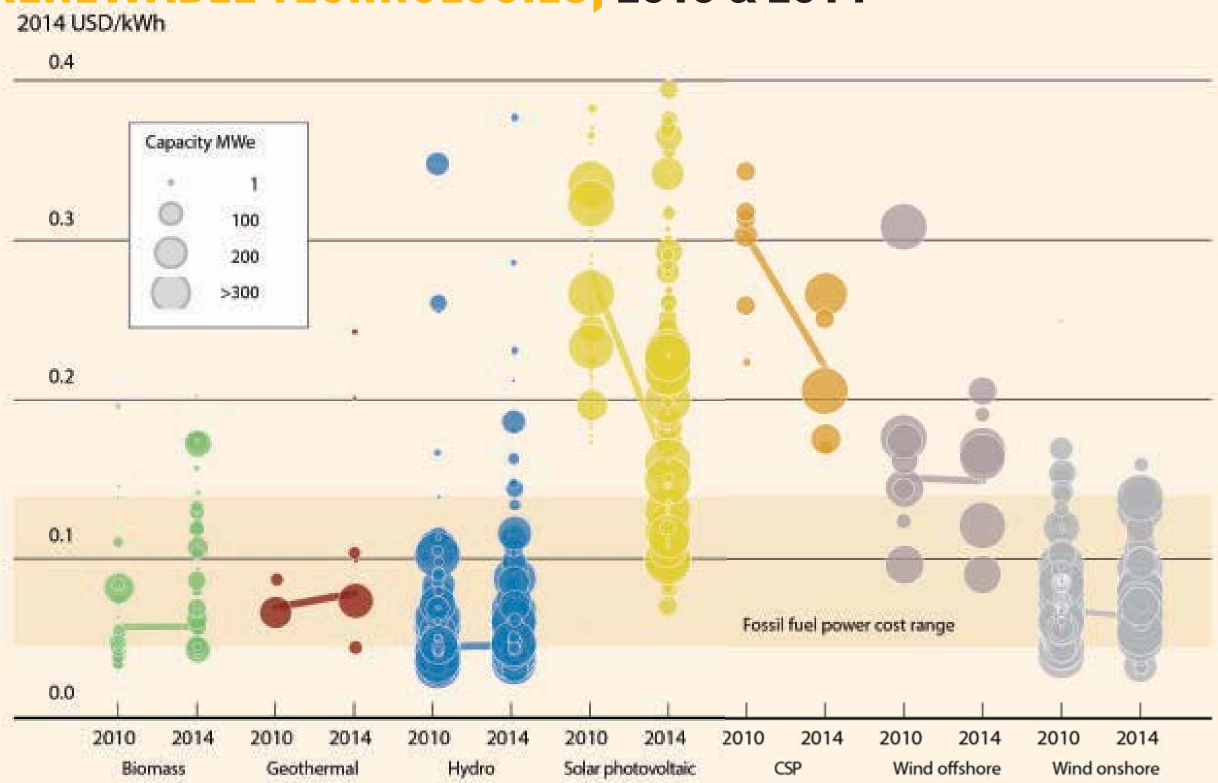
These results form the backbone of *Renewable Power Generation Costs in 2014*, a report published in January by the International Renewable Energy Agency, an intergovernmental organization based in Abu Dhabi. The organization has more than 130 member countries.

According to the report, "Regional, weighted average costs of electricity from biomass for power, geothermal, hydropower, and onshore wind are all now in the range, or even span a lower range, than estimated fossil fuel-fired electricity generation costs." Electricity from photovoltaic panels is also becoming less expensive, with the cheapest installations about on par with many fossil fuel power plants.

"Given the installed costs and the performance of today's renewable technologies, and the costs of conventional technologies," the report continued, "renewable power generation is increasingly competing head-to-head with fossil fuels, without financial support."

The report used a range from 4.5 cents to 14 cents per kWh for the levelized cost of electricity from fossil fuel sources. continued on p.15 »

THE LEVELIZED COST OF ELECTRICITY FROM UTILITY-SCALE RENEWABLE TECHNOLOGIES, 2010 & 2014



Source: IRENA Renewable Cost Database.
Note: Size of the diameter of the circle represents the size of the project. The centre of each circle is the value for the cost of each project on the Y axis. Real weighted average cost of capital is 7.5% in OECD countries and China; 10% in the rest of the world.

BATTERIES FOR MANAGING THE GRID

5-megawatt, lithium-ion energy storage system at Portland General Electric's Salem Smart Power Center in Salem, Ore.
Image courtesy of Portland General Electric.

Cost and limited manufacturing capacity of have kept utilities from committing to the use of batteries for large-scale electrical storage. Now, a Texas electric distribution utility is stepping out with a plan to spend up to $5.2 billion on batteries to back up its transmission and distribution grid and reduce power fluctuation from renewable power sources. In a study it performed to justify the plan, Oncor Electric Delivery claims the move would lower consumer electric bills and preclude costly construction of new power plants.

But there is a catch: In Texas, distribution utilities such as Oncor are prohibited from owning power plants, and state lawmakers, who de-regulated the industry 12 years ago, would have to amend a law defining batteries as power producers. Oncor officials are pushing for legislation to be introduced for the change, but opposition is already brewing from power producers, including sister companies of Oncor.

Still, the proposal shows a growing confidence in the viability of lithium-ion batteries for large-scale energy storage. A study done by Navigant Research, a market research company specializing in clean technology, shows grid energy storage jumping to 20,800 MW by 2024, from 538.4 MW this year. The report predicts that revenue will grow to $15.6 billion annually, from $675 million.

For Texas's state-wide grid, according to a study performed for Oncor by the Brattle Group, an economic and financial consulting company, 3,000 MW to 5,000 MW of grid-integrated storage would be the most cost-effective solution, based on installed cost of storage of $350 per kWh. Other analysts believe the price of batteries will drop by half over the next seven to eight years, to $230 per kWh.

> **"AFTER SEVERAL YEARS OF FALTERING GROWTH, LITHIUM-ION BATTERIES ARE EMERGING AS THE BREAKOUT TECHNOLOGY."**
>
> **— NAVIGANT RESEARCH**

The price reduction is expected to come from economies of scale, and a lot of that is tied to Tesla Motors' $5 billion "gigafactory" in Reno, Nev., which is projected to open in 2017 and to churn out batteries for 500,000 vehicles per year. Tesla has said about 30 percent of production would be for utility-scale batteries.

The plant also will produce batteries that can be used with rooftop solar systems to store power. SolarCity Corp., a sister company of Tesla (both led by engineer and entrepreneur Elon Musk), is offering solar panels packaged with lithium-ion batteries for sale to California homeowners and companies.

Oncor executives will not comment on their plans, but have said in published reports they expect battery prices to be competitive by 2018. A spokeswoman says Oncor does not have a detailed plan in place, but batteries would be installed across the entire state-wide grid, not only in its service area. The state's grid has a capacity of about 81,000 MW.

For the plan to work, the Brattle report claims the batteries must be installed across the entire grid.

"Considering both the impact on electricity bills and improved reliability of grid-integrated storage, customer benefits would significantly exceed costs," said Judy Chang, the lead author of the study. "However, while beneficial from an integrated system-wide perspective, an efficient scale of storage deployment would not

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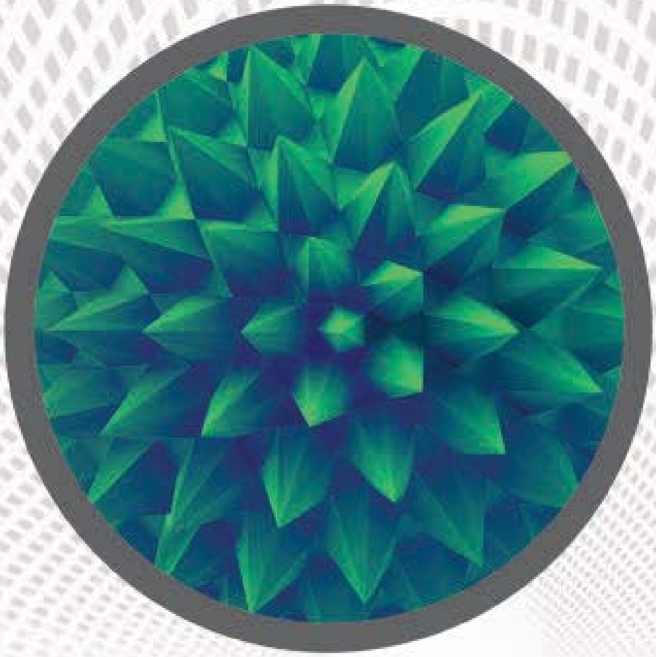

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BATTERIES: FOR THE GRID

be reached if deployed by merchant developers who rely solely on participation in the wholesale market, or by retail customers who use it solely for backup power, or by wire companies who deploy it solely for capturing [transmission and distribution] benefits. These entities, independently and separately, will not be able to capture the full value of the storage to viably support the magnitude of investment."

The U.S. Department of Energy lists Texas as the state having the most installed capacity from wind turbines, at 12,976 MW. Sparsely populated West Texas is a natural spot for wind machines. But wind, along with solar systems, produces power intermittently, and feeding it into the grid efficiently presents operational problems. The state also is seeing increasing investment not only in utility-scale solar systems, but in smaller rooftop systems. Oncor officials believe batteries will provide an efficient way of managing distributed loads and storing energy until it is needed.

Other states are pursuing batteries as well, and Navigant researchers believe the market is on the threshold of growth. "The grid-scale energy storage market continues to develop in a piecemeal fashion, but there are signals it is poised for significant expansion in the coming years," wrote Anissa Dehamma, a Navigant senior research associate. "In particular, after several years of faltering growth, lithium-ion batteries are emerging as the breakout technology in this sector."

As Oncor pursues its plan in Texas, state officials in California also are pushing utilities to embrace the technology. In 2013, state power officials formalized plans for California utilities to build 1,300 MW of storage capacity by 2020. Southern California Edison, one of the state's investor-owned utilities, recently announced it had signed contracts for 250 MW of storage, including batteries. ME

JOHN KOSOWATZ, ASME.ORG

STEM IN CAMBODIA

AN ORGANIZATION IS helping to improve the way Cambodian schoolchildren learn about science and engineering.

The firm, Advancing Engineering Consultants of Dover, Del., guides infrastructure building projects in Africa and Southeast Asia. Now it shares some of the basics of its work as hands-on lessons and a book for school kids in Cambodia.

Reaching students at a young age and providing an introduction to engineering concepts is one of Advancing Engineering Consultants' methods for local capacity building, said Bryce Gaboury, the cofounder and managing director of the firm.

Capacity building is the efforts to train people on how to operate, maintain, repair, and build machines to meet their basic needs.

The firm works with many different non-governmental organizations in Cambodia to expose children and students to various types of engineering careers through hands-on workshops, he said.

"We go around and do several engineering workshops every year where we present the book, then do some hands-on activities like building a bridge out of straws, a small flashlight, etc." Gaboury said. "The kids make things like hot air balloons and structures that float in tubs of water."

The book, "Buildings and Bridges," illustrates the basics of engineering in full color, with real-world examples, he said. The books are left with the kids after the workshops, he said.

The firm also works with several canal rehabilitation projects in Cambodia through the USAID Harvest Project.

"AE believes that engaging the local community in projects like this is integral to the project success and the development of the community," Gaboury said. ME

ENGINEERINGFORCHANGE.ORG

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RENEWABLES COMPETE WITH FOSSILS

Using data from installations around the world over the past five years, the authors of the report looked at the cost of electricity from seven kinds of renewable power: Biomass, geothermal, hydro, solar photovoltaic, concentrated solar thermal, onshore wind, and offshore wind. The levelized cost of electricity from biomass and hydropower—longstanding renewable sources—were at or below that of fossil fuel power.

Wind power costs have also remained steady, the report stated, with the best wind projects delivering electricity at around 5 cents per kWh. China and India had the lowest wind costs, while projects in Brazil were the most expensive.

Perhaps the biggest development over the past five years has been in solar. The levelized cost of power for residential systems fell by half between 2010 and 2014, and according to the report, "The most competitive utility-scale solar PV projects are now regularly delivering electricity for just 8 cents per kWh without financial support." The report predicts that, by 2025, both residential and utility solar power projects will achieve cost parity with fossil power plants.

Renewable energy may still present problems with grid managers, but nothing so great to preclude its use. "There are no technical barriers to the increased integration of variable renewable resources, such as solar and wind energy," the report said. "When the local and global environmental costs of fossil fuels are taken into account, grid integration costs look considerably less daunting, even with variable renewable sources providing 40 percent of the power supply. In other words, with a level playing field and all externalities considered, renewables remain fundamentally competitive." ME

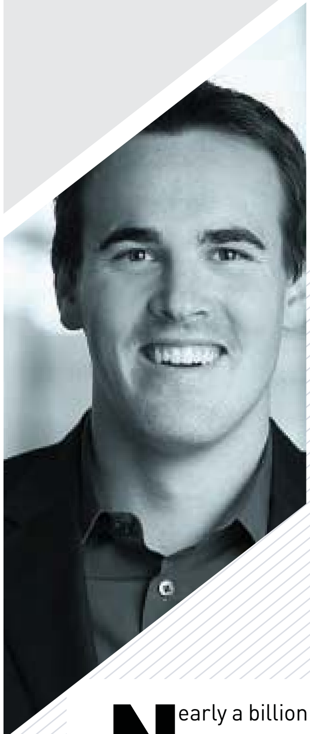
EPA DELAYS CARBON RULES FOR POWER PLANTS

The U.S. Environmental Protection Agency will delay the implementation of rules aimed at curbing carbon emissions from power plants.

EPA will issue final rules under a combined process by "mid-summer," said Janet McCabe, acting assistant administrator for the agency's Office of Air and Radiation.

According to a fact sheet, "Clean Power Plan and Carbon Pollution Standards," the EPA is asking states to submit compliance plans in the summer of 2016. There are provisions for one- and two-year extensions, and the proposed beginning of the compliance period is 2020.

The agency said it will write a separate implementation plan for states that have threatened to refuse to submit their own. ME



MAKING GAINS IN RWANDA

It will take new business models, not small donations, **to provide meaningful development.**

Nearly a billion people in the world drink dirty water. Two billion don't have a sanitary toilet. Three billion use campfires every day. Governments and charities spend billions of dollars every year to address these problems. And there are big successes in some places, but more innovation is needed.

In Rwanda, most rural villagers drink untreated water and burn firewood on open stoves. For the past ten years, our team has been learning how to address these challenges. In 2014, we reached nearly half a million people with water filters, improved cookstoves, and extensive health education. In 2015, we are on track to reach another two million people.

In the last three months, we've had a staff of nearly 1,000 working across the western province of Rwanda, a 6,000 square kilometer area, distributing filters and stoves at 400 community meetings and visiting nearly 110,000 homes. Working with the Rwanda National Police and the Ministry of Health, we moved 220,000 products across muddy roads and into homes.

So why Rwanda? Almost 20 years ago Rwanda suffered a genocide that killed nearly a million people. Some may still think of Rwanda as failed state.

In fact, Rwanda today is considered among the least corrupt countries in Africa. It has one of the fastest GDP growth rates in the region, and has the fastest annual decline in child deaths globally. But still, pneumonia and diarrhea remain the leading causes of illness and death among children in Rwanda.

Our company, DelAgua, is a for-profit social enterprise using an innovative funding mechanism to distribute the filters and cookstoves free of charge to the poorest 25 percent of households across the country. Our business model involves United Nations carbon credits—generated from the projects themselves and sold to international buyers. This creates pay-for-performance system where we are incentivized to have an impact because that's how we get paid.

The United Nations carbon credit market is a $120 billion a year industry. More than 90 percent of credits come from just five countries, and less than 2 percent from all of Africa. My team was the first in the world to commandeer this system and apply it to household drinking water.

This approach stands in contrast to a typical approach in poverty reduction programs globally. Typical funders, from church and community groups, universities, all the way up to the U.K. Department for International Development, the U.S. Agency for International Development, and the World Bank, provide funding for projects that are intended to improve the health and livelihood of people in developing communities. These include things like water pumps and water filters, cookstoves, latrines, and solar lighting systems.

This funding usually lasts a couple of years, and during that time the implementers will try to evaluate their impact. If you can afford it, you might run a randomized controlled trial to see if the projects are improving health or other outcomes. But, usually sooner rather than later, the funding runs out, and everyone moves on.

This has resulted in sad statistics. Some estimates suggest that at least half the water programs in some African countries are broken a few years after they're installed.

Our intention is to instead lay the foundations for a long-term presence in Rwanda, making substantial contributions to public health and economic development.

The program, called Tubeho Neza (meaning "let us live well") is a partnership between DelAgua and the Rwandan Ministry of Health. We recruited more than 850 community health workers to manage the distribution and help households with installation and maintenance. This year, we'll be back in nearly every household reinforcing healthy behaviors.

Independent researchers from the London School of Hygiene and Tropical Medicine and Emory University are running a randomized controlled trial and using cellular sensors, household surveys, and other techniques to measure uptake, correct usage, and water and air quality improvements.

Many of us have heard of the idea that a donation of something like $25 will bring water to someone for his or her entire life in a developing country. But $25 donations haven't solved this problem yet.

We need new and better business models, to engage businesses in these challenges, in a way that can help pay for ongoing services. We need payments to be based on performance, and not pictures and promises. ME

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

CHINA OPENS IP COURTS

China has opened three new courts specializing in cases of intellectual property rights, according to Xinhua, the state news agency.

The first court opened in Beijing in November 2014. A second IP court was launched in the southern city of Guangzhou in mid-December, and the third opened in Shanghai at the end of the month.

The Supreme People's Court had proposed the specialized courts and the plan was approved in August 2014 by China's top legislature, Xinhua reported.

According to Xinhua, the intellectual property courts will hear civil and administrative lawsuits regarding patents, new plant varieties, and technological knowledge.

One reason for the courts is the volume of cases. The agency reported that China's courts currently hear more than 100,000 intellectual property rights cases a year, and the number is expected to increase.

The IP court in Beijing, for instance, accepted 221 cases in its first month, Xinhua said. More than 60 percent of the cases are administrative lawsuits regarding brands.

Creating specialized courts is also expected to assure consistency of decisions.

Intellectual property cases in Guangdong, the province where Guangzhou is the capital, accounted for almost 30 percent of the country's total in 2013, an increase from 20.55 percent in 2009, according to Xu Chunjian, deputy head of the provincial Higher People's Court.

According to Xu, the court in Guangzhou will hear intellectual property cases from all over Guangdong Province, except for Shenzhen City, so the whole province will follow the same standard. ME

"Net net, the world is projected to save $1.6 trillion this year on lower oil prices. That's more than $1 trillion going into the global economy."

— **Gary Cohn,** *Goldman Sachs's president and chief operating officer, at the World Economic Forum in Davos, Switzerland*

BYPASSING THE KEYBOARD

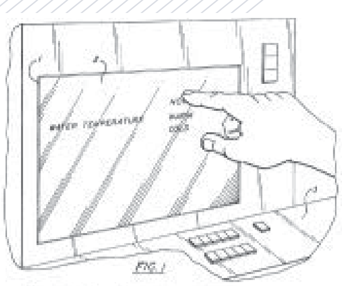
Touch screens and voice recognition are decades old. Now, here come eye tracking and mind reading.

Touch screens are now ubiquitous. They are one of the technologies that my kids were born with but didn't exist, at least commercially, when I was young.

Several sources list the first touch screen patent as No. 3,911,215 dated October 7, 1975, by George Hurst and William Colwell Jr. of Elographics Inc. in Oak Ridge, Tenn. The patent describes two sheets separated by spacers. Each sheet is energized and when a pen touches the top sheet it deflects to touch the bottom sheet producing signals that correlate to the x- and y-coordinates of the pen.

That same patent, though, reveals that a 1972 patent (No. 3,632,874) describes basically the same idea. Another patent, No. 3,482,241 dated August 2, 1966, has an abstract which reads:

"A plurality of touch-sensitive contacts, placed adjacent the screen of a cathode ray tube, which may be selectively actuated for indicating which portion of the image on the cathode ray screen is to be examined in further detail. The position of the actuated contact with respect to the viewing screen indicates which portion of the image has been selected to an output means such as a data processing system. Either resistance change or capacitance change across the actuated contact may be sensed."



IT'S OK TO POINT

An early capacitive touch screen that was sensitive to pressure of a human finger was the subject of Patent No. 4,233,522, issued to GE in 1980.

A capacitive touch screen patent, No. 3,593,115, was issued to IBM on July 13, 1971, but the stylus had to be wired to an output device. A capacitive touch screen which reads finger position is disclosed in GE Patent No. 4,233,522 dated November 11, 1980.

Then came gesture recognition.

IBM Patent No. 5,252,951 (October 12, 1993) is entitled "Graphical User Interface with Gesture Recognition in a Multiapplication Environment." Synaptics Inc. won Patent No. 5,543,591 in 1996 for methods of recognizing a tap, double taps, and other gestures on a touch screen.

That brings us to Apple's Patent No. 7,469,381 (December 23, 2000) for the "slide to unlock" and "bounce back" display features of the iPhone. This was one of the patents used in the smart phone patent wars along with design patents covering the minimalist design of the iPhone touch screen.

Someday the touch screen may be fully superseded by voice recognition, finger or hand waving, or even eye movement. All of these technologies, of course, are already the subject of numerous patents and pending patent applications.

An early voice recognition patent is No. 2,575,909 (1951). A recent eye tracker example is Google's Patent No. 8,510,166. You wear glasses (Google Glass?) with a video camera and an eye tracking camera. Back at Google, they can tell what you fixate on in each scene you come across. Scary.

Even scarier, read the mind-machine interface patents like No. 7,187,967 by Neural Signals Inc. The abstract of the patent reads, in part, "a system and method for capturing a neural signal inside a patient's skull, transmitting it to a remote receiver, and using it to control an application." I wonder if it works in reverse.

Sometime in the not too distant future, according to futurist Ray Kurzweil, there will be no need for any kind of computer interface because we will be the computer and it will be us. Kurzweil now works at Google. Is he right? Maybe.

I'm almost certain my children's children will not know what a keyboard is and their children will probably only know of touch screens from visits to a museum. Don't touch! ME

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

CARBON CAPTURE TEST PASSES MILLION-TON MARK

The U.S. Department of Energy has reported that a carbon capture and sequestration demonstration in Illinois has stored one million metric tons of carbon dioxide in a deep saline formation.

The demonstration, known as the Illinois Basin-Decatur Project, is operated by the Midwest Geological Sequestration Consortium, with funding from the DOE.

Carbon dioxide is captured from an ethanol-production facility operated by the Archer Daniels Midland Co. in Decatur, Ill. The gas is compressed before traveling across a mile-long pipeline and injected approximately 7,000 feet below the surface into the Mount Simon Sandstone formation.

Partners include Gallagher Drilling Co. and Schlumberger Carbon Services.

The injection test began in November 2011 and has performed better than expected, sustaining pressure increases well below regulatory limits, the DOE said. Over the course of 100 years, the injected carbon dioxide is projected to remain hundreds of feet below a 300-foot-thick shale formation that will act as a seal and inhibit upward migration of the CO_2.

The project is part of the development phase of the Energy Department's Regional Carbon Sequestration Partnerships initiative, which is helping develop and deploy carbon capture and storage technologies across the country.

The Midwest Geological Sequestration Consortium, led by the Illinois State Geological Survey, is evaluating CCS options for the 60,000-square-mile Illinois Basin, which underlies most of Illinois, southwestern Indiana, and western Kentucky. ME

INSTITUTE TO FOCUS ON COMPOSITES

The Department of Energy and a consortium of 122 companies, nonprofit groups, and universities led by the University of Tennessee-Knoxville will invest more than $250 million to launch a Manufacturing Innovation Institute for Advanced Composites in the Knoxville area.

The federal government will provide $70 million, and the balance of funding—more than $180 million—will come from other sources.

It is the fifth institute under the National Network for Manufacturing Innova-

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Q&A URSULA BURNS

WHEN URSULA BURNS WAS APPOINTED CEO of Xerox Corp. in 2009, she became the first African-American woman to lead a Fortune 500 company. And she has transformed Xerox into a thriving, profitable international services provider. Burns holds a bachelor's degree in mechanical engineering from Polytechnic Institute of New York University and a Master of Science degree from Columbia University. She received ASME's 2014 Kate Gleason Award, which recognizes female entrepreneurs and achievers in the field of engineering.

ME: Was there a project or achievement that you are particularly proud of?

U.B: I spent the first 15 years of my career in an engineering lab. One of my first projects involved replacing high-speed rotating aluminum discs with glass to save a manufacturing step. I worked with my lab partner for almost four years, and we did it. It gave me a big feeling of accomplishment when Xerox applied it to a product, and taught me how to stick with one thing for a long time.

Other accomplishments involve solving customer problems and transforming Xerox's business to a service-based model. I am proud of bringing people together to work on those problems. Bringing together good minds of different types from different backgrounds to attack a problem is something that engineers are unbelievably good at.

ME: Were there things you had to learn or unlearn to go beyond your technical training?

U.B: Many. One of the most interesting was how to deal with people who are not engineers. Engineers have an organized, process-based approach to projects. They believe most problems can be solved with smart people and hard work. Those attributes are not native to all disciplines, yet I had to learn how to include those disciplines in the problem-solving and leadership process.

ME: Was the move from engineer to business leader difficult?

U.B: We have to stop looking at the transition from engineering to business as an odd occurrence. If you are a successful engineer, you can become a successful contributor in business, academia, or anywhere else. The roads don't part, they come together more naturally. I never thought of them as different.

ME: What inspired you to pursue mechanical engineering as a career?

U.B: My mother spent a lot of time and the little money she had in making sure we had the best education. For us, that meant the local Catholic school. It didn't have a broad education. It was primarily reading, writing, basic arithmetic, and a lot of discipline. When it came time for me to go to college, my guidance counselor told me I could be a teacher, a nun, or a nurse. With my mother's pushing, I decided to research what people who like math could do for a living.

ME: And that was mechanical engineering?

U.B: At that time, the number one career for people with math training was chemical engineering. I tried it, but changed to mechanical engineering after my first semester. It put together a lot of practical things and I loved it. The long and short of it is that I lucked into mechanical engineering.

ME: So, you "lucked into" your career? Do you think there are better ways to involve students in STEM?

U.B: I call it celebrating and inspecting what we expect. We should celebrate the breadth of contributions that engineers make to society. We celebrate sports people, politicians, actors, and actresses, so why not engineers? We also have to fundamentally change the educational structure. First, we need better educators, particularly in primary and middle schools. Second, we need a curriculum that's more up to speed with technology and kid's interests. Third, we absolutely must have parents or adults who can open up options for kids, show them what engineers do and put them onto that path.

ME: What advice would you give to women who want to be leaders but struggle to balance work and personal life?

U.B: I think it's a fool's folly to think we can actually balance, in any short period of time, the many things that are on our plate. I think about balance not in days or weeks, but over a lifetime. We have to slow down, particularly women who have been taught to overachieve in every single endeavor. They believe they have to be outstanding every single day at being a parent, spouse, and contributor at work. If you are trying to do that, you are going to crash and burn, and very likely not be outstanding at any of it. This is true for men as well. **ME**

WAVE ENERGY DEPENDABLE, STUDY SAYS

ONE OF THE ONGOING knocks against renewable energy sources—intermittency—doesn't apply to wave power systems.

Scientists inspect a wave power research buoy off the coast of Oregon.
Photo credit: Pat Kight, Oregon State University

Unlike coal or nuclear power plants, which can run all day every day, wind and solar power stations must be opportunistic. And because of their inherent unreliability, such plants must be backed up by stand-by generating plants or massive amounts of energy storage.

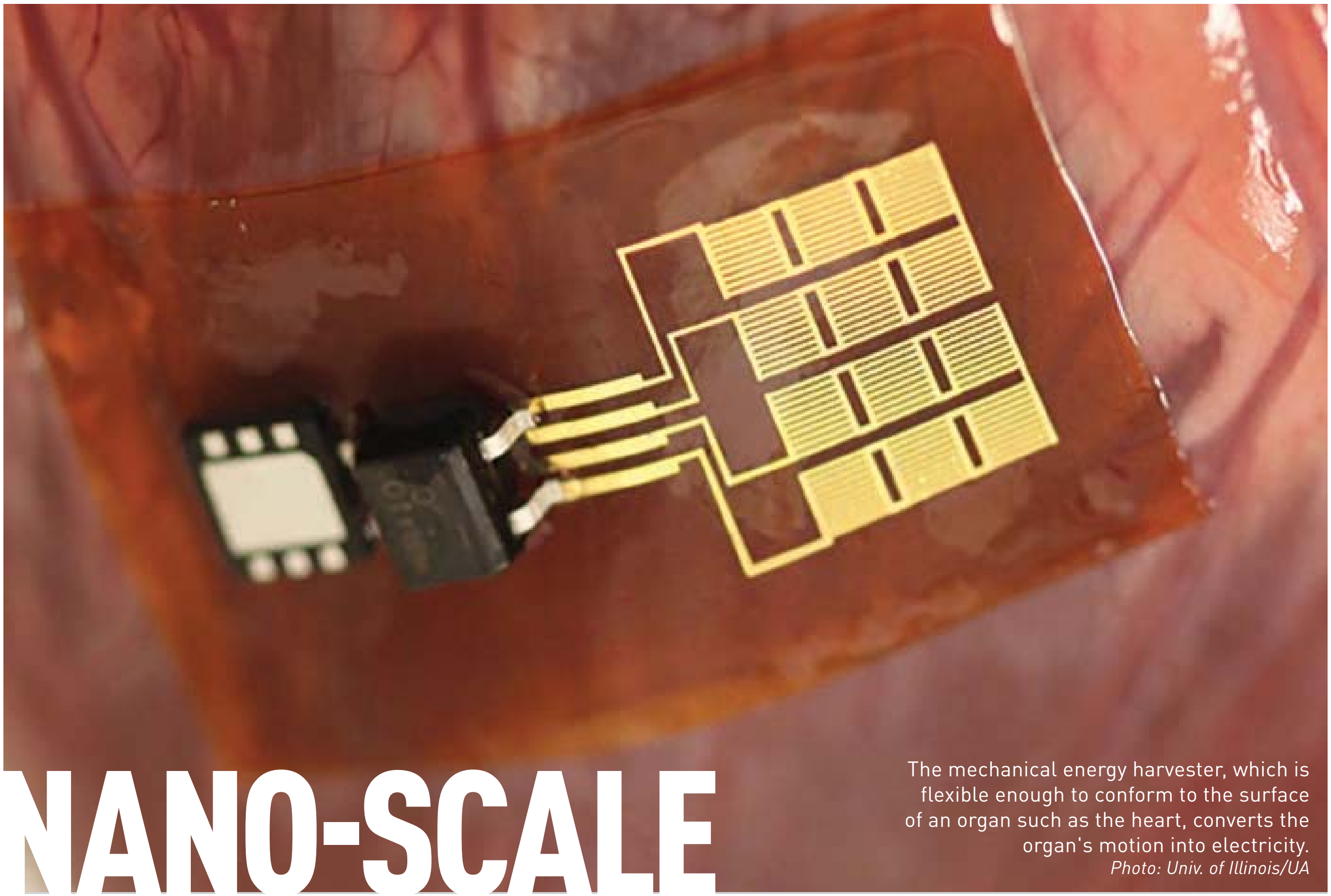
But not every renewable energy source is so unreliable. According to a recent analysis in the journal *Renewable Energy*, wave energy systems, which capture some of the power embodied in ocean waves, should provide a steady source of electricity that can be integrated easily into the power grid.

The study, led by Simon Parkinson of the Institute for Integrated Energy Systems at the University of Victoria in British Columbia, looked at how large-scale ocean wave energy developments in the Pacific Northwest would affect the operation of the electrical grid there. There are no commercial wave energy facilities operating in the region right now, but ocean conditions there are considered to be perfect for deploying wave power systems.

The analysis studied how a hypothetical addition of 500 megawatts of generating capacity, comparable to around five large wind farms, could be added to the grid. The researchers used data from several points along the Washington and Oregon coast to provide a forecast for how much wave energy would be available, and how that would change from minute to minute and hour to hour.

It was found that by placing wave energy arrays at many places, the short-term variability was reduced. That made it easier for grid operators to know how much electricity they could expect. According to Parkinson and his co-authors, "When modeled within the operational structure of the region's primary balancing area authority, large-scale wave energy is found to provide a relatively high capacity value and costs less to integrate than equivalent amounts of wind energy."

Much research has been done into developing wave energy technologies. Some estimates place the potential wave energy resource to be 2,000 GW worldwide. **ME**



The mechanical energy harvester, which is flexible enough to conform to the surface of an organ such as the heart, converts the organ's motion into electricity.
Photo: Univ. of Illinois/UA

NANO-SCALE TRANSDUCERS

IN AN AGE WHEN EMBEDDED SENSORS and actuators are creating "the Internet of things," nano transducers are helping to put humans back into the equation. This month, we look at how one lab uses a patient's own heart, lung, and diaphragm movement to create piezoelectric charges that may one day power pacemakers. And another lab uses sensors to measure human-machine system performance in the automotive field.

Pacemakers are critical pieces of medical technology, but they require battery changes once every six years. A new class of implanted nano transducers may eliminate that problem. Developed by a team led by Canan Dagdeviren, at the time a doctoral candidate at the University of Illinois, these piezoelectric ceramic nano materials could enable future pacemakers to convert the body's autonomic physical motion to electrical power by bending and stretching through direct contact with the beating heart, rising diaphragm, or expanding lungs.

The transducers could also use voluntary muscle motion to power an externally mounted monitoring device.

The development of the new device family has specific benefits for heart patients. Such a device could not only end the need to surgically replace pacemakers when their batteries grow weak, but could ultimately make them affordable and practical to a much larger global population who may be able to afford the costly procedure only once.

"The motion of the human heart normally generates energy, but this simply

HEART-SURFING CERAMICS

THE LAB Frederick Seitz Materials Research Laboratory, Illinois University, Urbana-Champaign. John A. Rogers, laboratory director.

OBJECTIVE To use biomechanics to extend the useful life of pacemakers beyond the current six-year battery life.

DEVELOPMENT A nano-scale piezoelectric device generates its own power by converting the motion of the heart, lungs, and diaphragm to electrical charges as it bends and stretches.

dissipates as heat. We wondered: 'What if we could use that physical motion to power pacemakers and other medical devices?' " said Dagdeviren, who is now a post-doctoral researcher at the Massachusetts Institute of Technology.

The answer was a 500-nanometer-thin slice of ceramic piezoelectric material atop a larger plastic sheet (itself only the thickness of a human hair). Piezoelectric materials convert physical energy directly to electrical energy.

The material generates 0.3 microwatt per square centimeter. But it can be applied in four layers, which can generate a total of 1.2 microwatts per square centimeter, enough to power pacemakers and other devices.

A device made from that material may be several years out from possible FDA approval. Before that occurs, the material will have to prove to be flexible enough to conform to the heart's shape, thin enough to stack like capacitors, safe enough not to put a strain on the patient, and strong enough not to break after millions or billions of heartbeats.

"If you think of a block of aluminum, it's not going to be easy to bend that, but if you take a thin slice of aluminum such as a sheet of aluminum wrap, it's extremely flexible. It's the same idea here," Dagdeviren said. "If you take a nano slice off a piece of ceramic material, it's going to have a very low flexibility index and it's proving not to be brittle, as you might expect of ceramics."

To check the practicality of a device made from the material, Dagdeviren and her team tested devices in the hearts of live pigs, sheep, and cows. This included both open- and closed-chest testing, which can have a large impact on the pressure exerted on the device.

Since Dagdeviren's graduation, her advisor, John Rogers, has researched the transducer's ability to monitor the flow of blood as a means to determine blood pressure. A similar thin skin-mounted transducer could power wearable health sensors. ME

Yingzi Lin has developed an unobtrusive sensor at the Intelligent Human-Machine Systems Lab.
Photo: Northeastern University

MONITORING, UP CLOSE

THE LAB Intelligent Human-Machine Systems Lab, Northeastern University College of Engineering, Boston. Yingzi Lin, laboratory director.

OBJECTIVE Designing intelligent systems that assist and interact with human operators in more natural, friendly, and efficient ways.

DEVELOPMENT A nano-scale monitoring network able to monitor physical processes from the subject's grip on an automotive steering wheel.

At Northeastern University's College of Engineering, Yingzi Lin and the Intelligent Human-Machine Systems Lab are developing a flexible nano skin, a film that allows a super-thin transducer layer to come between people and machines to monitor the operator's state without the distractions that come from being wired to sensors.

The plan for the nano skin is to fill it with sensors to measure a range of conditions, including heart rate, sweat rate, even blood alcohol concentration.

The current goal is to remove the hard wiring of sensors to subjects in automobile driving simulators so that study can be more efficient and less obtrusive.

"We recognized the need for a natural sensor that would just exist between the subject and the machine—one a subject could simply grip to automatically connect with our system," Lin said. "We investigated all the existing sensors and then looked at nano technologies, and realized we would have to create something."

So far the project, funded by the National Science Foundation, has resulted in a transducer to detect skin temperature and a practical means of producing the material.

A former graduate student, Hongjie Leng, worked on the sensor before he returned to Beijing with his doctorate to start his own company.

Another graduate student has been working with Lin on a sensor to measure heart rate. Other sensors are being considered. The plan is to incorporate a series of sensors in the one nano skin.

A single device with an array of sensors would make the experience of test driving simpler for the subject, and would make the changing of subjects faster and easier.

Lin's focus to date has been on automotive applications. She also sees potential for studying a variety of human-machine systems and applications using the resulting nano skin transducer systems, such as the human-robot interface, particularly in tele-control, as machines move farther from their human operators. ME

ELLIOT LUBER is an independent writer based in Seaford, N.Y.

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FOCUS ON COMPOSITES

tion. The new institute will work to develop lower-cost, higher-speed, and more efficient manufacturing and recycling processes for advanced composites.

Composites such as carbon fiber combine light weight and exceptional strength. As a result they hold out hope for lighter and more efficient vehicles, turbine blades, and other applications, especially if research can bring down the cost of the materials.

The first institute was the National Additive Manufacturing Innovation Institute, now called America Makes, which operates in Youngstown, Ohio. It was announced in August 2012.

The other three are the Next Generation Power Electronics Manufacturing Innovation Institute at North Carolina State University, the Digital Manufacturing and Design Innovation Institute in Chicago, and the Lightweight and Modern Metals Manufacturing Innovation Institute in Detroit. ME

RUSSIA: GAS PIPELINE TO TURKEY IN 2016

The Russian energy company Gazprom expects to build a pipeline to Turkey and begin delivering gas by late 2016, according to a report by Tass, the Russian news agency.

Construction has yet to begin on the pipeline. Current plans are for Gazprom to build the portion under the Black Sea. A Turkish partner, Botas Petroleum Pipeline Corp., will join Gazprom to build the land-based portion of the line in Turkey.

The pipeline is called the Turkish Stream. According to Tass, it will comprise four lines capable of transporting 63 billion cubic meters of natural gas a year. The new line will run 660 km along the old corridor of the now-abandoned South Stream and 250 km in the new corridor towards Turkey's European part.

About 50 billion cubic meters of the gas will flow to a new gas hub on the Turkish-Greek border.

The South Stream gas pipeline was to run across Europe to Tarvisio, Italy. Several European countries protested Russia's involvement in Ukraine. After Bulgaria decided to end construction in its territory, Russia's president, Vladimir Putin, ended the project.

Russia chose to build a pipeline to Turkey, with a gas hub on the border with Europe. ME

SUGAR TO FUEL IN AFRICA

An Indian biofuels company has been hired to install ethanol and alcohol production facilities at a sugar mill near Lake Victoria in East Africa.

Praj Industries of Pune, India, has signed an engineering, procurement, and construction contract with Kakira Sugars, based in Jinja, Uganda. The contract calls for Praj to build a plant that will produce 60,000 liters per day of fuel ethanol and beverage alcohol. The plant will process cane molasses from the Kakira Sugar Mill.

Kakira Sugars, part of the Madhvani Group, is a leading sugar and power producer in Uganda. According to Kakira's website, it operates a power plant producing at a rate of 22 megawatts of electricity. The company says the power plant supplies 12 MW to Uganda's national grid.

Praj will provide key technologies for fermentation, distillation, and wastewater treatment including biomethanation followed by biocomposting.

The steam required and 50 to 60 percent of the electricity consumed by the plant will be generated by the distillery itself. Effluent generated by the plant will be converted into biocompost for renewing soil fertility.

Praj recently commissioned a plant in Makeni, Sierra Leone, to produce fuel grade ethanol from cane sugar. The plant, owned by Addax Bioenergy SL, can produce more than 80,000 cubic meters of ethanol.

Besides producing ethanol, the site has facilities to generate enough electricity to power the plant. ME

CONSORTIUM AIMS FOR BETTER SHIPS

Four organizations have agreed to collaborate to develop new hull designs for large ships. The goal is to design vessels that show improved hydrodynamics for better fuel efficiency.

A memorandum of understanding was signed in January by Sembcorp Marine Ltd. based in Singapore, the University of Glasgow in Scotland, the University of Glasgow Singapore, and Singapore's Agency for Science, Technology, and Research. The three-year agreement is intended to enable the research organizations to combine their scientific expertise with Sembcorp Marine's experience in industrial maritime applications.

In addition to the goal of upgraded hydrodynamics, the consortium will look to reduce ship exhaust emissions and discharges by improving scrubber and ballast treatment systems.

At present, oceangoing transport carries about 90 percent of all international trade and accounts for 3 percent of global greenhouse gas emissions. The International Maritime Organization has issued stricter standards on ship-related air pollutants and marine environmental issues that are expected to go into effect this year.

As part of this collaboration, Sembcorp Marine and A*STAR will work to improve gas abatement technology through use of an advanced scrubber design. The scrubber is intended to reduce ship-borne emissions of SO_x, NO_x, particulate matter, and greenhouse gases, in particular CO_2, from fossil fuel-burning engines. ME

AN ALL-YEAR GAS AIR-CONDITIONING UNIT

H.C. PIERCE, GAS AIR CONDITIONING DIVISION, SERVEL INC., EVANSVILLE, IND.

During World War II Servel made wings for the P-47 Thunderbolt. By 1945 it was preparing to introduce its all-year air conditioner in a return to the civilian market.

LOOKING BACK

American industry was gearing up for peace when this article appeared in March 1945.

The all-year air conditioner is a completely self-contained gas-actuated unit, designed to provide all the functions of complete year-round air conditioning. Heating, humidifying, air cleaning, and circulation in winter; cooling, dehumidifying, air cleaning, and circulation in summer are accomplished with one simple unit.

The chief component parts of the assembly are an indirect steam-heating system, an absorption refrigeration unit, an air-filtering section, and a centrifugal-fan section.

Gas is used as a fuel for winter operation and as a source of energy for summer operation. The unit contains a gas-fired boiler, or steam generator, which produces steam twelve months of the year. During the winter cycle, steam is delivered to a heating coil within the fan section of the unit assembly. During the summer cycle steam is delivered to the absorption refrigeration unit also contained within the unit assembly.

Any of the functions of complete air conditioning is available, by selection, through a coordinated control system. Temperature conditions are automatically maintained as desired.

The complete conditioner is compact and requires little space for installation. The height of all units is seven feet, depth four feet nine inches, and over-all width five feet three inches. The width at the base is two feet nine inches.

The first of these projected models will have a cooling capacity of three tons of refrigeration, coupled with a heating capacity of 120,000 Btu per hr. The other two models will have a refrigerating capacity of 5 tons each and heating capacities of 120,000 Btu and 180,000 Btu, respectively. Refrigerating ratings are based upon standard conditions of 75 °F cooling water and an inlet air condition of 80 °F dry-bulb and 67 °F wet-bulb temperatures. Heating ratings indicated are in terms of gas input in British thermal units, the output being 80 per cent of these figures.

In addition to the three units mentioned, a 7.5-ton refrigeration unit, with balanced heating capacity, is also planned. **ME**

AIRPLANES INTO SHELTERS

Buckminster Fuller's Dymaxion house never caught on, but it proposed a peacetime use for wartime factories. The first prototype, built in 1945, used aluminum, an aircraft material that idle factories could produce in abundance.

Dymaxion House exhibit in the Henry Ford museum. Dearborn, Mich.

ASME SETTING THE STANDARD

Training & Development

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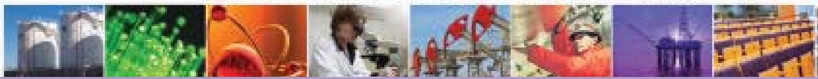

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2015 SPRING

MARCH-APRIL 2015 – ORLANDO, FLORIDA USA

PD100	Introduction to Elevators and Escalators	30-31 Mar
PD313	Fundamentals of Fastening Systems	30-31 Mar
PD456	Tools and Methods of Finite Element Analysis	30-31 Mar
PD389	Nondestructive Examination - Applying ASME Code Requirements (BPV Code, Section V) ASME CODE COURSE	30 Mar - 1 Apr
PD506	Research and Development Management	30 Mar - 1 Apr
PD515	Dimensioning & Tolerancing Principles for Gages & Fixtures	30 Mar - 1 Apr
PD619	Risk and Reliability Strategies for Optimizing Performance	30 Mar - 1 Apr
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PD679	Selection of Pumps and Valves for Optimum System Performance NEW!	30 Mar - 2 Apr
PD602	Elevator and Escalator Combo Course	30 Mar - 3 Apr
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PD102	ASME A17.1 Safety Code and ASME A17.2 Inspection Requirements ASME CODE COURSE	1-3 Apr

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APRIL 2015 – SACRAMENTO, CALIFORNIA USA

PD391	ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids ASME CODE COURSE	13-14 Apr
PD570	Geometric Dimensioning and Tolerancing Fundamentals 1 ASME CODE COURSE TOP SELLER	13-14 Apr
PD624	Two-Phase Flow and Heat Transfer	13-14 Apr
PD146	Flow Induced Vibration with Applications to Failure Analysis	13-15 Apr
PD190	BPV Code, Section IX: Welding, Brazing and Fusing Qualifications ASME CODE COURSE	13-15 Apr
PD231	Shock and Vibration Analysis	13-15 Apr
PD442	BPV Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels ASME CODE COURSE TOP SELLER	13-15 Apr
PD467	Project Management for Engineers & Technical Professionals	13-15 Apr
PD506	Research and Development Management	13-15 Apr
PD615	BPV Code, Section III, Division 1: Class 1, 2 & 3 Piping Design ASME CODE COURSE	13-15 Apr
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PD721	Optimization of Plant Layouts Utilizing 3D CAD/CAE Systems NEW!	16-17 Apr

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APRIL 2015 – CHICAGO, ILLINOIS USA

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

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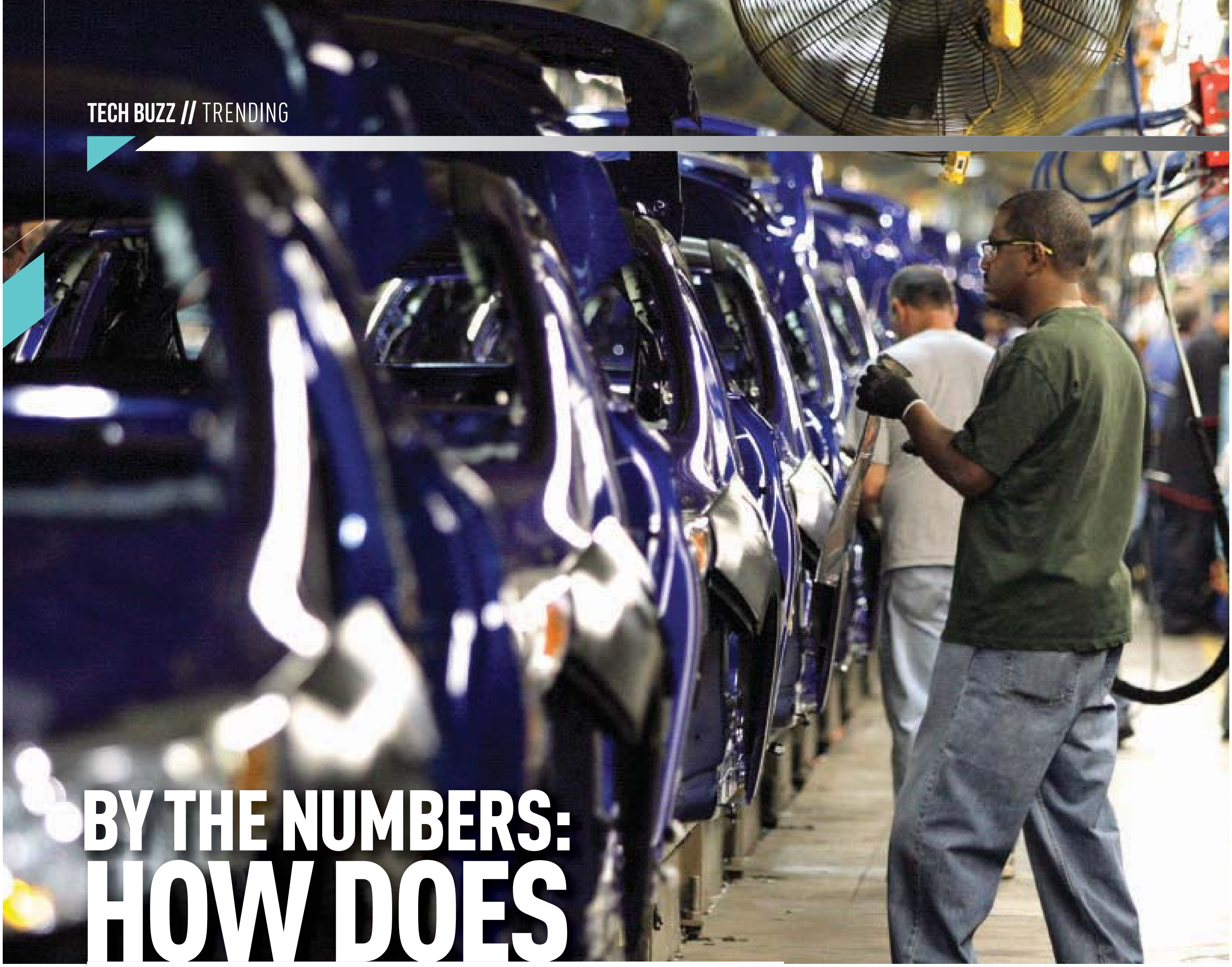

BY THE NUMBERS: HOW DOES MANUFACTURING PAY?

U.S. FACTORIES MAY BE CHURNING out more goods than ever before, but that production is being accomplished with fewer workers receiving lower wages.

CHANGES IN REAL WAGES, MOTOR VEHICLE PARTS MANUFACTURING WORKERS, 2003–2013

Year	Wage at 10th Percentile	Wage at 25th Percentile	Median Wage	Wage at 75th Percentile	Wage at 90th Percentile
2003	$11.61	$14.26	$18.35	$28.41	$36.54
2013	$10.38	$12.63	$15.83	$20.17	$27.13
Change	**-10.6%**	**-11.4%**	**-13.7%**	**-29.0%**	**-25.8%**

Source:Bureau of Labor Statistics

There are many good things to say about manufacturers. They are the backbone of the innovation economy and do most of the nation's R&D. They employ many skilled workers, from engineers and programmers to technicians and logistics managers. They are a major source of employment.

Yet manufacturers do not do not necessarily provide well-paying jobs for factory workers, who account for about half of the 12 million people employed in manufacturing (the rest are professionals and managers).

That was not always the case. In the late 1940s and 1950s, factory workers averaged nearly 10 percent more than the private sector as a whole. They maintained an edge in earnings as late as 2007. Yet by 2013, production workers were earning 7.7 percent less than their non-manufacturing counterparts, according to a new analysis of

COMPARISON OF REAL WAGES, 2003–2013, MANUFACTURING OCCUPATIONS VS. ALL OCCUPATIONS

Year	All Occupations	All Manufacturing	Motor Vehicle Manufacturing	Parts Manufacturing
2003	$17.13	$16.38	$31.45	$18.35
2004	$17.06	$16.16	$31.09	$18.26
2005	$16.88	$15.90	$28.38	$17.74
2006	$16.88	$15.76	$28.37	$17.43
2007	$16.97	$15.73	$29.09	$16.99
2008	$16.85	$15.65	$29.37	$16.49
2009	$17.32	$16.10	$29.62	$16.74
2010	$17.38	$16.10	$27.93	$16.69
2011	$17.16	$15.88	$26.11	$16.53
2012	$16.95	$15.74	$25.21	$16.14
2013	$16.87	$15.66	$24.83	$15.83
% Change	**-1.52%**	**-4.40%**	**-21.05%**	**-13.73%**

Source:Bureau of Labor Statistics

Bureau of Census and Bureau of Labor Statistics data by the National Employment Law Project.

NELP says the gap is growing. Between 2003 and 2013, real wages (wages after inflation) for factory workers declined 4.4 percent, three times faster than for non-manufacturing jobs. In 2013, the median hourly wage for production workers fell to $15.66. The best-paid 10 percent earned at least $27.17 per hour, down from $29.38 in 2003.

Of the nation's 6 million factory workers and first-line supervisors, 1.6 million made $11.91 or less per hour, and the bottom 10 percent made $9.60 per hour or less.

The trend is obvious in the auto industry. In the early 1950s, its factories once employed 2 percent of all American workers. Their employees earned 30 percent more than the average private sector worker—and that rose to 150 percent by the mid-1980s.

After contracting during the recession, auto sales have come roaring back. Production rebounded to 11.1 million vehicles in 2013, nearly twice as many as in 2009. Over those four years, automakers invested $38 billion in capital projects and added 350,000 new jobs.

Yet wages are declining. In part, this is due to a shift in employment from higher paying automotive assembly plants to lower paying parts facilities. This is a trend that really got under way in the mid-1980s, as vertically integrated automakers split off parts operations and began to outsource.

Today, 72 percent of auto industry laborers work in parts plants, which pay 36 percent less than assembly facilities. In fact, real wages at parts plants declined 14 percent between 2003 and 2013.

WAGES ARE DECLINING, IN PART, DUE TO A SHIFT IN EMPLOYMENT FROM HIGHER PAYING AUTOMOTIVE ASSEMBLY PLANTS TO LOWER PAYING PARTS FACILITIES.

Real wages at assembly plants fell even further. They dropped 21 percent, to $24.83 per hour in 2013 from $31.45 in 2003. In part, this is due to new union contracts that allow automakers to pay new hires lower wages, and the increasing number of non-union factories in low-wage regions in the South.

The NELP study also highlights another trend that depresses factory wages: automakers and other manufacturers increasingly fill jobs through staffing agencies, which provide lower wages and fewer benefits.

This is a difficult trend to quantify, since the government neither counts these "temporary" workers as factory employees nor includes their wages in industry averages. Still, NELP quotes a Cornell University study that found the number of staffing agency blue-collar temps rose to 1.4 million in 2000, from 419,000 in 1989.

This trend is continuing. NELP found that the total number of team assemblers (factory line workers) shrank 7 percent between 2002 and 2013. At the same time, the number of staff-placed assemblers rose to 176,590 (17 percent of all line workers) from 57,520. In the auto industry, staff-placed auto assemblers earned 29 percent less than assemblers hired directly by manufacturers. ME

ALAN S. BROWN

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TAKING THE HYDRO OUT OF HYDRAULIC FRACTURING

BY MARK CRAWFORD

WATERLESS METHODS AIM TO MAKE UNCONVENTIONAL OIL AND GAS WELLS MORE ENVIRONMENTALLY FRIENDLY.

A waterless fracturing operation in progress. Such methods may reduce the perceived environmental impact of "fracking."

THE DROP IN OIL PRICES BELOW $50 A BARREL this winter has been credited to many factors – economic struggles in China, the reduction in turmoil in North Africa, and greater fuel efficiency in automobiles among them. But undeniably, the surge in U.S. oil production had a major effect. In 2014, the United States produced around 3 billion barrels of oil, the most it has produced in a generation and a more than 60 percent increase over its production levels of just a few years before.

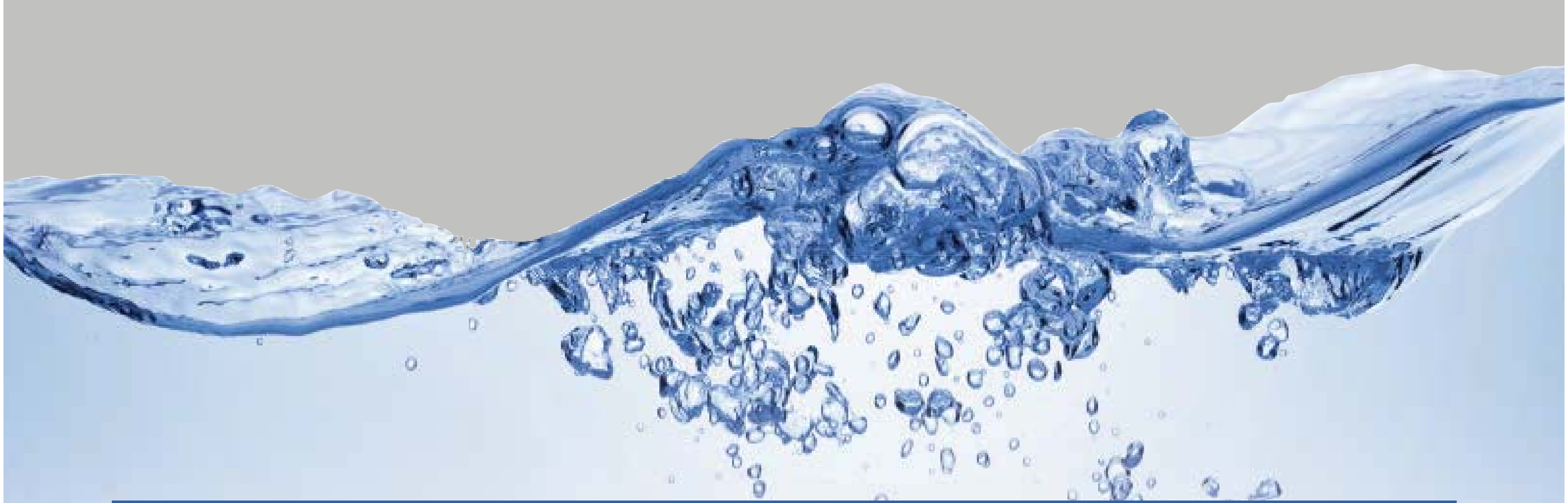
That surge is due to unconventional drilling and completion technologies that encompass a number of methods, but which is usually shorthanded as hydraulic fracturing or "fracking." In hydraulic fracturing, explosive charges shatter oil- and gas-bearing strata and then fluids pumped at high pressure force apart the fissures and insert fine grains to prop open the cracks to enable the petroleum to flow out.

The growth in hydraulic fracturing has not been met with universal praise. Indeed, in December, New York State banned the practice on health concerns. Generally, those concerns all come back to water.

First, the water use is immense. A typical hydraulic fracturing job requires between 2 million and 5 million gallons per well. This poses risks for depleting groundwater resources, especially in arid regions where water is scarce and important to other industries, such as ranching and agriculture.

Also, before the water is pumped down the drill hole, a proprietary mixture of chemicals is added to reduce friction, corrosion, and bacterial growth. Local landowners may be concerned that nearby fracking activity could contaminate the aquifers they rely on for drinking water, worries that are not alleviated by the secret nature of the chemical brew.

Fracturing's water problems have led some companies to look at other ways to "frack." Instead of using water as the main downhole fluid, these companies are developing new technologies that



WHAT ARE THE MAIN DIFFERENCES BETWEEN WATERLESS FRACTURING METHODS?

Albert B. Yost II, senior management/technical advisor for the U.S. Department of Energy's Strategic Center for Natural Gas and Oil in Morgantown, W. Va., ran through the options with us.

- **NITROGEN-BASED FOAM FRACTURING** uses a drill fluid that is mostly nitrogen, surfactants, and 8-25 percent water. Compressed nitrogen and a foaming agent are added to a water-based fracture fluid and injected under pressure. According to Yost, "Foam fracturing is highly suitable for low-pressure, tight gas formations that are sensitive to water."
- **CO_2-BASED FOAM FRACTURING** is similar to nitrogen-based foam fracturing but uses compressed carbon dioxide instead of nitrogen. This process can be limited by the availability of carbon dioxide within reasonable trucking, rail, and pipeline distances of well sites. Chesapeake Energy recently tested carbon dioxide foam fracturing on a well site in Ohio.
- **CO2/SAND FRACTURING** uses only sand and carbon dioxide, with no water. A closed-system blender augers sand out of a pressure vessel, which is then mixed and transported with liquid CO_2 down the wellbore. CO_2 is pumped as a supercritical liquid instead of a gas and no other additives are used. This process has been used successfully on hundreds of wells, mostly in Canada.
- **STRAIGHT NITROGEN- OR CO_2-BASED FRACTURING** has been used as an alternative to water-based hydraulic fracturing in shale formations that absorb water and swell, restricting gas flow. The gas is pumped without surfactants or proppant (sand). "This application has also been successful where the horizontal stress differences make proppant less important, or blockages from previous fracturing fluids need to be removed to restore production," Yost said.
- **GELLED-LPG FRACTURING** uses liquefied petroleum gas (LPG) and sand in a closed-system blender. The system has been used successfully in South Texas and western Canada. The gelled propane turns into a gas and exits the well along with the natural gas or oil stream produced, eliminating the need for water to be pumped into a well.

use far less water or, in some cases, no water at all.

Several hydraulic fracturing technologies have been developed over the past few decades that use little or no water. In general, waterless fracturing accounts for less than 3 percent of fracturing jobs in the U.S.

"Even though some of these fracturing methods have been available since the 1970s, they still simply represent a niche share of the market," said Albert B. Yost II, senior management/technical advisor for the U.S. Department of Energy's Strategic Center for Natural Gas and Oil in Morgantown, W. Va.

But to move into places that are unsuitable for–or skeptical of–traditional hydraulic fracturing, these waterless methods need to be brought into the mainstream.

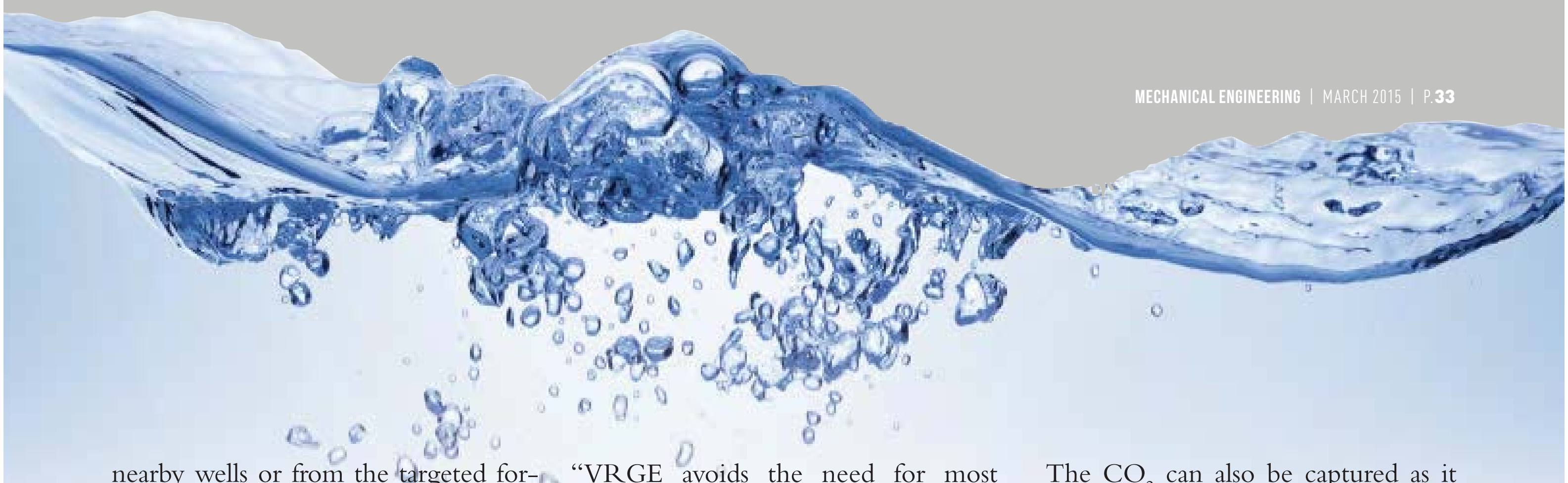
GETTING ENERGIZED

While waterless fracturing is still relatively rare in the U.S., it is more common in operations north of the border. About 25 percent of the fracturing jobs in Canada use waterless techniques, and as many as 40 percent of Canadian horizontal shale wells employ what's called "gas-energized" (foamed) fracking. The method involves using a foamed fluid consisting mostly of carbon dioxide, nitrogen, or methane to deliver both pressure and the proppant into the underground shale formation.

Water is still part of the foamed fluid, however, but it typically is only about 10 to 15 percent of the fluid.

Gas-energized fracturing has a significant advantage over traditional water-based methods: It requires less proppant, which saves money, and it can can double oil and gas recovery from a well. That economic case has led to a surge in interest in foam-based fracturing in the U.S.

Expansion Energy, based in Tarrytown, N.Y., has developed an innovative gas-energized technology that relies on a cryogenic, non-liquid fluid phase of natural gas—also known as cold compressed natural gas. Short for "Vandor's Refrigerated Gas Extraction," Expansion's VRGE process brings in a mobile cryogenic plant to a drill site to produce the CCNG from natural gas from



nearby wells or from the targeted formation itself. CCNG is very dense and can be pumped like a liquid.

The CCNG is pumped to high pressure with a cryogenic natural-gas pump and then vaporized via heat exchangers into high-pressure compressed natural gas. It is then blended with a proppant-carrying slurry and foaming agent and sent down the well.

This process creates, extends, and holds open fissures in the underground formation. When the pressure is reduced, the proppant holds open the fissures, releasing oil and gas.

Using low-weight hydrocarbons allows operators to recycle fluids in fracturing.

"Instead of relying on complex chemistry like water-based fracturing does, VRGE relies primarily on mechanical processes such as CCNG production (compression and refrigeration), cryogenic pumping, slurry blending and pumping, and fluid phase shifts," said Jeremy Dockter, co-founder and managing director for Expansion Energy.

"By using a hydrocarbon to produce a hydrocarbon," Dockter continued, "VRGE avoids the need for most chemical additives and biocides. Other gas-energized technologies, like CO_2 and N_2, introduce non-hydrocarbon substances into the product stream, which then must be captured and removed, driving up costs and adding logistical complexity. With VRGE, once the well begins to produce, the natural gas simply returns to the surface via the wellbore and can be sold to the market or re-used."

Overall, Expansion Energy says its VRGE process can reduce total completion costs by as much as $2 million per horizontal well versus standard water-based fracturing.

CARBON RECYCLING

Praxair, a supplier of industrial gases based in Danbury, Conn., has developed a system that relies on a different liquefied gas. Its DryFrac technology relies on liquid carbon dioxide that is mixed with sand and sent down the hole under high pressure.

The CO_2 can also be captured as it returns to the surface.

A key challenge that Praxair solved with this technology is the ability to blend the liquefied carbon dioxide and sand at precise concentrations, customizing it to the shale formation being fractured. Carbon dioxide is delivered and stored on the well pad. DryFrac blenders are delivered to the site with the blender vessel in a horizontal position, which is then hydraulically lifted to the vertical operating position and locked in place.

"Once all the piping to and from the blender is connected, sand is pneumatically conveyed into the blender vessel," said Mark Weise, business development director of oil and gas services for Praxair. "We then add liquid carbon dioxide to cool down and pressurize the vessel and sand in preparation for pumping."

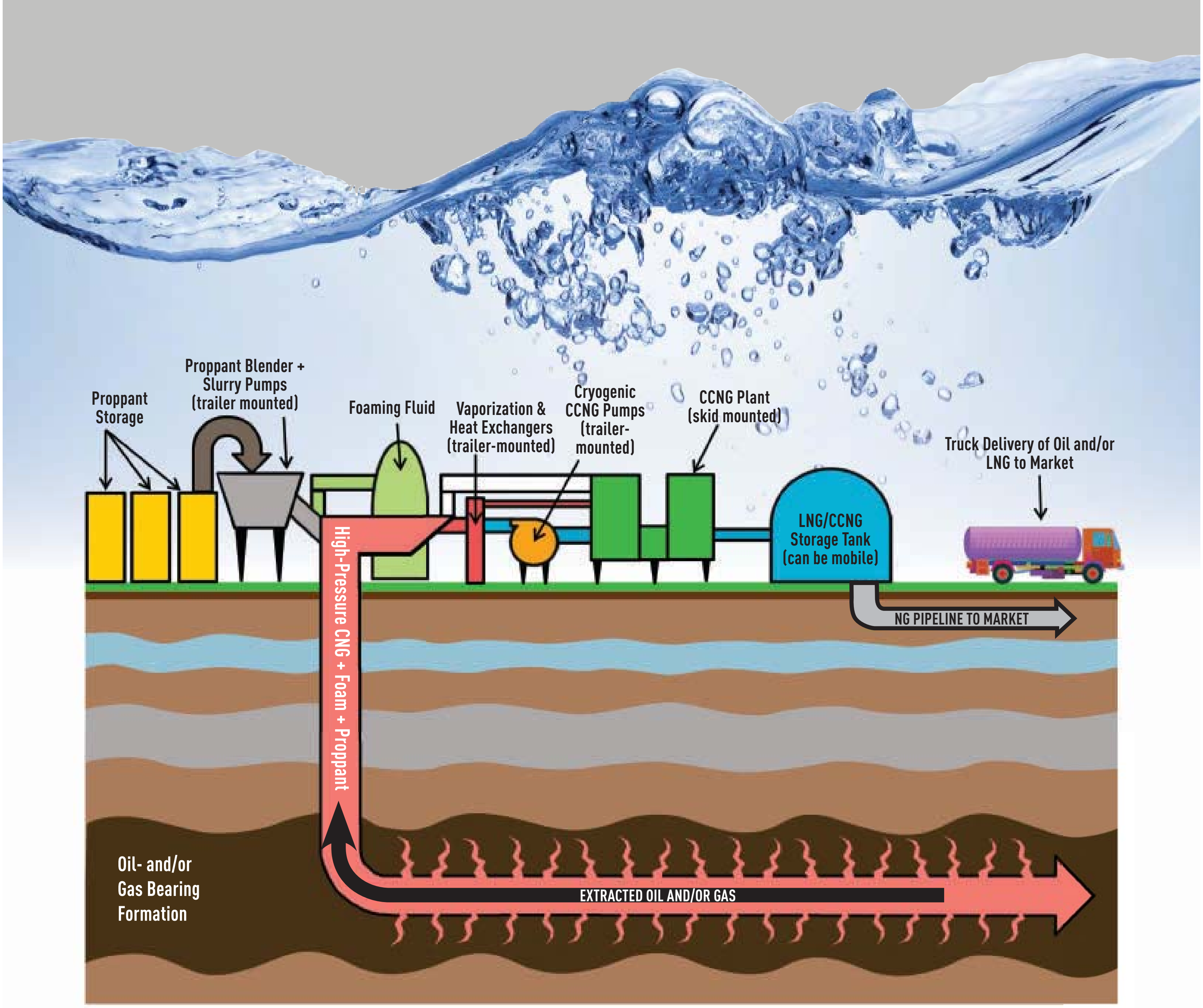
After a safety check, completed in coordination with the service company and the operator, CO_2 begins pumping down hole at the specified rate. Praxair's blender delivers the preset concentrations of sand over the course of the stage. Once the sand has been fully pumped, the job is completed and the system can be disassembled and moved to the next well pad.

According to Weise, DryFrac has been used successfully on several jobs. Initial results have shown up to double the production over wells in the same formation that were fractured with water.

"These results are generating an interest within the industry and we expect to see more operators using our technology over the next six to nine months," Weise said.

UNDER THE HOOD

Another waterless method of fracturing wells relies on low-weight hy-



drocarbons such as propane or butane. When the earliest versions of this technology were developed in the 1960s, however, using low-weight hydrocarbons to recover oil was considered to have more safety risks because flammable compounds were being used under high pressure.

To reduce this risk, GASFRAC Energy Services of Calgary has developed a technology to convert these hydrocarbons to a low-flammability gel. The gels are also more effective than water for distributing sand into fractures.

"The unique design of our equipment allows us to safely pump fluids that no one else in the industry can pump," said Greg Brown, director of engineering for GASFRAC.

"We hold multiple patents on the equipment that we utilize for our LPG and HRVP (high Reid vapor pressure) fracturing fluid systems, which represent significant mechanical innovations," Brown said.

"Our ability to custom-engineer properties of the fracturing fluid, such as surface tension and viscosity, allows us to match the same properties of the reservoir fluids, at reservoir conditions," Brown said. "This way we provide the customer with a fracturing fluid that is custom-tailored to their specific reservoir, enhancing hydrocarbon production."

GASFRAC recently received a patent for its new vapor hood, which enables a fracturing crew to pump RVP fluids up to 8 psi. The hood is a modification to a conventional tub-style blender where a sealed assembly sits on top of the blender tub.

"This modification creates a closed system that allows explosive vapors generated by the fluid during pumping to be directed away from equipment to a safe area, where they can be managed effectively," Brown said. "This process allows operators to use recycled fluids previously thought to be too volatile for use as a fracturing fluid."

To date GASFRAC has performed more than 2,000 well completions using this technology. BlackBrush Oil and Gas is currently using this process for some of its wells in South Texas and plans to expand its use in other regions.

CHOOSING WELL

The biggest challenge for waterless fracturing technologies is to consistently deliver improved oil and gas recovery across a range of reservoir con-

ON THE HORIZON: CRYOGENIC NITROGEN

Engineers at the Colorado School of Mines in Golden have been working hard to develop "cryogenic fracturing"—a waterless fracturing method that uses liquid nitrogen as the drilling fluid. Chilled to temperatures below -321 °F, liquid nitrogen is pumped down the hole at high pressure. When the super-cold nitrogen hits the warmer host rock, the rock shatters.

The biggest benefits of cryogenic fracturing are environmental—no water or chemicals are used in the process, and the nitrogen evaporates underground. Initial lab results are promising, with field testing at a drill site planned in 2015.

Two key challenges, however, remain:

1) overcoming liquid nitrogen's lack of energy capacity for carrying sand;

2) keeping the nitrogen cold, both on site and as it travels thousands of feet to the target formation.

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"Choosing which technique is best for a specific well should be based on economics, environmental impacts, and technical and safety considerations," Yost said. "Any new fracturing process must also overcome the technical and economic barriers of competition from previously capitalized processes, demonstrate improved economic rates of production, and be able to meet the anticipated operational schedules expected by the oil and gas industry.

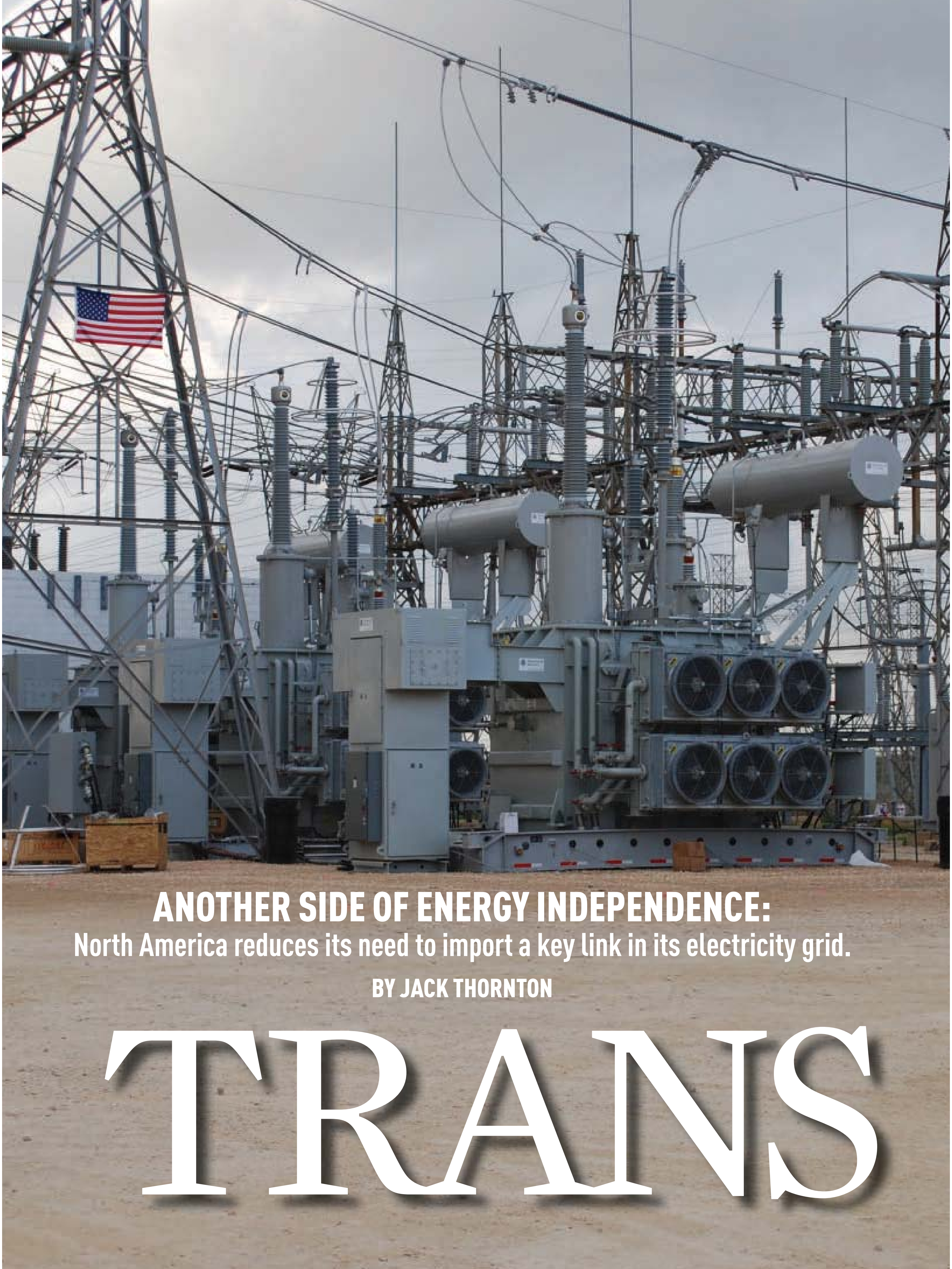
Brown agreed.

"The biggest research and development challenge facing waterless fracking is the fact that, when a new concept is developed for a fracturing system, companies are typically required to work with manufacturers to develop the equipment for testing and extraction as well," Brown said. "New systems are often incompatible with current equipment, so in order to test it or use it, new equipment has to be custom manufactured. This often becomes very time-consuming and costly, so it represents a major hurdle in new developments."

Even so, in places where hydraulic fracturing's water use is becoming a real constraint to exploiting shale formations, it's likely that petroleum companies will find that it's worth it to make the commitment to waterless fracturing. **ME**

Some waterless fracturing methods have shown about double the production compared to wells fractured with water.

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



ANOTHER SIDE OF ENERGY INDEPENDENCE:

North America reduces its need to import a key link in its electricity grid.

BY JACK THORNTON

TRANS

An industry-government partnership installed RecX, a prototype emergency transformer, at a CenterPoint Energy substation near Houston in March 2012. *Image: Electric Power Research Institute*

FORMED

ARGUMENTS FOR ENERGY INDEPENDENCE IN the United States have generally focused on sources of fuel. Before the widespread use of hydraulic fracturing, the U.S. economy relied on increasing levels of petroleum imports. That part of the country's energy supply was subject to disruptions for reasons ranging from embargoes to foreign wars.

Less widely discussed was another side of the energy independence issue, involving not fuel but a critical link in the delivery of energy: Specifically the huge transformers that step up voltage for long-distance transmission, and equally large transformers that step voltage down as electricity makes its way to customers.

In the fear that gripped the country after September 11, 2001, those transformers were seen as a vulnerability. They took months to replace. They are rated to handle several hundred megavolt-amperes of electricity, and they are custom engineered and built.

There were only two factories in the United States that built them. Most of those transformers, possibly 95 percent of them, were imported. If enough of them were destroyed, it could plunge regions of the U.S. into blackouts that could last weeks or months before power could be fully restored.

One possible solution was a test program involving the Department of Homeland Security and other government agencies to design an emergency transformer that could serve as an interim replacement. A demonstration was successful and the program is ending.

Meanwhile, the number of companies building big transformers in the United States has more than doubled since that program began. Manufacturing capacity near the point of delivery is expected to reduce lead times and reduce the need to rely on imported transformers.

Plants have been opened by three of the largest overseas manufacturers of grid transformers: Mitsubishi Electric Power Products, Hyundai Heavy Industries, and EFACEC. The original two transformer plants, owned by ABB and by SPX Corp., have expanded

For years, the availability of low-priced imports had made expanding U.S. capacity a risky investment. Then in 2012 the U.S. International Trade Commission, acting on a complaint filed by ABB and others, ruled that Hyundai Heavy Industries had violated U.S. dumping laws, by selling equipment in the United States at less than fair value.

1500-1800 large transformers in use

2 domestic factories (pre 9/11/2001)

90-95% of all new units were imported

400-600 units per year will need replacing

$1.4 MILLION average cost per unit

Since then, the Department of Commerce, acting on the ITC's decision, has collected 14.95 percent countervailing duties on imported Hyundai transformers rated at 100 megavolt-amperes and higher. By this time, however, manufacturers of big transformers had already recognized that U.S. business opportunities outweighed U.S. cost disadvantages.

Manufacturers declined to discuss the dumping case's impact on their decisions.

Mitsubishi Electric Power Products Inc. (known as "Meppi") opened its plant in Memphis, Tenn., in April 2013. Shipments began in mid-2014. It reported an order backlog of more than 20 transformers with ratings as high as 600 megavolt-amperes.

Hyundai Heavy Industries opened its Montgomery, Ala., plant in November 2011 and said it can produce up to 200 big grid transformers per year with ratings up to 550 MVA.

EFACEC, headquartered in Portugal, opened operations in Rincon, Ga., near Savannah, in April 2010. As of mid-2014 the company reports an order backlog of about 30 transformers, adding that it has shipped nearly 120 power transformers with capacities of 30 MVA and higher. EFACEC said its maximum rating is 500 MVA.

The three companies built a combined total of more than 800,000 square feet of factory space to build big transformers. Their investments add up to more than $500 million.

Meanwhile, SPX and ABB Inc. expanded their facilities. SPX invested $70 million to bring its Transformer Solutions unit in Waukesha, Wis., to more than 400,000 square feet; the expansion opened in April 2012. ABB said it has steadily expanded its Transformer Remanufacturing and Engineering Services in St. Louis, but declined to provide numbers.

Prior to these expansions, ABB and SPX together supplied perhaps 5 to 10 percent of the big transformers sold in the United States; virtually all the others were built overseas—which some saw as a worrisomely high dependence on imports for a vital sector of the U.S. infrastructure. The five U.S. plants now have the apparent capacity to meet the foreseeable demand for big grid transformers. Indeed, estimated capacity of the five plants adds up to more than a typical year's imports.

The U.S. grid may still absorb some imports, but the decline in imports has already begun. A U.S. Department of Energy report, *Large Power Transformers and the U.S. Electric Grid*, estimated that 496 big transformers were imported in 2013. That's a drop of more than 20 percent from the import peak of 610 units in 2009. Updated in April 2014, the report was done by the Infrastructure Security and Energy Restoration Office of the Energy Department's Electricity Delivery and Energy Reliability unit.

ELECTRIC CONNECTIONS

The North American grid spans the U.S., Canada, and the northwest corner of Mexico—200,000 miles of power lines carrying voltages of 230 to 765 kV. The grid is owned and operated by dozens of individual utility companies. They coordinate their efforts through the North American Electric Reliability Corp. in Atlanta.

Utilities use this network nonstop to buy and sell power to each other. These sales keep electricity supply and demand in balance.

The big transformers are critical to this balancing act. They connect power plants to the electrical grid. They step up electric force, because high-voltage transmission minimizes losses of power in transit.

Later, as electricity travels outward through local distribution systems, the long-distance grid's high voltages must be stepped down. That process takes more big transformers.

New and replacement transform-

Intermountain Rigging and HeavyHaul moving a 560,000-pound power transformer in Tulsa on a 24-axle beam trailer.

Image: Intermountain Rigging and HeavyHaul

ers present challenges in the factories where they are made and to the utility companies that buy them. Each grid transformer is the size of a small house and weighs several hundred tons.

They have almost no moving parts, require little maintenance, and typically operate for decades.

SUPPLY AND DEMAND

Because the grid has never been "standardized," each big transformer has to meet the electric current and voltage characteristics where it is to be installed. Engineers also must take into account distances the power is to travel and resistance factors such as the diameter of transmission wires.

This means several months of custom specification and design followed by weeks of detailed mechanical and electrical engineering.

Moving big transformers requires barges, special railroad cars, and custom over-the-road transporters that take up two highway lanes.

Experts in industry and government estimate that the U.S. portion of the North American grid has between 1,500 and 1,800 big transformers; definitions vary so the count is not certain.

Officials at the Electric Power Research Institute said the organization had no solid figures.

Inconsistent definitions and missing data aside, industry and government experts agree that 90 to 95 percent of the grid's new and replacement transformers have been imported in any recent year.

Government officials and many in industry saw the grid's huge dependence on imports as an Achilles heel for the U.S. economy. Many of the experts also agreed that hundreds of big grid transformers need to be replaced.

Some industry experts have calculated that as many as 400 to 600 of the grid's aging transformers should be replaced each year for the next several years. Making one estimate was SPX Corp. in a September 2012 investor presentation, which the Department of Energy quoted in its report on power transformers. SPX estimated the grid transformer business at $1 billion a year and added that replacements should go on for several years. Meanwhile, government data valued the 469 transformers imported in 2013 at $676 million.

Aside from the need to replace aging equipment, the grid is growing. It is connecting new power plants (fossil-fueled and nuclear) and new renewables (solar and wind). And it is evolving technologically to boost both resilience and reliability.

RECOVERY EXPERIMENT

In the wake of the September 11 attacks, the grid's heavy reliance on imported equipment was seen as vulnerability. Three federal agencies got involved—the Department of Homeland Security, the U.S. International Trade Commission, and the Department of Commerce.

In the aftermath of 9/11, Homeland Security was asked for help by the utility companies, to demonstrate how quickly even the biggest transformers could be replaced in an emergency power outage.

The department's Science and Technology unit coordinated a program that developed a backstop transformer dubbed RecX—"Rec" for "recovery" and "X" from the standard shorthand for a transformer.

The RecX project focused on transportation and speedy installation of a modularized grid transformer rather than grid standardization. The Electric Power Research Institute in Palo Alto, Calif., which has been working on standardization and better transformer designs since the early 1990s, took on this work as well and subcontracted the

Final assembly of a 525 MVA transformer at EFACEC's Rincon, Ga., plant.
Image: EFACEC

project to ABB in St. Louis.

ABB built the first RecX in St. Louis and then did final assembly, testing, delivery, and installation in just five days in March 2012. RecX was installed and is operating at a CenterPoint Energy substation near Houston, Texas. Prior to RecX, such an effort often took five months. ABB has designed an even larger version, but has not built it yet.

Sarah Mahmood, who heads Homeland Security's Science and Technology unit, said RecX was a demonstration project that has been wrapped up.

For national-security reasons, some in government (and some in the transmission business) had hoped to stockpile a few RecX-type modularized transformers at key sites around the country. Some current and former federal officials are on record saying that if big transformers in just nine strategic spots were taken out of service, portions of the U.S. and Canada grid would be without electric power for weeks. Full restoration could take months, officials warned.

The plan to stockpile RecX-like transformers stalled. According to Gerry Cauley, president and CEO of the North American Electric Reliability Corp.: "A limitation of the modular spares is that they would provide only temporary solutions. [They] are not designed for the decades-long lifetime of full-scale transformers." He compared long-term reliance on modular transformers to "riding on the temporary spare tire in a vehicle."

There are, of course, backups and fallback plans. Like any industrial equipment, transformers of all sizes are inventoried and tracked in industry databases. The Edison Electric Institute has a Spare Transformer Equipment

Program, or STEP, which binds utility company members to share urgently needed equipment on demand, in response to a geomagnetic storm, for example, or an act of terrorism.

Other grid risks include cyber attacks on control systems, vandalism, and sabotage on physical facilities, earthquakes, tsunamis, and extreme weather. All infrastructure facilities—pipelines, canals and locks, railroads, highways, and airports—face varying degrees of similar risks.

STEP includes even the largest grid transformers. Cauley noted that the North American Electric Reliability Corp. also maintains a database. "Another possibility for expanding the availability of spares," he added, "is repurposing older transformers that are being retired and use them as spares."

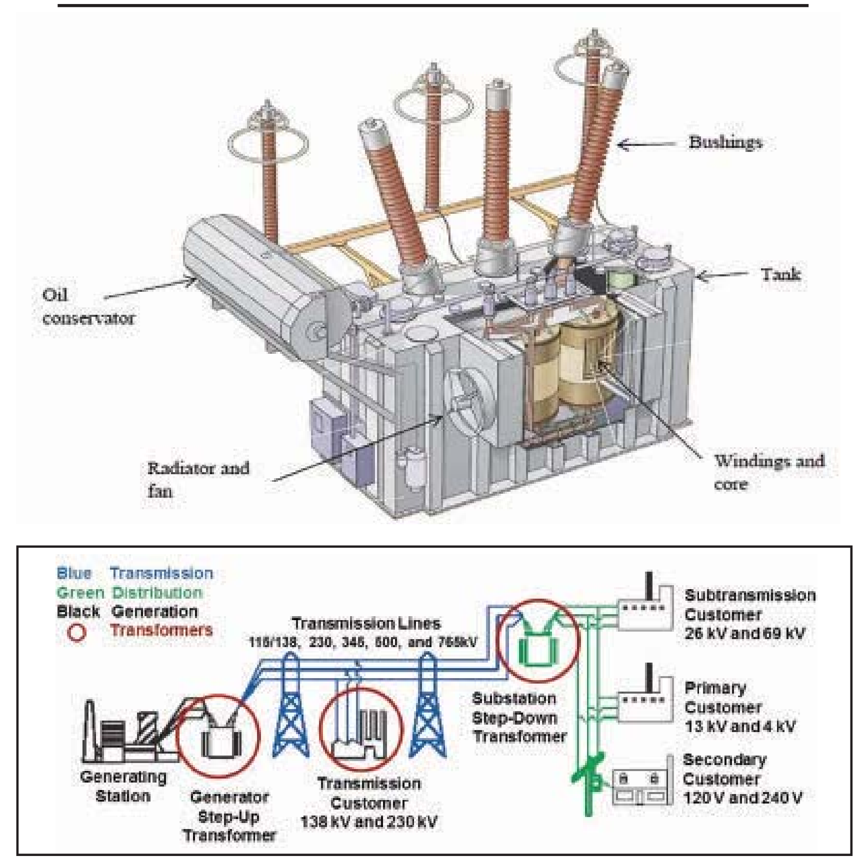
Conceivably catastrophic infrastructure risks are rare and unpredictable. They are classified as high-impact low-frequency, or HILF, events. Experts disagree (sometimes sharply) on the odds of any one risk becoming an unfortunate reality, as well as on the costs and consequences. Moreover, sound planning requires that each risk be weighed and ranked against all the others.

"The difficult decisions are what types of emergencies should be planned for, how many transformers are needed as spares, and what mix of customized full-scale units and modular units should serve the need," Cauley said. "Ultimately, procuring and maintaining spare equipment requires significant capital expenditure and maintenance costs for an event that may rarely or never happen."

This is the crux of the infrastructure security debate. According to Cauley, each utility company has to decide for itself, "with consideration of rate-payer value and in consultation with local and state regulators."

Home-based manufacturing of transformers can have major implications for the security and robustness of the grid. Building big transformers in the U.S., closer by thousands of miles to installation sites, can simplify and speed up the development of transformers. Shorter distances can also reduce transport time.

ANATOMY OF A POWER TRANSFORMER



U.S. Department of Energy

HILF? IT HAPPENS

Large-scale loss of grid transformers is considered a high-impact, low-frequency event, but HILFs can happen.

Just after midnight on April 16, 2012, a small group of armed people attacked Pacific Gas & Electric Co.'s Metcalf substation near San José, Calif. The substation serves Silicon Valley.

In 20 minutes, the attackers shot holes in the cooling oil tanks of 17 big transformers, which overheated and shut down. Power was rerouted and a blackout avoided.

Investigation revealed evidence that the attack had been carefully planned and executed. Phone wires, through which the site was monitored, had been severed, for instance. The perpetrators have not yet been found.

Repairing the damage took almost four weeks and cost $16 million. Had the Metcalf transformers been damaged beyond repair, replacement could have taken several months.

Oddly enough, the attack occurred about a month after the RecX transformer prototype was installed in Texas.

Today, the distant manufacturing sites and long delivery times that so worried government officials in the past have been seen in a new light. They represent an annual replacement market of several hundred massive machines, sufficient to support a major manufacturing expansion in North America, even without snipers in the dark. ME

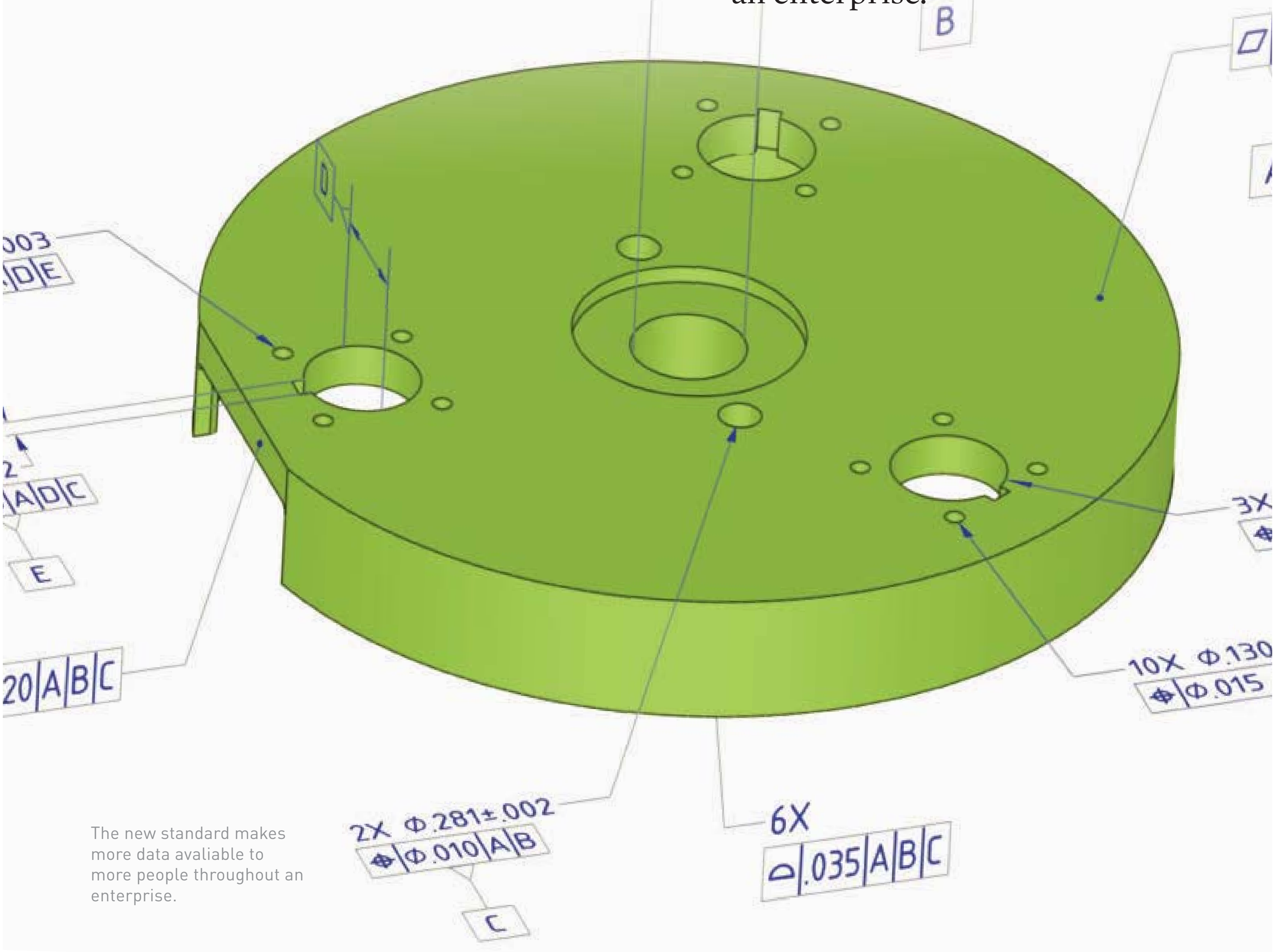
JACK THORNTON is a contributing writer to the magazine. He is based in Santa Fe, N.M.

A STEP UP

A NEUTRAL FILE FORMAT BRINGS MORE INFORMATION INTO PLAY.

BY BRYAN R. FISCHER

THE INTERNATIONAL ORGANIZATION for Standardization has released a new standard for the exchange of product-model data, ISO 10303-242, which is a new application protocol standard in the STEP family of standards. The standard, published last December, significantly improves STEP's capabilities, especially in providing useful information for an enterprise.



The new standard makes more data avaliable to more people throughout an enterprise.

STEP is commonly used in industry to share 3-D CAD model geometry with organizations using different CAD software with different proprietary data formats. Thus, STEP is commonly used to move data between CAD systems (CAD-to-CAD) in a neutral data format. More importantly, STEP is also used as the basis for downstream processes, such as inspection, manufacturing, and assembly. These uses are significantly improved by the release of the new standard.

The full title of this new STEP application protocol standard is ISO 10303—*Industrial Automation Systems and Integration—Product Data Representation and Exchange—Part 242: Application Protocol: Managed Model-Based 3D Engineering*. It's often abbreviated to AP242.

From my perspective, the biggest benefit that AP242 offers to industry is the promise of neutral 3-D semantic data models of parts and their product and manufacturing information (PMI). So now, in addition to the geometry, all that PMI will be available in downstream processes.

AP242 offers the promise of true data interoperability in a neutral format. It's the next step in the transformation of business from the old 2-D drawing world that started with the Industrial Revolution to the semantic 3-D data world where we're heading. Semantic models of 3-D product definition data and the resulting increase in productivity are where the promise of computerization leads. It's a natural progression.

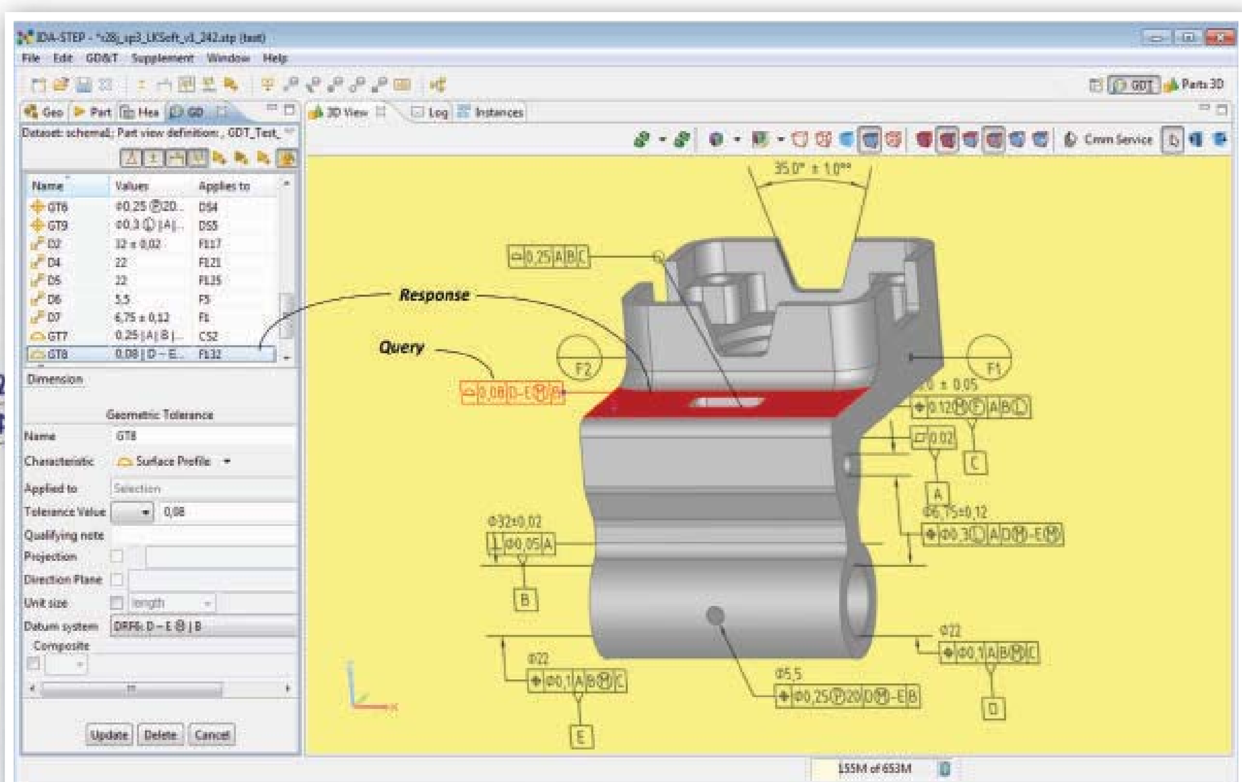
Semantic means the data is correctly modeled, structured, and formatted in a predictable manner properly associated to the applicable 3-D geometric data.

Interactive, semantic 3-D datasets are superior to 2-D product definition data in many ways. The query and graphical response capabilities as well as the capability to rotate and zoom in 3-D systems are key reasons to move away from 2-D drawings.

Also, much more information can be conveyed in 3-D and the information is presented more naturally and is easier to understand. Static, 2-D media like drawings can't provide the same interactivity and ability to group, filter, and drill down into data that 3-D systems can.

STANDARD GOALS

The STEP AP242 standard lies at the convergence of many technological improvements. With the ubiquity of laptops, tablets, and other portable viewing tools, more of the workforce can and should have access to these interactive datasets. And with ever more powerful data management systems, datasets can be structured to encompass more of the product lifecycle and remain relevant longer.



A geometric tolerance is queried using the IDA-STEP GD&T editor. Selecting the profile of a surface tolerance causes the associated surface to highlight in response. "Query," in this context, means to obtain information from the model, which includes geometry, product and manufacturing information, attribute data, metadata, and the like. Note that the related semantic PMI entities are also highlighted in the GD&T view list.

This is an exciting time to be working in 3-D product definition standardization and in industry.

AP242 combines the best aspects of AP203 *Configuration Controlled 3-D Design of Mechanical Parts and Assemblies* and AP214 *Core Data for Automotive Mechanical Design Processes*. AP242 was created as an alternative to updating AP203 and AP214, which have similar functionality.

The main goals for AP242 were to include all the functionality of AP203 and AP214, develop a business object model to define structured approaches for common uses, develop a semantic data model to represent product and manufacturing information, and more rigorously address external element references, composite parts, kinematics in assemblies, and tessellated data.

STEP AP242 was developed by an international team led by PDES Inc., an international consortium of industry, government, and university members that aims to accelerate the development and implementation of standards that have to do with product lifecycle management interoperability. The development team was also led by ProSTEP iViP of Darmstadt, Germany, an international association that helps develop standards to manage product data and create virtual products.

Representatives from original equipment makers and software vendors as well as standardization and subject-matter experts also participated in the multiyear effort to bring STEP AP242 to fruition.

I participated in this project as a subject-matter expert with specific focus on dimensioning, tolerancing, geometric dimensioning and tolerancing, and on ASME Y14.41 and ISO 16792 digital product definition standards.

AP242 includes semantic data models for dimensioning and tolerancing and for geometric dimensioning and tolerancing as defined in ASME Y14.5 and ISO Geometrical Product Specification standards. These standards define the meaning of product and manufacturing information.

These standards have existed for decades, initially developed in the

"AP242 IS THE MEANS FOR INDUSTRY TO PROTECT ITS INVESTMENT IN ITS INFORMATION THROUGHOUT THE LIFE OF ITS PRODUCTS."

— HOWARD MASON
BAE SYSTEMS

The semantic information of the new standard is computer-interpretable and facilitates the automation of processes on the factory floor.

era of 2-D drawings. Thus, much of their content applies to 2-D drawings and presenting information in a 2-D context.

But the semantic information of the new standard is computer-interpretable; it can be used in semi-automated and automated systems and is intended to be used by software designed for tolerance analysis, inspection, and manufacturing. This information is not intended to be used like the information shown on a 2-D drawing. It is supposed to be used or consumed by software. Thus, it is critical that the GD&T and other PMI is represented semantically and it is critical that the standards defining the PMI, such as ASME Y14.5 and ISO 1101, include robust definitions that support semantic data modeling. Much of the 2-D content in these standards needs to be updated to support semantic data modeling.

To remedy some of this shortcoming, AP242 also supports the ASME Y14.41 and ISO 16792 standards, which govern the structure and use of 3-D digital product definition data.

The National Institute of Standards and Technology sponsors and participates in much of the work done on STEP standards. To ensure we develop a useful, interoperable data standard, the proposed data models and methods must be rigorously tested and validated.

Another organization, the CAx Implementor Forum, is an essential part of STEP development. The CAx-IF works in parallel with the AP242 team to develop recommended practices for the implementation of AP242 in CAD and data translation software, to test the data models and best practices, and to provide critical feedback to the AP242 team.

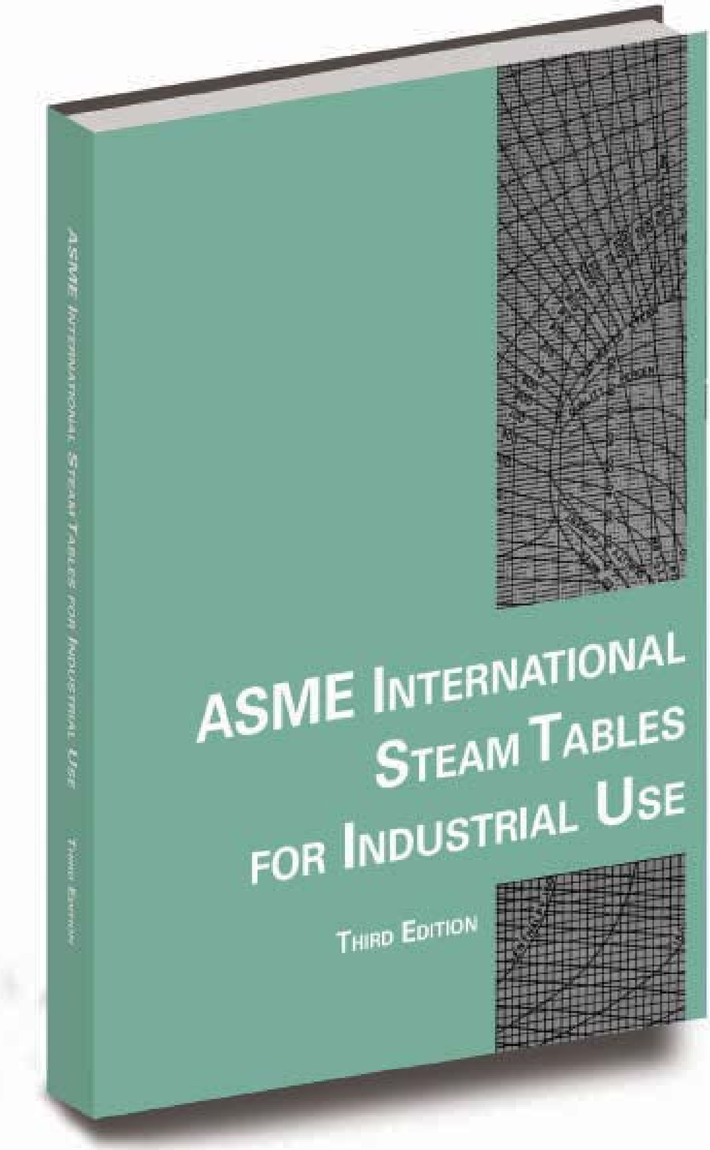
The CAx-IF includes CAD, translation, validation, and STEP software developers, and STEP and other subject matter experts. CAx-IF tested prototype versions of AP242 through the standard's development. The developers believe that most of the bugs have been worked out of CAD software and other software that supports AP242, which will expedite its industrial deployment.

Major CAD systems currently support STEP AP242 format, including Catia, Creo Parametric, NX, and others. AP242 tools and translators are available from Capvidia, CoreTechnologie, Datakit, ITI Transcendata, LKSoft, Theorem Solutions, and others.

Product data management software also supports AP242 and its business object model. For instance, Jotne EPM Technology's express data manager allows users to automatically generate databases that comply with AP242. These databases can be used for quality assurance of AP242 data, as part of a PDM system, and for other uses.

Developers of the standard are enthusiastic about its possible application. One of those who contributed to the development process is Howard Mason, corporate information standards manager, at BAE Systems, the British defense and aerospace company. As Mason put it: "AP242 is the means for industry to protect its investment in its information throughout the life of its products, and forms part of an integrated set of standards that cover the product information requirements of the entire product lifecycle." ME

BRYAN R. FISCHER is principal of MBD360 LLC, Sherwood, Ore. which offers training and consulting in 3-D model-based technologies.



FEATURED

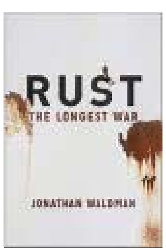
ASME INTERNATIONAL STEAM TABLES FOR INDUSTRIAL USE, THIRD EDITION (CRTD-VOL. 58)

PREPARED BY WILLIAM T. PARRY, JAMES C. BELLOWS, JOHN S. GALLAGHER, ALLAN H. HARVEY, AND RICHARD D. HARWOOD

ASME Press Books,
Two Park Avenue, New York, NY 10016-5990. 2014.

The subtitle of this book tells us that it is "Based on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97)." The main update for this edition is the incorporation of the new IAPWS formulation adopted in 2011 for the thermal conductivity of water and steam. This is reflected in new Tables S-9, S-10, U-9, and U-10, along with new Figures S-4, S-5, U-4, and U-5, and revision of Appendix B. The thermodynamic property information is unchanged from the Second Edition. The authors also made minor updates to some of the background text and references.

300 pages. $95; ASME Members, $76,
ISBN: 978-0-7918-6036-6.

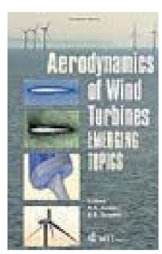


RUST: THE LONGEST WAR

Jonathan Waldman
Simon & Schuster, 1230 Avenue of the Americas, New York, NY 10020. 2015.

In *Rust*, journalist Jonathan Waldman travels from Key West to Prudhoe Bay to meet the colorful and often obsessive people concerned with corrosion. Waldman sneaks into an abandoned steelworks with a brave artist and nearly gets kicked out of Ball Corporation's Captain School. Across the Arctic, he follows a massive high-tech robot, hunting for rust in the Trans-Alaska pipeline. On a Florida film set he meets the Defense Department's rust ambassador, who reveals that the Navy's number one foe isn't a foreign country but oxidation. Along the way, Waldman encounters flying pigs, Trekkies, decapitations, exploding Coke cans, rust boogers, and nerdy superheroes.

304 PAGES. $26.95. ISBN: 978-1-4516-9159-7.



AERODYNAMICS OF WIND TURBINES: EMERGING TOPICS

R.S. Amano and B. Sundén
WIT Press, 25 Bridge Street, Billerica, MA 01821. 2015.

Focusing on the aerodynamics of wind turbines, Amano and Sundén present advanced topics including: basic theory for wind turbine blade aerodynamics; dynamics-based health monitoring and control of wind turbine rotors; experimental testing using wind tunnels with an emphasis on small-scale wind turbines under low Reynolds numbers; computational methods; ice accretion; and structural reinforcement techniques for wind turbine blades. Many of the subjects covered can apply to gas turbine heat transfer and fluid mechanics.

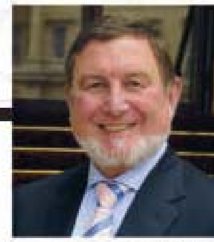
196 PAGES. $186. 978-1-7846-6004-8.

Global Gas Turbine News

Volume 54, No. 1 • March 2015

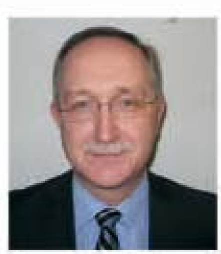
Turbo Expo
Montreal, Canada
June 15-19, 2015

Keynote Speakers
Monday, June 15



Richard (Ric) Parker
Director of Research & Technology
Rolls-Royce Group

Chris Lorence
General Manager of Engineering Technologies
GE Aviation



Ed Hoskin
Vice President, Engine Development Programs
Pratt & Whitney Canada

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ASME Turbo Expo Keynote and IGTI Awards Program

Join thousands of turbomachinery professionals at the year's most commanding gathering of business leaders, technology contributors, and authorities in the field of turbomachines. It is an ideal occasion to gather essential marketplace insights, learn about pivotal achievements, and connect with colleagues from around the world.

This is the 60th Turbo Expo, an opportunity to reflect on how gas turbine technology has evolved and been applied over the decades. It is an opportunity to consider how far we have come in the last 60 years, how our heritage is influencing what we do today, and thus how it impacts our future.

The program opens with keynote presentations given by prominent experts from the turbomachinery industry. Ed Hoskin, Vice President, Engine Development Programs Pratt & Whitney Canada; Chris Lorence, General Manager of Engineering Technologies GE Aviation; and Richard (Ric) Parker, Director of Research & Technology Rolls-Royce Group will address the important keynote theme: Building on our Heritage. The three leaders of gas turbine OEMs (original equipment/engine manufacturer) will reflect on how their own company has built on its heritage over the last six decades, clarify how that heritage impacts the way they work today and share their vision for the future. We build on our heritage in many ways. The research reported at this conference is very different from the research presented at the first Turbo Expo. However, there is a direct link, and by reflecting on how gas turbine technology has changed over the last six decades we can better envision how it will change in the future.

The keynote is followed by the ASME IGTI annual awards program which honors individuals, your peers, who have made significant contributions to the advancement of the turbine technology and industry.

TECHNICAL ARTICLE

Gas Turbine Cooling Flows and Their Influence in Output

by Mr. Brent A. Gregory and Mr. Oleg Moroz, *both of Creative Power Solutions, Fountain Hills, AZ.*

Introduction

In a modern gas turbine engine, up to 20% of the main compressor (inlet) flow is bled off to perform cooling and sealing of hot section components.

Cooling flows are necessary for the engine to function, however too much cooling has a negative impact on the performance and output. To optimize performance one needs to know what cooling flows to monitor and control.

This article presents the importance of understanding cooling flow monitoring especially when applied to land-based gas turbines. Aircraft engines are strictly hands off to access and control cooling flows but this is not so with land-based units. Strategically placed instrumentation in the cooling flow delivery system can monitor the health and hence the output of the gas turbine generator utilized in a simple or combined cycle operation.

In some four stage turbines the design will usually provide cooling to the following components (in order of decreasing flow)

1) Vane 1 – Cooling to vane 1 is provided internally to keep materials at a safe temperature.
2) Rotor and blade cooling – An external pipe will take air from an engine compressor, cool this air in an external heat exchanger and provide the air for cooling turbine blades and the rotor.
3) Vane 2 – Two pipes (a main line and a bypass) will provide cooling for vane 2.
4) Vane 3 – Two pipes (a main line and a bypass) will provide cooling for vane 3.
5) Vane 4 – Two pipes (a main line and a bypass line) will provide cooling for vane 4.

Some OEMs have different delivery systems than pipes. For instance much of the cooling flow may be channeled through the major internal skeletal structure of the engine.

Vane 1 and rotor and blade cooling are usually non-adjustable. They are determined by the design of the engine. When the rotor and blade cooling is provided via an external pipe, that flow can be easily monitored. Vane 1 cooling flow is generally not measured although a thermocouple in the region of the vane "box" will help determine flow from an algorithmic model.

The easiest flows to measure and control are Vane 2 through 4 flows. The main line carries most of the flow which is determined by pressure difference between the compressor (where the flow is extracted) and the turbine (where the flow is introduced). The flow is controlled by an orifice that's in the pipe. The bigger the orifice throat area, the more flow will pass.

There is also a bypass line that is smaller than the main line. It has a valve that will modulate the cooling flow to adjust for different engine operating conditions. The adjustment is forced by engine control. Cooling flows for Vanes 2-4 are controlled by disc cavity temperatures. If more cooling flow is needed to bring down disc cavity temperature to the control limit the valve will open up to bring in more cooling flow. Disc cavity limits are used to keep turbine parts at a safe operating temperature.

If an engine is having trouble staying within disc cavity temperature limits, cooling flows can be adjusted by changing orifice plates in the main or bypass lines. This, however, should be done with care since changing cooling flows will have an impact on engine life and engine performance.

To monitor cooling flows a good approach is to look at disc cavity temperatures as well as bypass valve positions. Comparing actual disc cavity temperature with what it's being controlled to will give an idea if an engine is being overcooled or undercooled.

Another useful exercise is to look at bypass valve position for vane 2, 3 and 4 cooling flows. If the bypass valve is fully open that would mean that not enough cooling flow is being provided. If the bypass valve is fully closed, that would mean that the engine is being overcooled. It should be noted that some control systems treat 100% as fully open and some as fully closed. A quick check in the control manual should clear up this issue.

It's best to trend both bypass valve positions and disc cavity temperatures over a range of temperatures and engine load operation to get a better idea if the orifice plates in the main lines are sized properly.

The impact of cooling flows on engine life and engine performance is presented later in the article.

Engine upgrades often are a result of increasing the firing temperature, improvements of the turbine and compressor efficiency and an increase in the safety margin of the engine components by better cooling or new technology, such as coatings or internal blade geometry.

Principles of Gas Turbine Cooling

The OEMs may represent the cooling in a diagram often referred to as the worm chart. Figure 1 shows a schematic of the turbine and the various amounts of flow as they are reintroduced to the gas path.

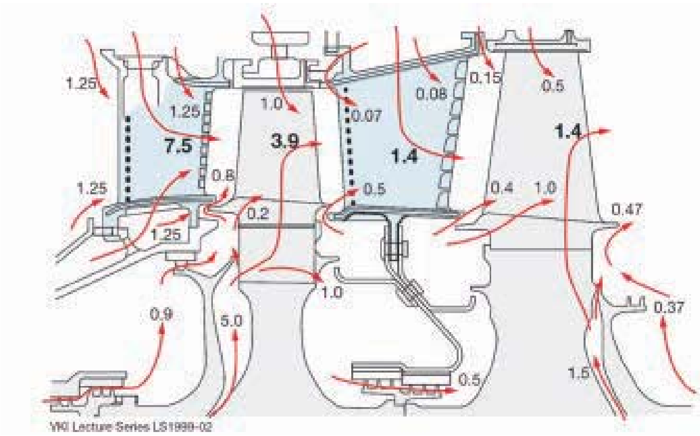

Figure 1 – A "worm chart" showing cooling flows in the first two stages of a gas turbine. (Courtesy VKI lecture series LS1999-02)

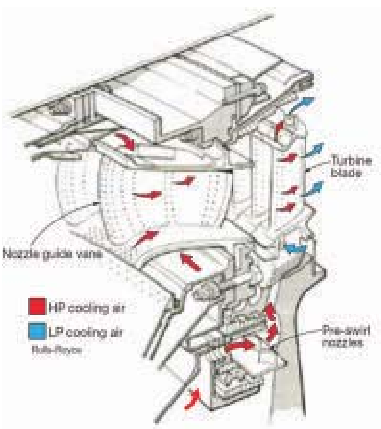

Figure 2 – The flow circuit diagram (in this case between the first nozzle and the second stator). (Courtesy Rolls-Royce)

Actual representation of the cooling flows can be modeled using a more sophisticated 3-D characterization of the flow as shown in Figure 3.

Figure 3 – Computational fluid dynamics (CFD) model of cooling flow emerging on the surface of a turbine blade and its influence by the main stream flow. (Courtesy of B&B-AGEMA GmbH)

Effect of Gas Turbine Cooling on Performance

To demonstrate the effect of cooling flow on the performance of a gas turbine typical of a simple cycle or combined cycle operation CPS produced a theoretical model in a commercially available code (GasTurb) and changed cooling flows to see the impact on operating point (the model uses a generic compressor and turbine map). GasTurb allows changing the amount of cooling flow and the energy of cooling flow.

Cooling Flows Overview

As discussed, the main purposes of cooling flows are to maintain safe vane and blade metal temperatures during gas turbine operation. Cooling flows have a net positive result on gas turbine performance. Since turbine cooling flows do not go through the combustor, some of the work is lost. However, cooling flows allow for a higher firing temperature which leads to a net higher gas turbine power output and better efficiency.

Engine Operation Overview

At base-load, most gas turbine engines are operated on an exhaust temperature control curve. A sample exhaust temperature control curve is presented in Figure 4.

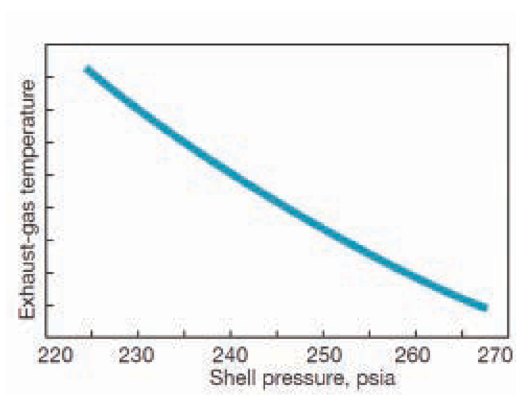

Figure 4 – Sample Base-load Exhaust Temperature Control Curve

The base-load exhaust temperature control curve is usually created by running the engine model through a range of ambient temperatures at some given design firing temperature. Based on the model output and site specific conditions, a control curve for base-load operation is created. The above control curve was created using an F-frame model developed in GasTurb.

The main disadvantage of the curve is that there is no awareness of what the actual firing temperature of an engine is. So if cooling flow increases, firing temperature increases as well in order to maintain the same exhaust temperature output for a certain shell pressure. On the other hand, if cooling flows decrease the exhaust

...Continued on next page

TECHNICAL ARTICLE

...Continued from previous page

temperature will decrease, so now firing temperature will drop in order to maintain the exhaust temperature called out by the control curve.

Firing temperature in this case is referred to as the temperature coming out of the combustor. The industry standard nomenclature for firing temperature is T4, and this nomenclature will be used from here on.

To predict engine cooling flows, site specific gas turbine models are needed. Generating these will usually require performance software and a good amount of reliable engine data. However, measuring cooling flows is not as complicated. By recording temperature, pressure and pressure drop across a known orifice, it can be calculated to keep track of cooling flow measurements.

One of the main reasons to track cooling flow measurements is to have an idea of how T4 is changing with time. Knowing the exact value is not the goal here. With engine variations and inability to track vane 1 cooling flow, the actual T4 value is very hard to determine. However, knowing the trend of T4 will help assess and make decisions regarding engine performance.

First law of thermodynamics states that energy is always conserved.

Energy in = Energy out

A T4 estimate can be calculated by creating a heat balance around the combustor. Total airflow into the engine can be computed from a heat balance created around the engine. Proper plant instrumentation has to be installed and calibrated in order to accurately determine inlet air flow.

While total airflow into a gas turbine can be computed from a heat balance around an engine, air flow into a combustor will depend on how much cooling flow was taken off of a compressor prior to air reaching the combustor.

In order to have an accurate representation of cooling flows, instruments that are used to calculate flows have to be regularly calibrated. It's best to set up a calibration plan for the whole gas turbine to make sure that the instrumentation shows what is actually going on with the engine.

With accurate data and a bit of engineering "know-how" engine performance can be assessed.

Benefits of Measuring Cooling Flows

Effect of Cooling Flows on Engine Operation

The benefits of monitoring engine cooling flows are being able to better assess engine performance and engine operation.

Upcoming plots were created using commercial software, GasTurb. The software allows modeling of heavy duty gas turbines along with other turbomachinery. An F-frame engine was modeled based on public data available. GasTurb uses generic, publicly available compressor and turbine maps.

The plot shown in Figure 5 shows the impact of cooling flow changes on firing temperature, power output, heat rate and exhaust energy.

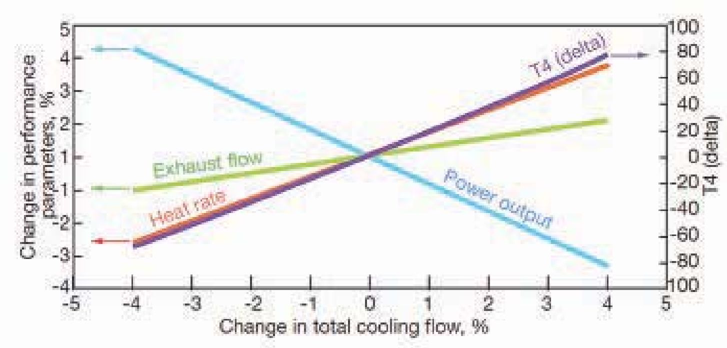

Figure 5 – Effect of Cooling Flows on Engine Performance

In the plot above, total engine cooling flow is being changed by +/- 4%. Based on experience, total cooling flow can account for up to 20-25% of total engine flow.

The plot above was created by keeping an engine on the base-load exhaust temperature control curve that was generated based on the GasTurb model. This way the changes presented more closely resemble actual changes that may be seen during operation.

The power and heat rate impact is significant from the performance point of view. However, just as significant is the impact that firing temperature may have on the lifecycle of the turbine parts. Based on experience, increasing the firing temperature by +40 deg F may decrease the life of hot section parts by 50%!

If turbine firing temperature is being trended any spikes or falls in T4 can be identified and immediately investigated. That way there are no surprises that may cause extended scheduled or even forced outages.

Maintaining Optimal Engine Performance

Another benefit of keeping track of cooling flows and trending T4 is maintaining optimal engine performance output. As mentioned before, the base-load exhaust temperature control curve is created based on design firing temperature. It is not aware of what the actual engine firing temperature is.

It is well known that turbine degradation has an inverse exponential profile. Most of the degradation is seen in the first few thousand hours, with degradation leveling out as more time goes on. A sample degradation curve is presented in Figure 6.

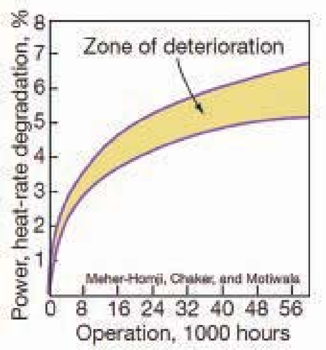

Figure 6 – Long-Term Deterioration of Power and Heat Rate Showing Zone of Deterioration versus Operating Hours.

Ref. "Performance Deterioration in Industrial Gas Turbines." Cyrus B. Meher-Homji, Mustapha A. Chaker, and Hatim M. Motiwala.

An engine completing an outage may have tight blade clearances in the turbine sections as well as new turbine components and sealing (providing these parts were replaced). Clearances will open up as the engine goes through several initial thermal cycles. As shown, seals will also see most degradation during those initial few thousand hours of operation.

This will cause the gas turbine to degrade. Once the gas turbine is degraded it is not able to extract as much energy out of the working fluid (mix of air and fuel) which causes the gas turbine exhaust temperature to go up. The control curve "sees" the exhaust temperature going up and will cause the engine to decrease the firing temperature. If the firing temperature decreases, that's a big plus for the parts since now their lifecycle is extended. However, it is detrimental to engine performance.

Figure 7 shows how decreased firing temperature due to engine degradation affects an engine's performance.

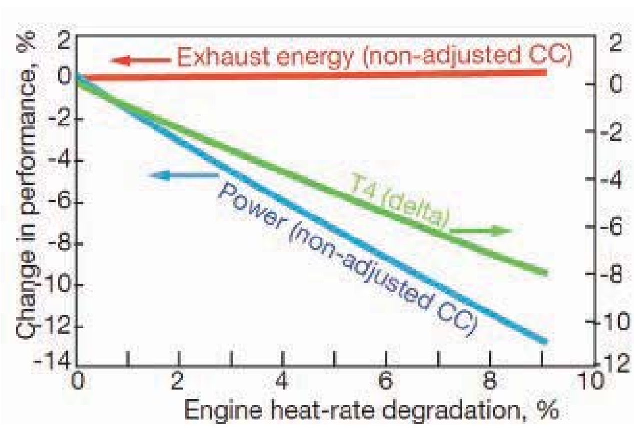

Figure 7 – Performance Behavior with Engine Degradation

For the above plot, the GasTurb model was maintained on the design exhaust temperature control curve. Thus T4 is dropping as engine heat rate* increases. Engine heat rate increase is modeled based on turbine degradation only. Compressor degradation is not included.

As mentioned previously, because the turbine is not able to extract as much work out of the working fluid, the exhaust temperature goes up and T4 has to drop in order to stay on the control curve.

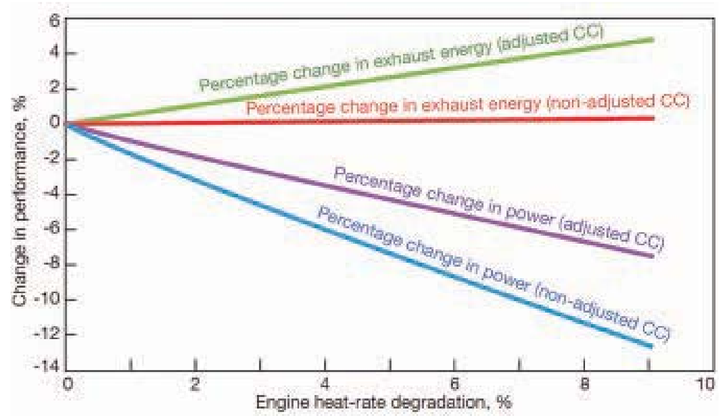

Figure 8 – Impact of Maintaining Constant T4 through Engine Degradation

Figure 8 shows a plot of how an engine performance can be optimized by adjusting the base-load control curve, so that an engine operates at constant T4.

Blue and red lines are the same as from Figure 7. Purple and green lines were developed by keeping the firing temperature at the design level as the engine degrades.

In Figure 8, the purple line represents the unrecoverable and expected engine degradation. The blue line represents power loss due to both unrecoverable engine degradation and inability of the control curve to adjust so that the engine is maintained at a constant T4 value.

The benefit of monitoring cooling flows and trending firing temperature is that when firing temperature drops, the control curve can be adjusted and some of the gas turbine performance (and hence output) may be re-gained.

An example of potential power recovery due to a control curve adjustment is presented here.

Sample potential recovery calculation	
Engine operation since "as-new" condition, hr	8000
Heat-rate loss over 8000 hr (Fig 6), %	3.2
Engine output at ISO, MW	200
Power loss with non-adjusted control curve (blue line in Fig 8), %	–4.8 (9.6 MW)
Power loss with adjusted control curve (purple line in Fig 8), %	–2.8 (5.6 MW)
Potential recoverable power output, %	~2 (4 MW)

Table 1 – Sample Potential Recovery Calculation

That's a potential recovery of 4MW at 8,000 hours. This value is only an estimate because the heat rate deterioration is assumed to be due to turbine degradation only. Compressor degradation is not considered.

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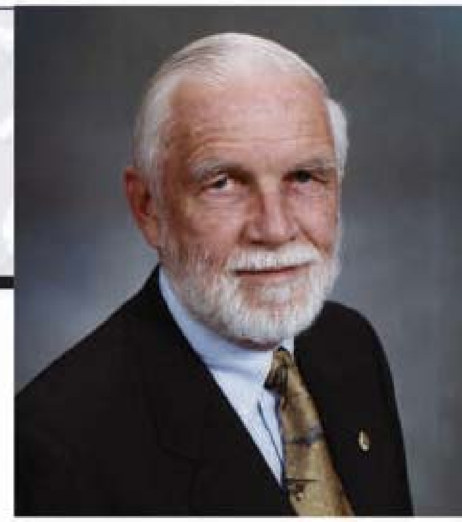
As the Turbine Turns

60 Years of Turbo Expo

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



For the last three score years, the International Gas Turbine Institute's Turbo Expo has been the preeminent gas turbine conference. Our upcoming IGTI June 15-19, 2015 Montreal Turbp Expo will be the 60th such gathering – surely a record in longevity and vitality for a single technology conference.

Our very first, then called the First Annual GasTurbine Conference and Exhibit, was held April 16-18, 1956 at the Hotel Statler in Washington, DC. This inaugural all-gas turbine meeting had 25 exhibitors, 6 technical sessions with a total of 17 papers and an attendance of 750. Now fast forward 59 years to our Düsseldorf Turbp Expo in 2014. It had over 1200 reviewed papers delivered in 332 technical sessions over a five-day period. Exhibit displays were offered by over 100 companies to some 3000 attendees. We fully expect Montreal to mirror these Düsseldorf numbers, reflecting the sixty year growth of the Turbp Expo technical community and the gas turbine industry itself.

The Very Beginning

On May 8-10, 1944, ASME's 17th National Oil and Gas Power Conference was held mid-continent (wartime) at the Mayo Hotel in Tulsa, OK. The technical program consisted of four sessions (a total of ten technical papers); three on diesel engine technology and one (two papers) on the newly emerging gas turbine. As *Mechanical Engineering* magazine reported: "Demonstrating the technical interest aroused by the gas turbine, the first new prime mover in 50 years, a capacity crowd of approximately 250 attended the first technical session which was devoted to that subject." In anticipation of this intense interest in new gas turbine technology, on May 7, 1944, the Executive Committee of the Oil and Gas Power Division voted to form a ten member Gas Turbine Coordinating Committee (GTCC) to provide "...coordination and dissemination of new technical information on the gas turbine through periodic meetings and the presentation of technical papers." This newly formed GTCC, with R. Tom Sawyer of the American Locomotive Company as its chairman, was the start of IGTI.

As the international gas turbine community grew, the number of papers sponsored increased to the point that it was obvious a separate meeting was needed. The first one was held in Washington, DC., in 1956 as mentioned above, with succeeding annual meetings taking place in other US cities. In 1966 Zurich was chosen as the first European site for the gas turbine conference. Not long after, the annual meeting developed into its present schedule of locating in North America and Europe in alternate years.

1979 and Onward

As the gas turbine conference increased in size in the years after 1956, it became more and more apparent that a separate ASME staff was needed to take over the administration and operation. In 1978, Donald D. Hill became Director of Operations and set up his office and staff in Atlanta. In 1986 it was made an institute of ASME - the International Gas Turbine Institute.

Projects and services developed, produced and financed by IGTI have increased since 1979, supported by a staff of five to seven. The Atlanta office had been IGTI's headquarters and hub of its international activity. Last March the ASME Board of Governors voted to close the Atlanta office, and it has been moved to new offices in Houston.

The Future

What do the next 60 years hold for IGTI? During the last 60 TURBO EXPO years,

As the Turbine Turns...

through the efforts of many thousands of engineers (many of them IGTI participants), gas turbines have come to dominate aircraft propulsion and now enable unmatched thermal efficiencies to be achieved in electric power plants. With energy a central concern in modern society, gas turbine technology will continue to be innovative, with Turbp Expo as a forum.

One of the global areas for booming markets – and future technology – is Asia. As a reflection of this, IGTI will be holding Turbp Expo 2016 in Seoul, South Korea.

This will not be IGTI's first venture in Asia. In the past we have held technical conferences in Beijing, Jakarta and Singapore. For the last three years there has been an IGTI sponsored annual gas turbine conference in India.

The first of these was the 1985 Beijing International Gas Turbine Symposium and Exposition – the very first such Western-sponsored gas turbine conference in China. Art Wennerstrom, now retired Wright-Patterson Air Force lab director and past IGTI board chair, was a key organizer of this very early IGTI China meeting. He worked closely with Prof. Chung-Hua Wu, a fellow of the Chinese Science Academy. During pre-conference discussions, PRC government officials asked Don Hill how many Chinese attendees IGTI wanted. The number agreed upon was 25,000! As a session organizer and session chair at this Beijing conference I didn't count the many Chinese going through the exhibit area – but there was always a long, long queue outside, all during the exposition, composed mostly of aviation and power plant personnel from all over China.

The future of gas turbines and IGTI is bright. I urge you all to participate in the start of IGTI's next 60 years.

Pre-Conference Workshops

Gas Turbine Aerothermodynamics and Performance Calculations

Saturday, June 13, 2015

Instructor: Syed J. Khalid, Parametric Solutions Inc.

Introduction to Optimization Methods and Tools for Multidisciplinary Design in Turbomachinery

Saturday & Sunday, June 13 & 14, 2015

Instructor: Dr. Tom Verstraete, Von Karman Institute for Fluid Dynamics

Modeling Rotating Compressible Flows for Advanced Internal Cooling Design

Sunday, June 14, 2015

Instructor: Dr. Bijay (BJ) K. Sultanian, Ph.D., PE, MBA

The Interaction of the Technologies to Design an Integrally Geared Centrifugal Compressor

Sunday, June 14, 2015

Instructors: Jim Hitt, Cameron Compression Systems; Anand Srinivasan, Cameron Compression Systems

Gas Turbine Component Life Prediction and Life Cycle Management

Sunday, June 14, 2015

Instructors: Ashok Koul, Ph.D, P.Eng., FASM, Life Prediction Technologies Inc; Avisekh Banerjee, Ph.D, P.Eng., Life Prediction Technologies Inc.

Design, Operation and Maintenance Considerations for Cogeneration and Combined Cycle Systems

Sunday, June 14, 2015

Instructors: Rakesh Bhargava, Ph. D., Innovative Turbomachinery Technologies Corp; Cyrus Meher-Homji, P.E., Bechtel Corporation; Manfred Klein, MA Klein & Assoc; Steve Ingistov, P.E., Watson Cogeneration Company

...Continued from page 51

Conclusion

Cooling flow monitoring along with properly calibrated plant instrumentation allows for trending of engine firing temperature and engine performance using fundamental thermodynamics. Performance issues arising during engine operation can be accurately assessed and plans for corrections can be made during scheduled outages.

A quick way to determine if there are cooling issues in an engine is to trend disc cavity temperature and bypass valve positions. If the bypass valves are either fully open or fully closed that may lead to engine undercooling or overcooling. If disc cavity temperatures are under the limits that they are controlled to then the engine is being overcooled; if they are over the limits then the engine is being undercooled. The trends should be plotted for a range of ambient conditions and engine load variations.

Neglecting to monitor cooling flows and engine health may lead to underperforming engine, unnecessary forced outages or early replacement of engine components.

References

1) GasTurb simulates the most important gas turbine configurations used for propulsion or for power generation. Virtually all gas turbine performance simulation problems can be solved with GasTurb, http://www.gasturb.de/

**One measure of the efficiency of a gas turbine that converts a fuel into heat and into electricity is the heat rate. To express the efficiency of a gas turbine as a percentage, divide the equivalent Btu content of a kWh of electricity (which is 3,412 Btu) by the heat rate. For example, if the heat rate is 10,140 Btu, the efficiency is 34%. If the heat rate is 7,500 Btu, the efficiency is 45%.*

A VIEW FROM THE CHAIR

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

Welcome back to the Global Gas Turbine News, the quarterly newsletter of the ASME International Gas Turbine Institute (IGTI). In this issue, I would like to update you on GT India 2014, ORC 2015 and Turbo Expo 2015 as well as changes in Turbo Expo's review process and improved communication between IGTI and editors of its journals.

GT India 2014 was held in New Delhi, India, December 15-17, 2014. 238 participants from 12 countries registered for the conference, and 85 papers were presented. Nicholas Cumpsty delivered the keynote address, and many other IGTI members led workshops and delivered invited lectures. There was also strong industry participation, including a panel session with representatives from GE, Siemens, and MHI and an exhibit featuring ANSYS and GE. I thank our Indian organizers and the corporate sponsors - GE, ANSYS and QuEST.

The ORC Power Systems Committee of IGTI will organize the Third International Seminar on ORC Power Systems, to be hosted by the Ghent University and the University of Liege, in Brussels, Belgium, October 12-14, 2015. The global ORC market is growing rapidly, and IGTI aims to be at the forefront of this emerging field. Further details can be found at http://www.asme-orc2015.be.

Of course, Turbo Expo remains the flagship conference for IGTI. For the 60th Expo, to be held in Montreal on June 15-19, 2015, 1,170 papers are undergoing review process at the time of writing this article. These numbers promise to be even larger than the previous North American record set in San Antonio in 2013.

The key to the continued success of Turbo Expo is its review process. By custom, the Review Chair interfaces directly with Session Organizers to ensure timely and thorough reviews. With increased volume, the existing system has become unmanageable. Therefore, at the request of the IGTI Board, Howard Hodson has been working with a group of volunteers to further improve the process. In our new process, the objective is to "devolve responsibility and incentivize the chain of command" by getting Technical Committee Chairs and Vanguard Chairs more involved in the review process. As in the past, the Review Chair will still oversee the entire review process for Turbo Expo; however, the Technical Committee Chairs and Vanguard Chairs will now oversee the review process within their committees and tracks, respectively. These changes will be tried out in the Turbomachinery Committee and Aircraft Engine Committee for Turbo Expo 2015. If successful, such practice will be recommended to all of the committees in the future.

Along with conference organization, journal publication is the other core activity of IGTI. IGTI's two journals are the *Journal of Engineering for Gas Turbines and Power* and *Journal of Turbomachinery*; the editors of these journals volunteer countless hours interfacing directly with authors. I would like to take this opportunity to thank Dave Wisler and Ron Bunker for their selfless service as editors.

To enhance communication between editors and the IGTI community, the IGTI Board began to meet regularly with editors, beginning in 2014. It is hoped that this change will enable IGTI to better achieve its mission to promote the advancement of technologies and knowledge about turbomachinery.

I look forward to seeing all of you at 60th Turbo Expo in Montreal.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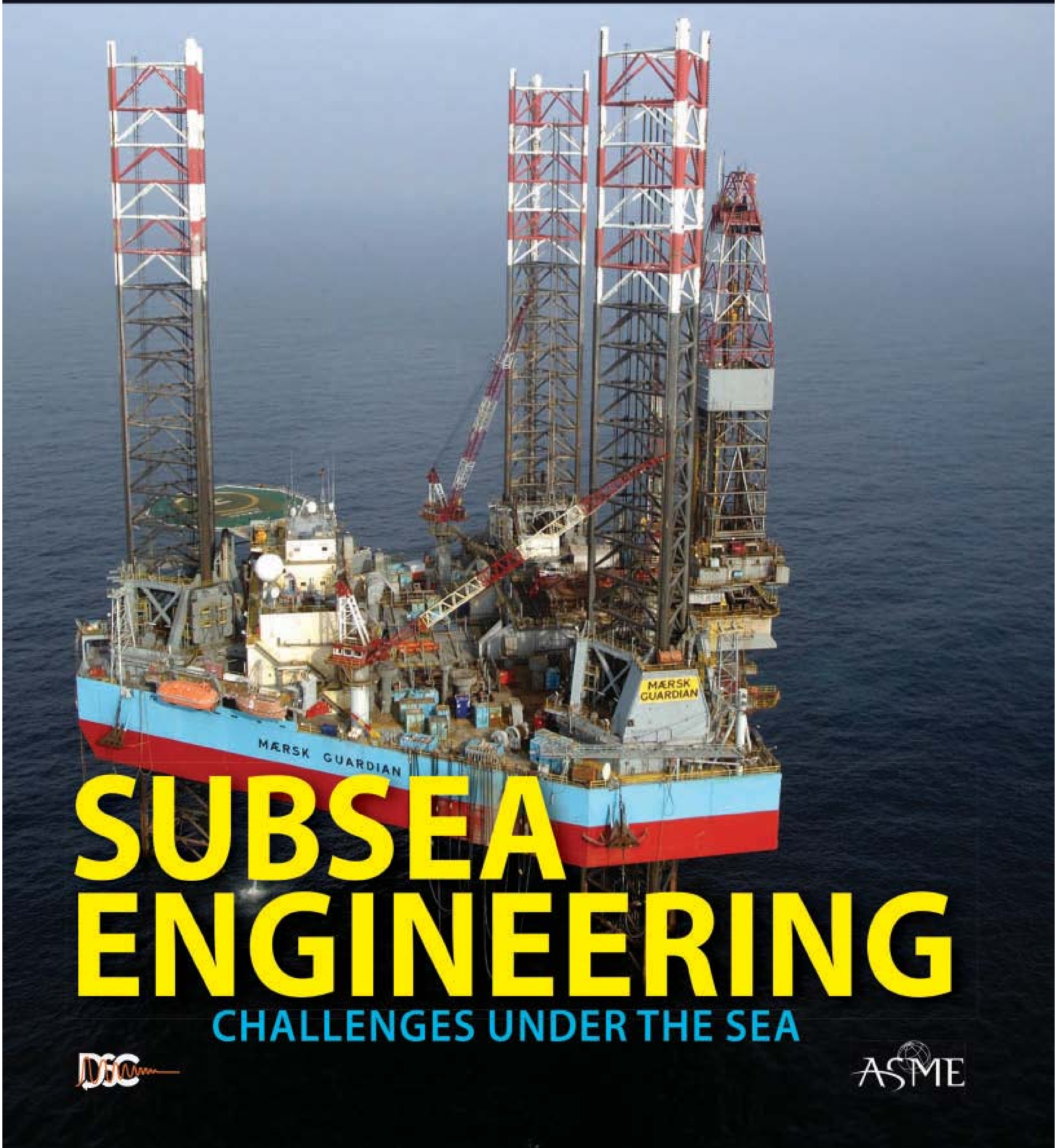
DYNAMIC SYSTEMS & CONTROL

MARCH 2015 VOL. 3 NO. 1



SUBSEA ENGINEERING

CHALLENGES UNDER THE SEA

DSC

ASME

SUBMIT ARTICLE IDEAS TO:

PETER H. MECKL, PURDUE UNIVERSITY, meckl@purdue.edu (765) 494-5686

SUBMIT DSCD NEWS ITEMS TO:

RIFAT SIPAHI, NORTHEASTERN UNIVERSITY, rifat@coe.neu.edu

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

June 2015
Humanoid Robots

Subsea Engineering Challenges

This issue begins the third year of publication for the ASME *Dynamic Systems and Control (DSC) Magazine*. It also represents the first issue for which I am serving as the editor. This month's issue features the oil and gas exploration industry, with particular focus on the challenges of engineering subsea wells.

The three feature articles cover deepwater oil production. The first article, by Matthew Franchek, introduces the technologies used in subsea engineering and lays out the challenges that arise in the high pressures and low temperatures that exist at depths beyond 10,000 feet. The second article, by Egidio Marotta, describes a new analysis led design process that uses predictive tools to aid in the design of undersea components to ensure reliable performance under adverse conditions. The third article, by Phaneendra Kondapi, provides engineering solutions for flow assurance, guaranteeing that oil will flow even with wax build-up, solid deposition, and corrosion. I'm grateful to Matt Franchek, who helped identify the authors in this feature section.

Although not directly related to subsea engineering, the fourth and final article, by Paul Phamduy and Maurizio Porfiri, describes a novel robotic fish design, so it is in keeping with the nautical theme. They detail the design of the robotic fish, including strategies to allow the fish to maneuver in the water by filling or emptying ballast tanks. The robotic fish can be controlled using a tablet and is designed to allow children to use it for learning about science with an interactive and fun experience.

In the next issue of this magazine, the focus will turn to humanoid robotics. As always, if you have any ideas for articles or additional content, please contact me **(meckl@purdue.edu).**

Peter H. Meckl
Editor for DSC Magazine

2014 ASME Dynamic Systems and Control Conference

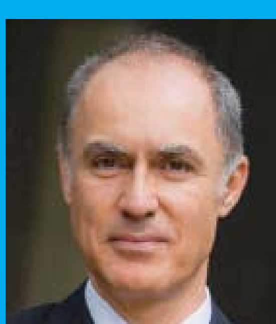
The 2014 ASME DSC Conference was held October 22-24 in San Antonio, Texas, under the leadership of General Chair **Suhada Jayasuriya** and Program Chair **Jordan M. Berg**. In remembrance of Professor Suhada Jayasuriya, who passed away on July 12, 2014, the conference organizing committee held a program with a celebration of Suhada's achievements and contributions to the DSC community, and dedicated this DSC conference to Suhada.

The 2014 DSCC comprised 280 papers, selected from 370 submissions covering the broad field of the theory, practice, and education of automatic control. The conference technical program also included special and frontiers sessions focusing on energy, bioengineering, medicine, advanced manufacturing, and cybersecurity, as well as a Mathworks workshop on techniques for project-based learning with low cost hardware support, graduate student lunch workshop, and student-industry interaction session.

The conference featured plenary talks by **Jose A. Gutierrez** (Director of Technology and Innovation for Transocean Ltd.) on "*Innovation Journey in the Oil & Gas Drilling Industry*," and by **Robert Ambrose** (NASA) on "*NASA's Challenges for Robot Command and Control*". The Nyquist Lecture was given by **Naomi E. Leonard** from Princeton University, "*On the Nonlinear Dynamics of Collective Decision-Making in Nature and Design*".

The 2014 ASME DSC Conference has also benefited from the generous funds provided from the ASME DSC Division, to support the attendance of 82 graduate students at the conference. Moreover, the conference

Presentation of the 2014 Rufus T. Oldenburger Medal and Award to **Robert Bitmead**, University of California, San Diego (on right) by **Satish Narayanan** (ASME DSC Division, 2014-2015 Honors and Awards Committee Chair).



ERIK JEPSEN

KRSTIC RECEIVES THE IFAC HAROLD CHESTNUT TEXTBOOK PRIZE

Professor Miroslav Krstic has received the triennial Chestnut Textbook Prize of the International Federation of Automatic Control (IFAC) for the book *Boundary Control of PDEs*. The award is named in honor of late Harold Chestnut, the founding president of IFAC ('57), president of IEEE ('73), and member of NAE ('74).

2014 ASME Dynamic Systems and

ASME DYNAMIC SYSTEMS AND CONTROL DIVISION (DSCD) MEMBER NEWS

UNIV. OF MARYLAND COLLEGE PARK

■ **Jin-Oh Hahn** (University of Maryland College Park) receives Young Investigator Program Award from the Office of Naval Research, for his research on automated critical care systems. With support from ONR, Hahn will tackle the problems on mathematical modeling and closed-loop control of medication infusion processes applicable to the care of surgical and critically ill patients.

UNIV. OF TEXAS PAN AMERICAN

■ **Dumitru Caruntu** is the recipient of 2013-2014 Excellence Award in Research at the University of Texas Pan American. Recently, Professor Caruntu has also been named Associate Editor for the ASME *Journal of Dynamic Systems Measurement and Control*.

CLEMSON UNIV.

■ **Simona Onori** from Clemson University is leading the efforts in automotive transportation systems. As an active member of the ASME Automotive Transportation System Technical Committee since 2008, and a recently elected Chair of the Technical Committee of Automotive Controls by the IEEE Control Systems Society Board of Governors, Simona is now in a unique position to further the collaborations between the two technical committees, to strengthen the ties between ASME and IEEE in this field, and to expand toward stronger and more synergistic activities between the two societies.

Charles Stark Draper Innovative Practice Award was presented to **Ranjan Mukherjee**, Michigan State University (on right).

This year's Nyquist Lecture was given by **Naomi E. Leonard**, Princeton University (on right).

Henry M. Paynter Outstanding Investigator Award recipient was **Andrew Alleyne**, University of Illinois at Urbana-Champaign (on right).

Control Conference: *San Antonio*

Best Student Paper Award Finalists: from left to right: **Byung-joo Kim** the winner (University of Michigan), **Xin Zhou** (University of Michigan), **Kuo Chen** (Rutgers University), **Sanaz Behbahani** (Michigan State University), **Changliu Lio** (University of California at Berkeley). **Satish Narayanan** (at rear).

organizing committee continued the tradition of holding a Best Student Paper Award competition. In this year's competition, five student finalists presented their research results in a dedicated session.

On Thursday evening, the conference banquet and awards ceremony were held. The DSC Division level awards this year were as follows. Rudolf Kalman Best Paper Award was presented to **Zheng Shen** and **Christopher D. Rahn** from the Pennsylvania State University on their work "Physics-based model of a valve-regulated lead-acid battery and an equivalent circuit"; **Dawn Tilbury** from University of Michigan received the Michael J. Rabins Leadership Award; the Charles Stark Draper Innovative Practice Award was presented to **Ranjan Mukherjee** of Michigan State University; Professor **Andrew Alleyne**, University of Illinois at Urbana-Champaign, received the Henry M. Paynter Outstanding Investigator Award; and the Nyquist Lecture was presented by **Naomi E. Leonard** of Princeton University.

Satish Narayanan the Chair of the 2014-2015 Honors and Awards Committee of ASME DSC Division made the opening remarks at the awards ceremony.

This year's ASME Rufus T. Oldenburger award was presented to **Robert Bitmead** of the University of California, San Diego. Professor Bitmead gave a lecture on "*Connections: Control on Constraints, Traffic Instabilities and Healthcare Service Scheduling.*"

News contents edited by Rifat Sipahi.

UPCOMING CONFERENCES

12TH IFAC WORKSHOP ON TIME DELAY SYSTEMS
June 28-30, 2015
University of Michigan, Ann Arbor, MI,
http://me.engin.umich.edu/dirifac/

2015 EUROPEAN CONTROL CONFERENCE
July 15-17, 2015
Linz, Austria
http://www.ecc15.at/

ASME 2015 INTERNATIONAL DESIGN ENGINEERING TECHNICAL CONFERENCES AND COMPUTERS & INFORMATION IN ENGINEERING CONFERENCE
August 2-5, 2015
Boston, MA
http://www.asmeconferences.org/idetc2015/

PROJECT ATLANTIS:

Subsea Oil and Gas Production Cities

Matthew A. Franchek
Founding Director of Subsea Engineering
Professor of Mechanical Engineering
University of Houston

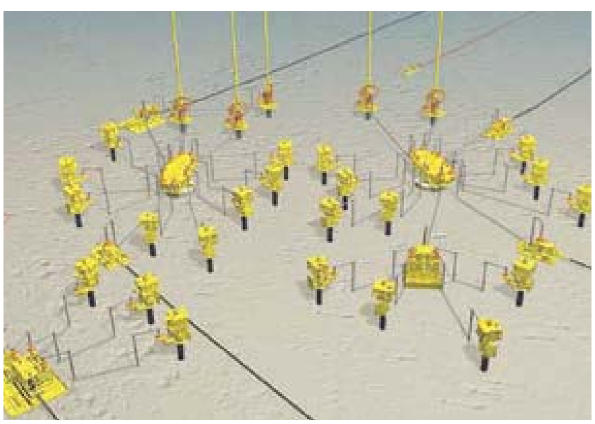


FIGURE 1 **Subsea multi-well and multi-manifold oil and gas production system.**
REPRODUCED FROM THE OIL AND GAS JOURNAL

Offshore oil and gas production has a history dating back to the late 1890s. The first offshore well was located 300 ft. from the California shoreline and connected to the coast by way of a pier [1]. The success and production performance of this first well produced a gush of additional offshore wells, each reaching further into the water. The next milestone in offshore oil and gas production was in 1947 when Kerr-McGee reached over 10 miles from the shoreline to produce hydrocarbons at a depth of about 20 feet [1-2]. The production facility was built on a "static-structure" that stood tall above the water line and its foundation was located on the mud-line (ocean-floor). What makes this offshore facility significant is that the shoreline was no longer visible from the production platform. By the mid-1970s, Shell Oil Company transformed offshore production through the marinisation of shallow water platform technologies to reach a reservoir in the Gulf of Mexico located 1,000 ft. deep, the Cognac. At the time, the Cognac production facility was the tallest structure in the world. A decade later, Shell continued to lead the quest for oil and gas production in deeper water with the world's first tension leg platform (TLP). The TLP is a floating structure with "sets-of-tentacles" located at each corner and fixed to the seabed. Controlling the tension in each tentacle enables dynamic control of the floating platform, namely isolation from wave motion. By the 1990's, the need for a production facility to hold onto the seabed and perhaps the desire to do so disappeared. The reason is to lower the capital expenditures (CAPEXs), thus improving the economic feasibility of producing deeper water reservoirs. Today's offshore oil and gas production facilities are located on the seabed. The only evidence of offshore energy production would possibly be a floating vessel, known as floating production and storage offloading (FPSO) vessel, used to transport the hydrocarbons to an onshore facility.

There are massive oil and gas reserves located in ultra-deepwater (depths greater than 10,000 ft.). Equally impressive to the billions of barrels of oil located in ultra-deepwater is that these reservoirs have shut-in pressures of 15,000 psi. The fundamental engineering challenges facing today's ultra-deepwater oil and gas production reside under a new engineering discipline, the subsea engineer. There is uniqueness to the harsh underwater location that manifests itself as a corrosive environment with external pressures of 5,000 psi and internal pressures reaching 15,000 psi. These underwater facilities (equipment) must have a useful service life of 30 years to be cost-effective despite being subject to huge producing well uncertainties (flow composition and pressures). Of even greater importance is that subsea production facilities must completely protect the environment.

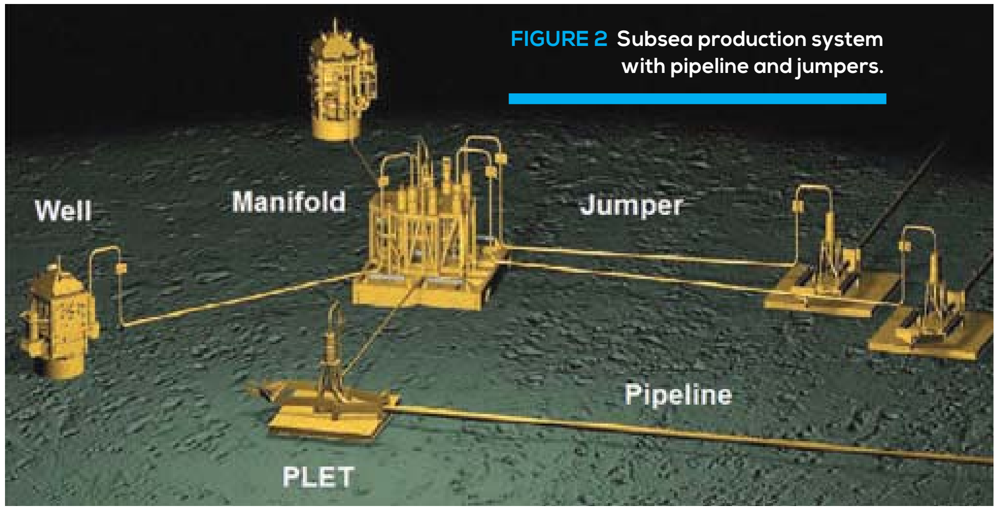


FIGURE 2 Subsea production system with pipeline and jumpers.

SUBSEA OIL AND GAS PRODUCTION EQUIPMENT

The major cost for producing an ultra-deepwater reservoir is the drilling operation. At this stage it is important to note that oil and gas reservoirs are not subsurface cavities filled with crude oil. Instead a reservoir is a subsurface formation of permeable rock containing hydrocarbons. Ultra-deepwater drilling is accomplished using dynamically positioned (DP) drill ships enabled through global positioning systems (GPS). The drilling operation is known as upstream oil and gas engineering. Offshore drilling operations are occurring everyday where the drill string (thick walled piping with a bit attached at the end) travels 2 miles to reach the mud line and then another 3 miles to the reservoir. Roughly speaking, this is equivalent to stretching a guitar string the length of a football field and twisting one end to perform drilling. Once the well is established, the engineering operations necessary to produce oil and gas are known as downstream engineering. This phase of subsea oil and gas production focuses on the design and installation of the subsea production system (Figure 1). The primary issues facing downstream engineers include equipment reliability, connectors (connections between subsystems) and multiphase flow (flow comprising oil, gas, water and sand).

Subsea hydrocarbon production facilities are separated into two primary categories, subsea (Figure 1) and topside (above the water). To describe an underwater production facility, we will begin at the wellhead. The wellhead is a pipe with a flange put in place by upstream operations. This pipe (well casing) travel into the earth's crust to penetrate the reservoir. The well casing within the reservoir is perforated to allow flow from the high-pressure reservoir. Bolted to the well casing flange is the so-called Christmas Tree (XTree) (Figure 2, see the engineered system below the word "Well").

XTrees can be either horizontal or vertical and allow both access and control of the reservoir. These two functions are needed to guarantee production flow (flow assurance) over the life of the well while producing the reservoir in a manner that does not collapse its porous rock composition.

The product flows from the XTree to a subsea manifold via a jumper (Figure 2). The jumper is a pipe designed to withstand sand erosion and product corrosion. All jumpers have U-like shapes enabling stiffness/flexibility and function [3].

Owing to the capital expenditures associated with ultra-deepwater systems, it is mandatory for each subsea production site to have multiple wells (Figure 2). Each well has its dedicated XTree and jumper, and is producing hydrocarbons. A subsea manifold gathers these individual productions into a central place. Subsea manifolds are not small. In fact, subsea manifolds can reach dimensions of up to 75ft. x 40ft. x 20ft., having huge weights that match their dimensions. A subsea manifold serves many functions. For example, the manifold allows access to the flow hydrocarbons to inject chemicals for flow assurance issues. Manifolds provide the primary location for pipeline cleaning using pipeline inspection gauges (PIGs). However, the primary function of the subsea manifold is to combine flow hydrocarbons from multiple wells and send the resulting aggregate through a single pipeline to the so-called tieback. The manifold is connected to the pipeline

FIGURE 3 **Subsea tieback with slug flow.**

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via the pipeline end termination (PLET) assembly.

Subsea tiebacks involve the transportation of flowing hydrocarbons collected at the manifold to an offloading location through a subsea pipeline (Figure 3). The FPSO previously cited is one example of an offloading facility. Other tieback locations include existing static structures of older offshore production facilities and back to shore. Tieback distances of over 50 miles are not uncommon with ultra-long tiebacks approaching 200 miles on the immediate horizon. Subsea pipelines are critical to the success of a subsea tieback. Subsea pipeline design is a multi-domain design problem concerned with multiphase flow, heat transfer, material erosion and corrosion, and many a misplaced ship's anchor. Pipeline designs are further complicated by irregular terrain of the ocean floor traveling over hills and valleys, and external vortex-induced vibrations (fatigue). The design, installation and maintenance of subsea pipelines are paramount for subsea production profitability and environmental protection.

The growing ultra-deepwater depths have begun to experience new challenges, viscous flow losses and hydrostatic head. Despite the high pressures of the reservoir, the pressure losses along the pipeline and hydrostatic head of reaching the surface have made artificial lift a necessity in many subsea applications. There are two basic artificial lift methods, gas injection and compression systems. Gas injection is the most common form of artificial lift. The injected gas is used to reduce the hydrostatic head in the riser to allow the reservoir to produce. Compression systems are multistage compressors driven by electrical motors. It is not uncommon for the electrical motors to be rated to 8 megawatts and stand about 20 feet tall. The multistage compressor comes in two varieties, single-phase and multiphase compression systems. Single-phase compressors have a subsea separator upstream which segregates the gas, oil, water and sand using gravity and baffles. Multiphase compressors do not require the upstream separator, directly boosting the pressure of the multiphase flow as it leaves the compressor. There are unfinished engineering challenges with both compression-based systems. The subsea separator has a foaming problem that occurs during the separation process. The multiphase compression system faces the stall phenomena similar to gas turbine engines. Both solutions face blade wear (due to sand) and corrosion.

If the tieback terminates to an existing platform or an FPSO, the pipeline must interface with a riser, a vertical pipe reaching the water's surface. Risers are subject to dynamic loading conditions caused by the water currents [4]. Risers are vulnerable to undesirable weather conditions such as hurricanes. Essentially, risers accumulate metal fatigue and present a

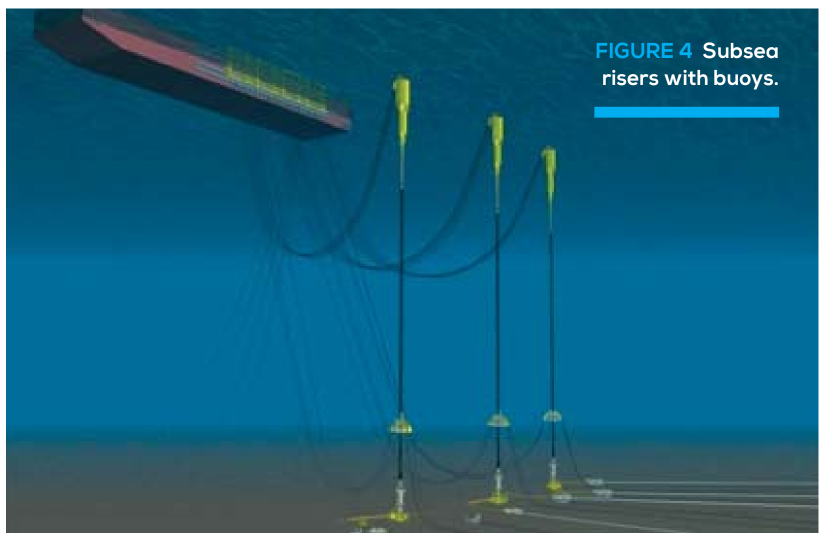

FIGURE 4 **Subsea risers with buoys.**

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completely different multiphase flow challenge than do pipelines (horizontal flow). Newly-designed risers are now terminating 300 ft. below the water's surface, thereby isolating them from storms. These risers have redundant buoys (the size of school buses) and cabling systems that provide riser support, stability and buoy separations.

The topside of subsea production is where the subsea production system is managed and the power necessary to run the subsea facility is supplied. Subsea production facilities are powered by two basic power forms, electrical power and fluid power. The electrical power supports sensors, subsea control modules (SCMs), and communication (including acoustic communication). The fluid power is the muscle controlling subsea production. The subsea gate valves (high pressure isolation) and subsea chokes (flow control) are actuated using hydraulics. Both forms of power have redundant sources for emergency shutdowns. Electrical power and hydraulic power are also stored subsea to reduce the source-to-consumption path. Also located on the topside are well intervention chemicals such as methanol, the master control system and emergency shutdown (ESD) system.

The topside and subsea production systems are connected to each other through an umbilical. The umbilical is a watertight conduit carrying electrical power, hydraulic power, chemical inhibitors, as well as other electrical conductors and optical fibers for sensor interfacing, communications and condition monitoring. The umbilical leaves the topside from the topside umbilical termination assembly (TUTA) and plugs into the subsea distribution unit (SDU). The SDU distributes electrical and hydraulic power, and receives sensor and other communications all through flying leads (cables and flow lines connecting one subsea subsystem to another).

ENGINEERING CHALLENGES FACE SUBSEA SYSTEM DESIGN

Designing subsea systems for 30 year long controllability, safety, maintenance, and real-time optimization are critical issues and present an open-ended problem. Below is a summary of the two primary challenges associated with the design of the subsea architecture. Topics not reviewed include condition and performance monitoring, materials and corrosion, and installation.

Safety is absolutely a primary focus on any subsea production system design. There must be multiple independent safety paths in place to isolate a producing well. The most common subsea safety system is located within the well. It is called the surface control subsurface safety valve and requires hydraulic pressure to keep the reservoir flowing. When hydraulic power is lost, the valve closes thus isolating the well. The subsea XTree can also be used to isolate the well by closing the choke. Downstream of the manifold is a high integrity pressure protection system (HIPPS). This system automatically closes a gate valve when the pressure in the pipeline is too high.

The presence of multiphase flow in a subsea production system complicates system design and operation. There are multiple flow regimes that can exist for multiphase flow in horizontal pipelines [5]. Pioneering work performed at the University of Houston provided mathematical relationships to predict the flow regime given gas and liquid velocities, including dispersed bubble flow, elongated bubble flow, slug flow and stratified flow to name a few. Vertical multiphase flow has completely separate flow regime prediction equations. However all of the cited multiphase flow studies are applicable to steady-state flowing conditions. The development of reduced-order mathematical models

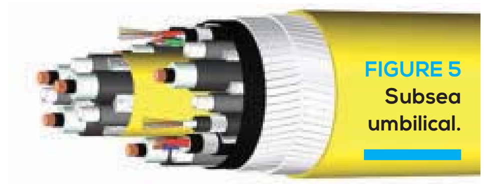

FIGURE 5 Subsea umbilical.

predicting multiphase flow under transient conditions is completely missing in the open literature. There is an unexplored coupling between the transient multiphase flow and the heat transfer (heat flow from the product through the pipeline and into the ocean environment). The field of modeling multiphase transient transport is important to the subsea architecture design and real-time optimization of subsea production.

SUMMARY

Subsea engineering presents many new challenges and opportunities for engineers from any discipline. An excellent tutorial reference source is [3]. Success in subsea engineering directly addresses energy security while protecting the environment and marine life. ■

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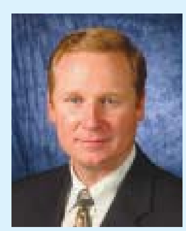
ABOUT THE AUTHOR



Dr. Matthew Franchek is the founding director of the University of Houston Subsea Engineering Program. He received his Ph. D. in mechanical engineering from Texas A&M University in 1991 and started his career at Purdue University as an assistant professor in mechanical engineering. He was promoted to full professor in 2001. While at Purdue, he initiated and led two industry supported interdisciplinary research programs: in automotive research and electro-hydraulic research. From 2002 to 2009 he served as chair of mechanical engineering at UH while simultaneously initiating the UH biomedical engineering undergraduate program. After his term as Department Chair, Dr. Franchek worked with Houston area companies to create the nation's first subsea engineering program. His expertise is in model-based methods for diagnostics and control of aerospace, automotive, biomedical and energy systems. His current research program focuses on multiphase pipeline flow, artificial lift, blowout preventers and electrical power distribution. He has authored over seventy archival publications, and over 100 conference publications.

ANALYSIS LED DESIGN IN SUBSEA ENGINEERING:

CHALLENGES FOR MODELING

The use of sophisticated modeling and simulation techniques, software, and hardware for the verification of design concepts is of utmost importance. This is especially true as production operators and service providers operate and design, respectively, subsea equipment for high-pressure high-temperature (HPHT) wells and for field equipment that may experience 10,000 ft. of seawater depth. Oil and gas fields reside beneath many inland waters and offshore areas around the world, and in the oil and gas industry the term subsea relates to the exploration, drilling and development of oil and gas fields in underwater locations. Many new reservoirs are exhibiting well conditions that can reach temperatures greater than 350 °F and pressures greater than 15,000 psi, thus the well is labeled as HPHT.

To ensure that hydrocarbons easily flow within subsea pipelines and equipment, thus preventing the formation of hydrates, waxes, and asphaltenes, and that reliability issues, such as metal fatigue, are properly addressed during the design phase, *analysis led design* will incorporate the use of modeling and simulation software. Such tools as ANSYS Mechanical and/or Abaqus for structural analyses, and Fluent, CFX, and STAR CMM+ for computational fluid dynamics (CFD) investigations will be significantly used. In addition, the interaction of physics such as fluid-structure interactions (FSI), vortex-induced vibrations (VIV), and flow-induced vibrations (FIV) have become of greater significance since these phenomena can lead to early-life fatigue failures (e.g., subsea jumpers).

Optimization of designs prior to validation can reassure the design engineer that the very best design goes into testing, that both functional and performance requirements are met, and maximum cost savings can be realized. Hence, the use of higher fidelity models, (e.g., 3-D versus 2-D or 1-D) with their higher nodal and element count requires novel analysis thinking, a new analyst/engineering skill set, and closer collaboration among the various engineering and design disciplines.

This article highlights some of the analysis challenges, which must be resolved, examples of complex subsea equipment analyses conducted on trees (XTs) and manifolds, and a vision for the future as it pertains to modeling and simulation in the context of *analysis led design*. This is just one roadmap (i.e., they exist in other industries) that can have a profound impact on innovation within the Oil & Gas Industry, especially, for subsea and onshore production equipment and systems engineering.

ANALYSIS LED DESIGN

The development of complex products such as subsea trees (i.e., assembly of valves, spools, and fittings used for an oil well that controls flow) , manifolds (i.e., a unit that transfers oil /gas from wellheads into a pipeline), BOPs (blow-out-preventer), jumpers (i.e., piping that connects trees to a manifold), separation systems (i.e., used to separate hydrocarbons from sand and water phases), boosting systems (single and multiphase pumps), piping systems, and riser systems requires, at times, numerous build-and- test hardware prototypes. To validate product performance (i.e., specifications) and govern-

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AND SIMULATIONS OF COMPONENTS AND SYSTEMS

ment regulatory requirements along with the need to verify stress and fatigue life concerns is tremendously expensive and time-consuming, to say the least. This issue can be addressed up front in the development cycle by evaluating and refining/ optimizing the designs with analysis tools so that fewer test/ validation cycles will be needed in the later parts of the development phase.

Analysis led design is one of the latest strategies in the product development process. Its emphasis is more on up-front engineering with a product quality optimization process that starts early in the conceptual design stage. Product development and manufacturing through *analysis led design* utilizes digital tools extensively for design, analysis and product optimization with the hope that virtual testing is not too far behind. The end goal is to produce products that meet customer needs quickly and inexpensively and thus, ensure their success.

An oil and gas *analysis led design* initiative is needed to change the prevalent test-first culture, which would have a major impact on the industry, with significant benefits that include shorter development time, lower cost, improved product robustness, and greater reliability. *Analysis led design* can significantly shorten product development time by getting designs right the first time where traditional hardware testing can take months or years to validate a design. Leveraging analysis early in the development process can eliminate design changes and repetition of lengthy endurance testing, thus providing tremendous reductions in overall development time due to reduction in long-hour tests that can last for weeks or months.

The importance of the *analysis led design* approach is clearly illustrated when placed in the context of the V-Model development process. The first leg is the project definition where the user's needs, performance requirements, conceptual and detail design are formulated prior to implementation and validation. Using *analysis led design*, the concept, technological characteristics, theory and mechanisms of how the product would perform are extensively studied and clarified. The use of simulations allows for the speed-up of "what-if" scenarios and optimization.

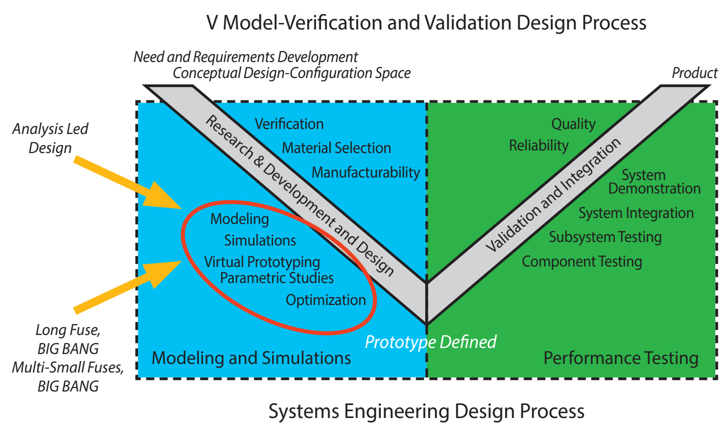

FIGURE 1 **Positioning of *analysis led design* activities in the up-front engineering phase.**

Figure 1 shows the utilization of *analysis led design* in the overall development process in the V-model. The analysis activities of modeling and simulation, virtual prototyping, parametric design studies, and optimization are all incorporated to achieve the end goals of minimizing the development cycle, rework, errors in design, costs, and to meet customers' needs per the requirement's analysis while enhancing design robustness.

HIGH-FIDELITY 3-D MODELING: COMPONENTS

Product development is a thorough process that requires a huge amount of resources to be channeled throughout in order to obtain a fully functional, well-developed product. It consists of brainstorming the general concept of the product and deciding its function, design and methods of manufacture, as well as its marketing method.

A good and reliable product must fulfill several characteristics such as being able to function efficiently, being of very high quality, and most importantly being able to satisfy the customers' needs. Higher-order 3-D simulations allow the design engineer to thoroughly investigate the design's characteristics in virtual space, without expensive pre-testing of prototypes, to verify the concept's performance against specifications set by the customer.

Such tools as ANSYS Mechanical and Abaqus for structural analyses, and Fluent, CFX, and STAR CMM+ for computational fluid dynamics investigations are used significantly in the oil and gas industry. Other commercial

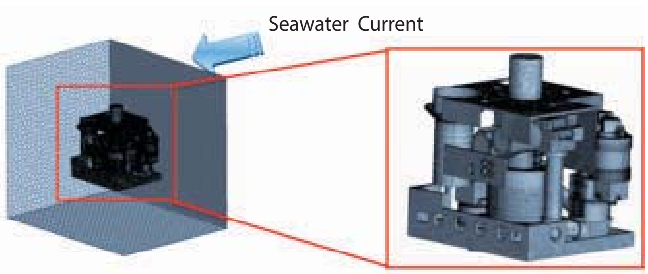

FIGURE 2 **Meshing used for the tree - CFD Modeling: 4.7 million polyhedral cells (6-layer fluid boundary inflation).**

software tools, such as RIFLEX and ZENRISER, are employed for static and dynamic analysis of slender marine structures. The dynamic behavior of offshore flexible or rigid riser or pipe systems is subject to hydrodynamic loading and vessel motion that need to be modeled to ensure reliable operation. They represent simulation technology used for riser analysis suitable for flexible, metallic or steel catenary riser applications.

In offshore applications, subsea trees and manifolds are employed for production purposes. Due to the harsh corrosive environment and constant cold condition, which approaches near freezing temperature, thermal insulation is used to ensure the reliable and cost efficient management of flow of hydrocarbons from the reservoir to top-side floating production vessels or via subsea piping systems to onshore processing facilities. The objective many times is to determine whether or not the thermal insulation system on a subsea tree and/or manifold is capable of maintaining the produced fluid temperature above hydrate formation temperature (HFT) for a specified period of time (e.g., greater than 12 hours) after shutting down the well. Higher-order fidelity, 3-D, transient computational fluid dynamic modeling is used to simulate such operating requirements. Figure 2 shows the meshing scheme used to model such a system to guarantee convergence in a timely manner.

The results of the steady state and transient cool-down time of a multiphase flow is shown by Figures 3 and 4, respectively, where red indicates hot and blue indicates cooler temperatures.

A "tree" is an assembly of valves, spools, and fittings used for an oil well, gas well, condensate well and other types of wells. The primary function of a tree is to control the flow, usually oil or gas, out of the well. A tree may also be used to control the injection of gas or water into a non-producing well in order to enhance production rates of oil from other wells.

The modeling of the actual physics (using CFD) of the fluid provides a more realistic insight of the actual thermal performance than traditional methods of determining cool-down times using finite element techniques. This is further magnified once the analysis complexity is increased by the introduction of a multiphase fluid in the flow stream instead of a single fluid (e.g., gas or liquid).

A subsea manifold is a large metal piece of equipment, made up of pipes and valves and designed to transfer oil / gas from wellheads into a pipeline. Manifolds are usually mounted on a template and often have a protective structure covering them. Manifolds vary greatly in size and shape, though these can be huge structures reaching heights of 30 meters (90 feet).

Figure 5 shows analysis results for a subsea manifold for a transient cool-down simulation.

The thermal design challenge becomes the determination of thermal insulation thickness and its placement to minimize thermal losses and thus prevent hydrate formation. Hydrates are ice-like crystals that form with natural gas and water and at combination of low temperatures and high pressures. Thermal insulation on subsea trees and manifolds is always required to prevent the rapid decrease

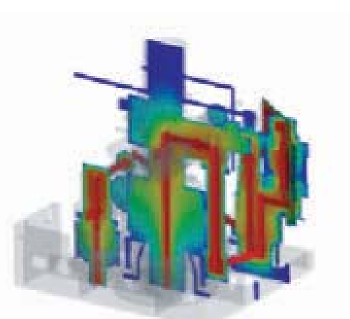

FIGURE 3 **Steady-State temperatures in the subsea production tree during normal operation.**

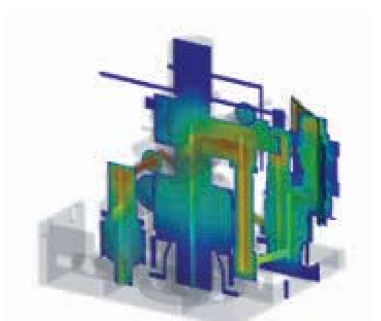

FIGURE 4 **Transient temperatures after 8 hours of cool down time in the tree.**

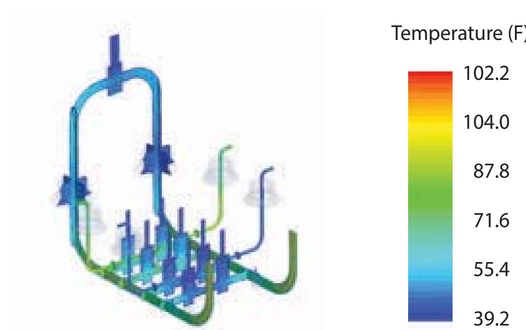

FIGURE 5 **Transient temperatures after 8 hours of cool down time in the manifold.**

Optimization Process Tool

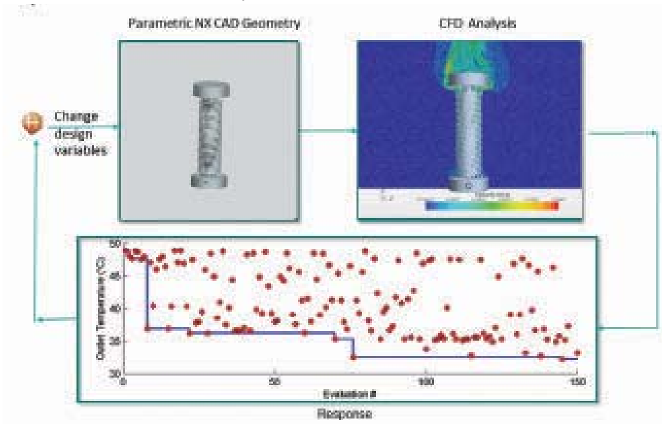

FIGURE 6 **Exploration of the design space through optimization algorithms**

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of produced fluid temperature below hydrate formation temperature.

DESIGN OPTIMIZATION – AUTOMATION OF COMPUTER SIMULATIONS

With focus more on up-front engineering, a product quality optimization process that starts early in the conceptual design stage is necessary. The *analysis led design* method adopts an active and advanced approach to respond to customers' demands. Rather than acting only when the problems occur, it considers every possible problem and solves them in advance, early in the product development stage. Product robustness and quality are enhanced with the use of optimization software tools.

Commercial software tools such as HEEDS and Isight allow for multidisciplinary design optimization. Whether the analysis is structural (linear or nonlinear, static or dynamic, bulk materials or composites), fluid, thermal, magnetic, or acoustic or a combination of these types of analyses (e.g., fluid-structure interaction, vortex-induced vibration, etc.) optimization techniques in conjunction with computer-aided engineering tools can help identify the optimal solution or the envelope for safe and reliable operations. When it's important to predict design sensitivities, or to gain a clearer understanding of the design space, a design of experiments (DOE) study is often the ideal approach. DOE methods allow for the extraction of a great deal of useful design information quickly, with the least computational effort possible.

The advantages of optimization in design, especially in the early up-front engineering stages, can be best illustrated when designing a heat exchanger. Heat exchangers for subsea applications, designed for best performance, must conform to multiple performance requirements. To determine the optimal design point, a multidisciplinary team of engineers must identify the significant parameters that affect the performance of the heat exchanger and also, interactions between significant parameters. Design engineers need to be smart in selecting enough data to accomplish the objective, but within available resources. What are the options? A design of experiments method with screening designs, surface response, or full factorial design techniques or specialized optimization algorithms such as genetic algorithms, simulated annealing, non-linear sequential quadratic or simultaneous hybrid exploration of the design space. The latter can provide both global and local optimization at the same time. Figure 6 illustrates the procedure of connecting intelligent optimization tools with CAE tools for determination of the design space through exploration.

Figure 7 shows the results of performing an intelligent search of the design space where the exploration provided three viable design solutions versus the traditional one solution with DOE surface response. The best choice will be determined on the basis of cost and manufacturability since each meets the performance requirements.

The design exploration space involved 183 design evaluations where 137 were deemed feasible (~75%), 7 were infeasible (~4%), and 39 were errors (~21%), having convergence issues in the CFD analysis.

The benefits from performing an optimization became apparent when the results revealed that more than one design option met all performance specifications and constraints imposed on the analysis. While the computational surface response analysis did provide one good design option from a total of 21 designs that were evaluated, the optimization study evaluated 183 options with three options providing the best solution. Total time duration for the surface response evaluations was 6 weeks; the optimization study required 2 weeks. The increase in engineering efficiency can clearly be quantified from this investigation.

Results: Top 3 Designs

FIGURE 7 **Results of the design exploration space with smart optimization algorithms.**

LOWER-ORDER 1-D MODELING: SYSTEMS

A 1-D simulation model is a mathematical representation of a system and its dynamic behavior in the physical world. For example, bringing models together allows engineers to better simulate and evaluate how a multiphase pump design performs in context, when given a gas volume fraction (GVF) load, requirements for total pumping head versus volumetric flow rate for best efficiency point, and even on specific reservoir locations with their unique inlet boundary conditions.

In thermo-fluid applications it is known that 3-D CFD simulations can provide detailed insights about fluid and flow properties in complex 3-D domains. However, from a systems level perspective, 1-D CFD simulations can give important information with respect to performance of an entire system of internal flows. The drawbacks of the two simulation methods are that the former requires high computational costs while the latter cannot capture complex local 3-D features of the flow. Therefore, the two simulation methods must become complementary; indeed a coupling of the two methods can incorporate the strongest attributes of the two methods while minimizing their drawbacks. Here lies the challenge for subsea applications.

The coupling possibility is not limited to the CFD field but can extend to multiphysics. An example of multiphysics one-way coupling is the simulation of vibrations in piping systems, fluid-structure interactions, (e.g. compressed gas systems, blow-down systems); this simulation is performed by modeling the pressure wave propagation inside the piping system with 1-D modeling and passing the forces exerted by the internal flow to a structural analysis tool for mechanical analysis. The interest in multiphysics modeling with one-way and two-way coupling is of the utmost importance in subsea applications.

For subsea offshore applications, this involves the simulation of all potential subsea equipment that may encompass what some people have coined, “the subsea factory.” The dynamic response modeling of an entire subsea production factory would allow the placement of various installations such as trees, manifolds, separation systems, single phase and multiphase boosting pumps and compressors in strategic locations where parasitic losses due to pressure drops, in piping systems such as jumpers, can be minimized while maximizing the safe and reliable production of valuable hydrocarbons.

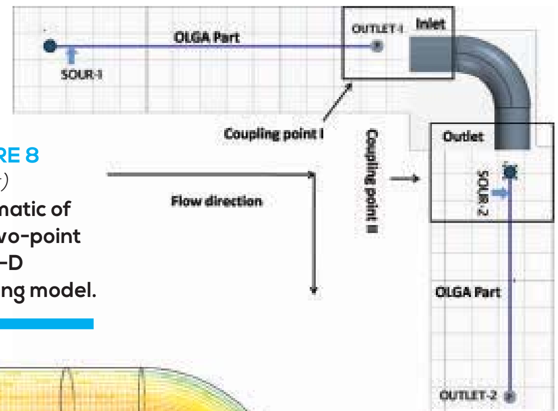

FIGURE 8 *(Right)* **Schematic of the two-point 3-D/1-D coupling model.**

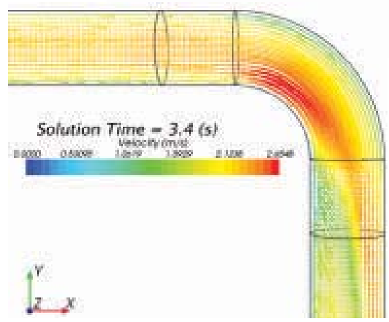

FIGURE 9 *(Left)* **Velocity profile on the horizontal cross section of the bend.**

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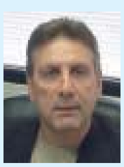
Figure 8 shows a schematic of a two-point coupling model. In the two-point coupling model the outlet of the upstream is modeled using 1-D physics, which then is coupled with the inlet to the 3-D modeled bend, using a CFD tool, and the outlet of the bend is coupled with the inlet of the downstream section of pipe, again modeled using 1d physics. Thus, a coupling of the 1-D horizontal and vertical pipe sections with the 3-D modeled elbow is achieved and analyzed.

As shown in Figure 9, the combination of coupling 3-D to 1-D modeling gave reasonable prediction of the flow field and thus, the forces acting on the bend induced by the fluid. This coupling technique allows for decreased computational needs while increasing the speed for the analysis.

CONCLUSION

In summary, while technical challenges still exist with respect to developing more accurate models, whether fluid, structural, acoustic, magnetic or multiphase flow models for boosting pumps, for subsea applications, the concept of using *analysis led design* methods in the up-front engineering phase has been well proven in many industries. The challenge still lies in gaining its acceptance as a routine practice for offshore and onshore applications to increase engineering efficiency. ■

ABOUT THE AUTHOR



Ed Marotta achieved his B.S. degree in chemistry from the State University of New York at Albany, 1980, post-graduate studies in chemical engineering at SUNY at Buffalo, 1982, and his MS and PhD degree in mechanical engineering from Texas A&M University in 1994 and 1997, respectively.

Ed’s present responsibilities involve the management of the Multi-Physics Simulations Group for GE Oil & Gas - ATO. In this capacity, Ed is responsible for leading a group of engineering specialists responsible for performing thermal, diffusion, and multiphysics analyses on all major systems and sub-system components, development of thermal best practices for multiphysics analyses specific to GE products. In addition, Ed is responsible for the development of low-dimensional, lower-order tools for integration and integrity management of subsea systems.

FLOW ASSURANCE: DÉJÀ-VU IN SUBSEA ENGINEERING?

PHANEENDRA KONDAPI,
GRANHERNE, A KBR COMPANY,
HOUSTON, TEXAS

Flow assurance is an understanding of multiphase flow fluid dynamics and analyses, an ability to identify flow-related problems using state-of-the-art prediction tools, and the knowledge to develop solutions that eliminate, mitigate or remediate flow-related issues encountered in subsea systems. Flow assurance is reliable, safe and cost efficient management of hydrocarbons from reservoir to export without any flow-related issues over the life cycle of the oil field.

Subsea developments continue to escalate in quantity and complexity as the exploration and production companies ramp up exploration of deepwater and ultra-deepwater reservoirs with complex formations in harsh environments with increased challenges [1]. Typical challenges involve ultra-deepwater, longer offsets and tiebacks, arctic environments, high pressure and high temperature fields, heavy oil, and low-energy reservoirs. Subsea field development involves multi-discipline activity to generate an optimized solution and typically parallel activities are performed. There is a significant level of interaction between these activities and flow assurance is a key enabler and integral part of the field development activity. A complicating factor is that the field characteristics change over time and the flow assurance approach must adapt with the evolving field.

Flow assurance issues can be grouped into three different categories. They are

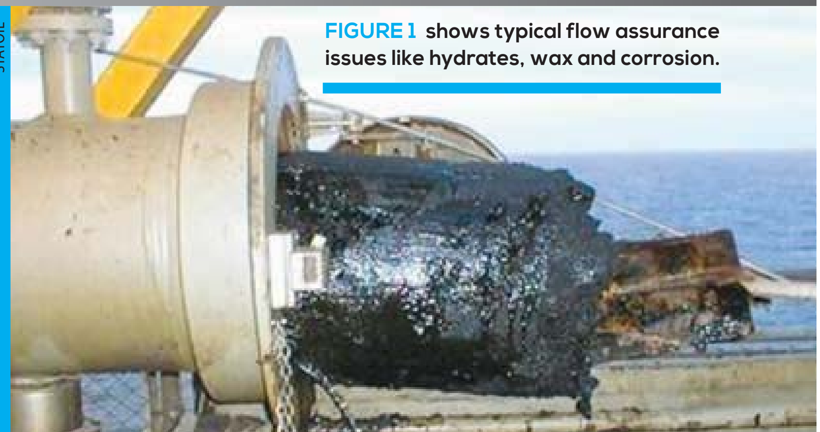
1. **Production Chemistry Issues**
2. **Operational Issues**
3. **Integrity Issues**

Typical production chemistry issues are hydrates, wax/paraffins, scales and asphaltenes. Operational issues are slugging, sand production, foam and emulsions. Corrosion and erosion fall under integrity issues. Figure 1 shows typical flow assurance issues like hydrates, wax and corrosion encountered in subsea oil fields.

PETROBRAS

HYDRATES

STATOIL



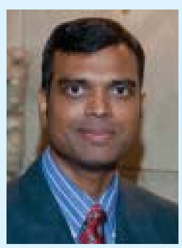
WAX

FIGURE 1 shows typical flow assurance issues like hydrates, wax and corrosion.

The key concerns in any subsea field are upsets in fluid behaviour and excessive solids deposition which can cause operating problems, including production shutdown and expensive interventions. Addressing flow assurance and incorporating flow management strategies early in the conceptual design phase can minimize costly occurrences. It is applied during all phases of system selection, detailed design, surveillance, troubleshooting operation problems, increased recovery in late life etc., through the production flow path from well tubing, subsea equipment, flowlines, initial processing and all the way to export lines. Flow assurance facilitates operability by the development and implementation of strategies to analyze line sizing and insulation requirements and manage solids including hydrate, wax, asphaltenes, scale, etc. Typical flow assurance analysis addresses establishing design basis with general information on fluid properties, reservoir properties, bathymetry, production profile/targets, etc. and assess system hydraulic and thermal design. Analysis also includes modification of design for transient effects like start-up, shutdown, cool-down, rate changes, well testing, pigging, slugging, pressure surges, leaks, etc. and to develop operating strategies to assess system economics. Other key areas addressed are topside separator sizing, inhibitor requirements, cool-down time calculations, flowline warm-up time calculations and pigging time calculations.

The industry is using existing and modified technologies combined with new approaches to maintain an uninterrupted flow of hydrocarbons from the reservoir to the topsides. Each field is different and there is not one simple solution for flow assurance. A tailored approach is needed to combat these issues for each field. Various state-of-the art flow assurance technologies [2] are available to mitigate these issues and these technologies are major enhancers and have great impact

ABOUT THE AUTHOR



Dr. Phaneendra Kondapi is a senior technical advisor at Granherne-KBR, Houston, Texas, USA. Before joining Granherne-KBR, Dr. Kondapi has worked with various engineering and consulting firms for over 18 years around the globe in various capacities as a manager, project mananger, project lead and simulation engineer. His technical interests include flow assurance, subsea processing, process simulation and optimization, operator training simulators and multiphase flow simulators. Dr. Kondapi is also a KBR adjunct professor of subsea engineering at University of Houston since 2011. He has supported the development of first and only subsea engineering program in the US. He teaches a flow assurance course using an innovative reverse circular teaching method developed by him. Dr. Kondapi is a member of Society of Petroleum Engineers, founding member of Upstream Engineering and Flow Assurance Forum of the American Institute of Chemical Engineers and founding faculty advisor of Subsea Engineering Society. He is also an active member of SPE Flow Assurance Technical Section, SPE Global Training Committee and Offshore Technology Conference Program Committee. He has organized many technical sessions at various workshops and international conferences. He has over 30 technical articles and presentations at various international conferences. Dr. Kondapi received his Ph.D. in chemical engineering from Tennessee Technological University and B.S. and M.S. degrees in chemical engineering from Andhra University. He is a recipient of SPE Teaching Fellow Award from the Society of Petroleum Engineers International in 2013.

CORROSION

on cost effectiveness and production. These technologies are categorized into five different solution types such as

- **Thermal**
- **Chemical**
- **Hardware**
- **Operating and**
- **Software technologies.**

Some of the technologies under thermal solutions are thermal insulation, direct electric heating and electrically-heated pipe-in-pipe. Thermodynamic hydrate inhibitors, low-dosage hydrate inhibitors (LDHI), defoamers, asphaltene inhibitors, paraffin inhibitors, scale inhibitors, H_2S scavengers, chemical demulsifiers and drag-reducing agents fall under chemical solutions. Subsea separation, subsea boosting, subsea compression, subsea coolers and pipe-in-pipe, bundles, coiled tubing tractors, desanders, erosion probes, acoustic sand detectors and acoustic leak detectors are some of the hardware solutions. Dead oil and hot oil flushing, pigging, depressurization and gas sweeping are operating solutions. Real-time flow assurance advisory systems and remote performance monitoring systems come under software solutions. Figures 2 and 3 show examples of thermal insulation and subsea separator.

But the success of flow assurance depends on the development of technologies that can enable cost-efficient and environmentally-friendly applications while contributing to increased earnings, production and improved recovery, enhancing and prolonging the use of existing infrastructure. These developments are based on the technology readiness and qualification stage, current industry application and growth potential, opportunities to go through improvements and advances to meet the new environmental regulations.

Oil and gas companies generate revenue from the oil produced. If the oil flow stops, their revenue stops. The more it stops the more they lose cash. Hence it can be termed as cash flow assurance. With fluctuating oil prices and unpredictable production issues, engaging flow assurance at every stage starting with the early phase ensures uninterrupted transportation of reservoir fluid from pore to process facilities in a safe manner and insures cash flow. Déjà vu? ■

FIGURE 2
Thermal Insulation

FIGURE 3
Subsea Separation

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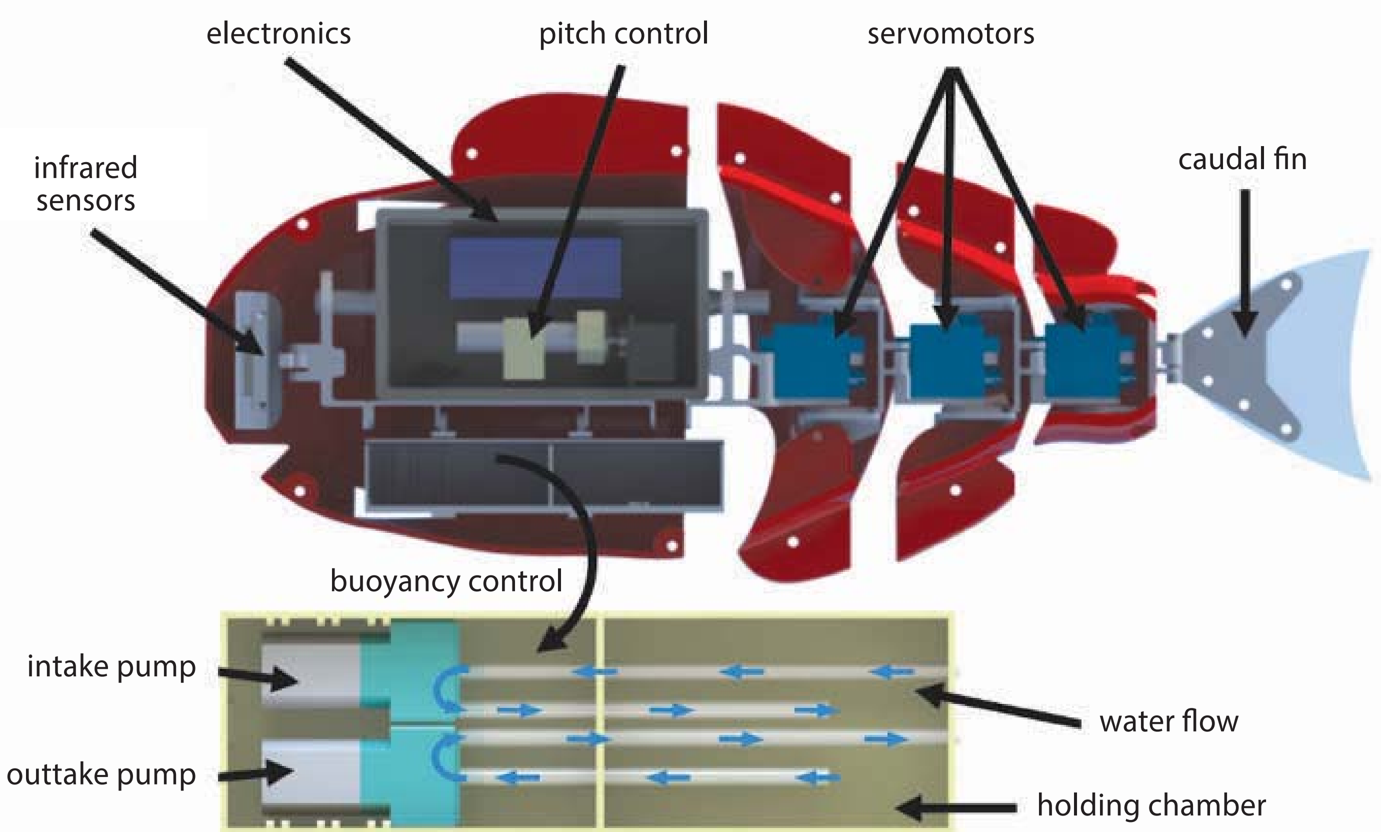
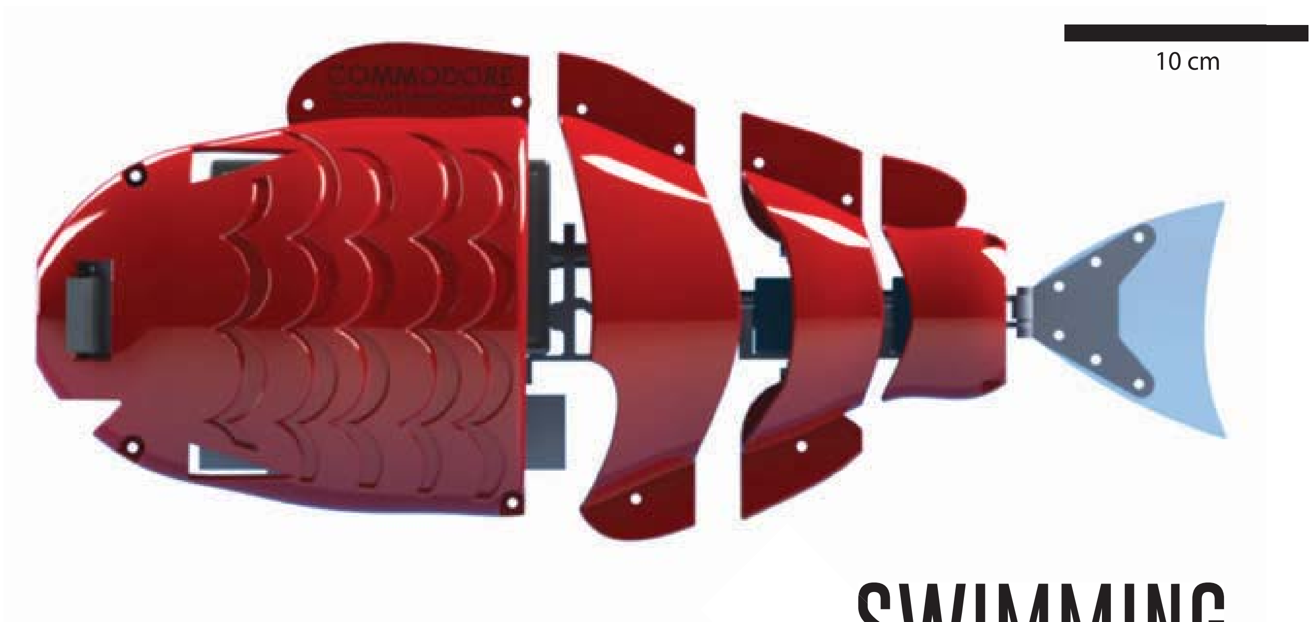
ROBOTIC FISH

Paul Phamduy and Maurizio Porfiri
Department of Mechanical and Aerospace Engineering
New York University Polytechnic School of Engineering





SWIMMING OUTSIDE THE SCHOOL TO AID INFORMAL SCIENCE EDUCATION

Informal science education is the process of scientific learning that takes place outside of the classrooms and academic institutions [1, 2]. It is the most predominant form of learning across life-long education, is spontaneous in nature, and has practically unlimited opportunities [1, 2]. Informal learning can occur through visits to museums and galleries, participation in science festivals, and even watching educational programs [1].

For visitors to informal science venues, robotics has been shown to be an effective tool to elicit their interest, as it often affords several elements of novelty [3]. Further, robotics offers quick feedback for participants to test new ideas or reinforce preexisting knowledge [4, 5]. Thus, a number of robotics-based exhibits, such as the exploratory rover [6], robotic dolphin [7], and remotely-controlled miniature boats [8], have been designed to increase visitors' interest in robotics, while delivering important topics in science, like space exploration [6] and environmental mapping [8].

Biologically-inspired robotic fish have been found to be particularly engaging [7, 9, 10], likely due to the additional connections to the natural world they can offer [11]. Thus, a few robotic fish exhibits have been deployed to engage and educate visitors in public aquariums and expositions [9, 10]. However, such exhibits are often limited in the level of interactivity they afford, which is known to be a key factor in informal science education [12, 13].

FIGURE 1 *(Above)* **The robotic fish, Commodore.**

FIGURE 2 *(Left)* **Exposed view of electronics, sensors, pitch control, buoyancy control, and robotic fish tail.**

A novel interactive robotic fish exhibit has been developed at the Dynamical Systems Laboratory of New York University (NYU) Polytechnic School of Engineering to address this gap [14]. The exhibit features Commodore (Figure 1), a robotic fish based on a multi-link design with a pitch and buoyancy control system for three-dimensional biologically-inspired swimming. An ad hoc iDevice application with three control modes varying in the level of robot autonomy provides visitors with a unique experience to control the robotic fish swimming.

BIOLOGICALLY-INSPIRED ROBOTIC FISH

Commodore is designed with inspiration from the Atlantic scup fish, *Stenotomus chrysops*. The cover of the robotic fish is fabricated through a rapid prototyping machine from solid-packing acrylonitrile butadiene styrene plastic. Its mechanical design includes a three degree-of-freedom motorized tail, electronics housing, and pitch and buoyancy control systems (Figure 2). The undulation of the tail enables the robotic fish to swim in two dimensions, and the pitch and buoyancy control systems allow the fish to dive and surface. The robotic fish measures 48 cm in length, 19 cm in height, and 10 cm in width.

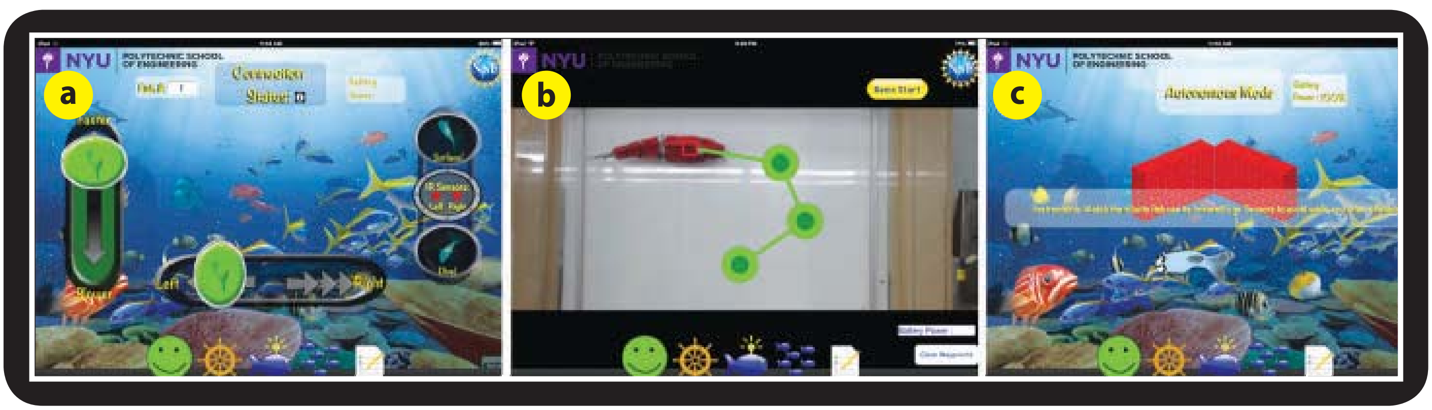
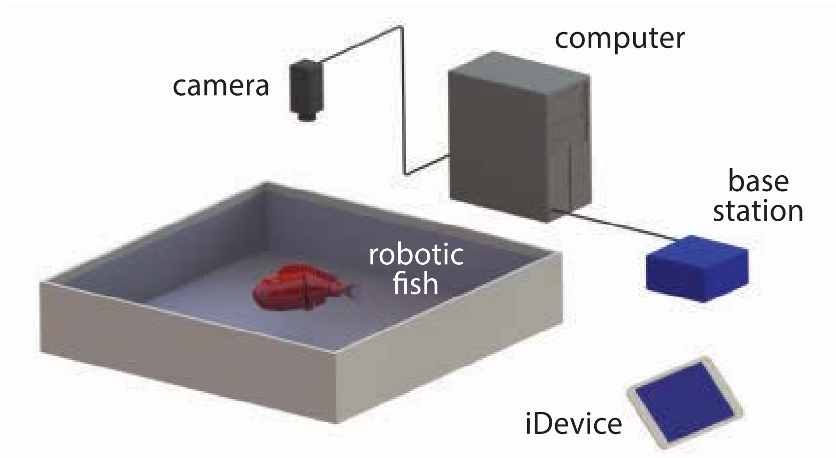


FIGURE 4 iDevice application screens (a) manual, (b) semi-autonomous, and (c) autonomous.

Electronics

The primary electronic components of Commodore include an Arduino-based microcontroller, a radio transceiver, and a 2200 mAh 7.4V lithium polymer battery. A battery charge sensor, composed of a voltage divider, is incorporated to assist with monitoring the battery power level. Two infrared (IR) sensors, facing 120° apart, are mounted on the front of the robotic fish to provide navigational information when walls or obstacles are detected.

FIGURE 3
Communication protocol between the robotic fish and iDevice.



Pitch and Buoyancy Control

The combination of the pitch and buoyancy control systems is used to adjust the depth of the robotic fish. Specifically, the buoyancy control system heuristically sets the robotic fish to neutral buoyancy by adjusting the water content within a rigid volume tank.

The pitch angle is regulated by shifting a balance mass with a 2.2 cm travel length. This mass is used to control the center of gravity of Commodore with respect to the center of buoyancy, thus tilting it upwards (positive pitch) or downwards (negative pitch). When Commodore is close to neutral buoyancy, adjusting the pitch angle while beating the tail allows rising and diving.

The buoyancy system comprises a rigid enclosure, fabricated using rapid prototyping, which contains two separate chambers (Figure 2). One chamber encases two motors, pumping water between the second holding chamber and the environment through airline tubing, while the other chamber simply holds the water. Commodore can reach neutral buoyancy as the water in the latter holding chamber is varied.

Fish Tail

The tail of the robotic fish consists of three servomotors connected by rigid plastic links and a rubber silicone caudal fin. Coordinating these three motors causes the tail to undulate and the Commodore to swim. A simplified model for carangiform fish swimming [15] is used to mimic the swimming pattern of a real scup fish.

COMMUNICATION AND IDEVICE APPLICATION

A communication network is developed to operate Commodore from a custom iDevice application (Figure 3). In the network, a user datagram protocol (UDP) is utilized to communicate between the base station, a desktop computer, and the iDevice for delivering important messages, such as the control mode and its key parameters. The base station comprises a microcontroller, a radio shield, an Ethernet shield, and a wireless router, and is used to translate commands from UDP to radio signals for Commodore.

The three control modes have separate screens on the iDevice application (Figure 4). i) In the manual mode, the user has the option to use sliders and buttons to directly control the robotic fish, including the tail-beat frequency, steering, diving, and surfacing. ii) In the semi-autonomous mode, the user can generate a waypoint path for Commodore to follow, by tapping on the iDevice screen that shows a real-time bird's-eye view of the tank through an overhead webcam. The robotic fish then automatically swims along the prescribed path by implementing a proportional-integral-derivative (PID) controller on its orientation, using feedback from the webcam. iii) In the autonomous mode, an animated fish is displayed on the screen, offering the user a visual representation of the swimming decisions of Commodore. When one of the IR sensors detects an object within its vicinity, the user observes a red brick wall appearing in front of the animated fish, and the robotic fish and its animation both react to turn away from the obstacle.

FIGURE 5 *(Above)* **Robotic fish platform deployed at the World Science Festival.**

FIGURE 6 *(Right, below)* **Robotic fish platform and educational materials at the Brooklyn Children's Museum.**

APPLICATIONS IN INFORMAL SCIENCE

The robotic fish platform was deployed in various informal science events and venues, in April 2014 at the USA Science and Engineering Festival, in May 2014 at NYU Polytechnic School of Engineering Research Expo, and in June 2014 at the World Science Festival (Figure 5). All events were open and accessible to the general public, whereby thousands of visitors interacted with Commodore over the course of the summer of 2014.

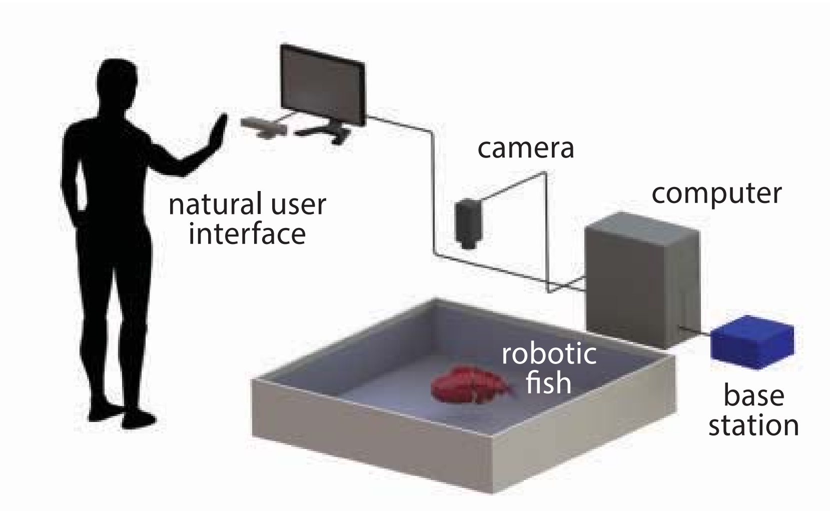


FIGURE 7 Natural user interface for controlling a robotic fish.

At these events, data from 224 visitors were recorded: users spent on average 85 seconds in the manual mode, 69 seconds in the semi-autonomous mode, and 5 seconds in the autonomous mode. Due to the nature of the events, the popularity of the exhibit amongst youngsters, and the high visitor traffic, when opportunity arose to use the iDevice application, visitors were inclined to select an interactive control mode over the autonomous, passive mode.

An optional questionnaire was administered to visitors after controlling the robotic fish, to acquire feedback on the usability of the platform and learn their thoughts on pertinent environmental issues. Users indicated that the experience was enjoyable, rating the exhibit on average 4.6 out of 5 stars, and identified marine pollution, overfishing, and climate change as the most pressing environmental issues we are currently facing.

To allow visitors additional time to interact with the platform and to examine uninterrupted interactions with Commodore, the platform was customized to operate in a 1000 liter tank (Figure 6) and demonstrated to the public in New York City, at The River Project from August 19, 2014 to September 22, 2014 and at the Brooklyn Children's Museum from October 9, 2014 to January 19, 2015. In this platform, the robotic fish was presented alongside educational material that was created based on the usability studies and interactions with education professionals.

OUTLOOK ON FUTURE RESEARCH

To further expand on the degree of interactivity of Commodore, we are exploring natural user

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interfaces. Such interfaces have been shown to be effective tools for enhancing user engagement and learning [16-18]. A proposed platform to control a robotic fish with a natural user interface is illustrated in Figure 7. This system can possibly involve a mini-game, such as to collect water temperature, to further encourage user engagement [19].

In a parallel research effort, we are also investigating a new autonomous charging station for the robotic fish to minimize maintenance by museum personnel. A proposed platform for enabling continuous use of an untethered robotic fish through a direct contact approach is sketched in Figure 8.

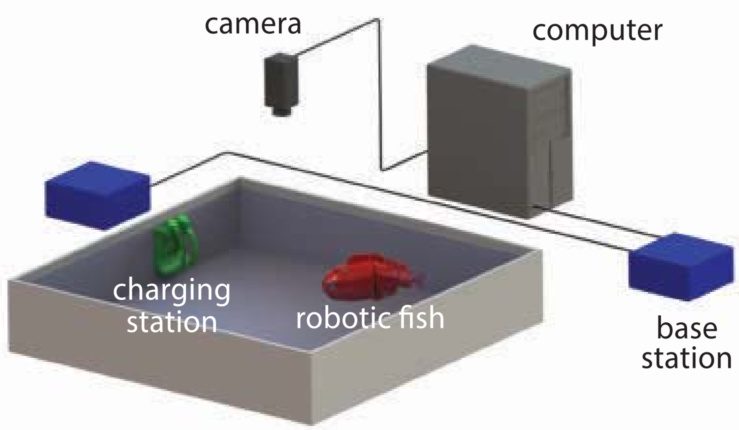

FIGURE 8 **Autonomous charging station for a robotic fish.**

CONCLUSIONS

An interactive robotic fish exhibit was developed to aid informal science learning. The platform has been well received by visitors and has contributed to increasing their interest in robotics. Integrating natural user interfaces and autonomous charging into the exhibit is expected to further enhance the visitor experience and strengthen the feasibility of robotics-based informal science education. ■

ACKNOWLEDGEMENTS

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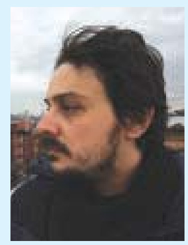
ABOUT THE AUTHOR

Paul Phamduy was born in Lowell, Massachusetts in 1988. He received B.Sc. and M.Sc. degrees in mechanical engineering from the University of Massachusetts, Lowell, in 2010 and 2012, respectively, and is working toward a Ph.D. degree in mechanical engineering at New York University. His doctoral research, supported by the National Science Foundation, focuses on biologically-inspired robotics with application to animal behavior and informal science education. Since 2012, he is a recipient of a National Science Foundation GK-12 fellowship in the Applying Mechatronics to Promote Science program.



Maurizio Porfiri was born in Rome, Italy in 1976. He received M.Sc. and Ph.D. degrees in engineering mechanics from Virginia Tech, in 2000 and 2006; a laurea in electrical engineering (with honours) and a Ph.D. in theoretical and applied mechanics from the University of Rome "La Sapienza" and the University of Toulon (dual degree program), in 2001 and 2005, respectively. From 2005 to 2006 he held a post-doctoral position with the Electrical and Computer Engineering Department at Virginia Tech. He has been a member of the faculty of the Mechanical and Aerospace Engineering Department of New York University Polytechnic School of Engineering since 2006, where he is currently a professor. He is engaged in conducting and supervising research on dynamical systems theory, multiphysics modeling, and underwater robotics. Maurizio Porfiri is the author of more than 150 journal publications and the recipient of the National Science Foundation CAREER award (dynamical systems program) in 2008. He has been included in the "Brilliant 10" list of *Popular Science* in 2010 and his research featured in all the major media outlets, including CNN, NPR, *Scientific American*, and Discovery Channel. Other significant recognitions include invitations to the Frontiers of Engineering Symposium and the Japan-America Frontiers of Engineering Symposium organized by National Academy of Engineering in 2011 and 2014, respectively; the Outstanding Young Alumnus award by the College of Engineering of Virginia Tech in 2012; the ASME Gary Anderson Early Achievement Award in 2013; and the ASME DSCD Young Investigator Award in 2013.

2015 ASME DYNAMIC SYSTEMS AND CONTROL CONFERENCE

Columbus, OH
October 28-30, 2015

The eighth ASME Dynamic Systems and Control Conference (DSCC) will be held in Columbus, Ohio October 28-30, 2015. **Giorgio Rizzoni** and **Rama Yedavalli** from the Ohio State University will serve as general chair and program chair, respectively.

The DSC Conference, organized and led by the members of the ASME DSC Division, provides a focused and intimate setting for dissemination and discussion of the state of the art in the broad area of dynamic systems and control from theory to industrial applications and innovations in education. Location of ASME DSCC 2015 makes especially **manufacturing** and **automotive engineering** appropriate themes, which will be covered through special tracks.

Other special tracks will focus on the intersection between life sciences and engineering, as well as information technology in mechanical and aerospace engineering. The program will also include contributed sessions, invited sessions, tutorial sessions, special sessions, workshops, and exhibits.

Draft manuscripts are due on **April 3, 2015**, and further details about the conference can be found at **http://www.asmeconferences.org/DSCC2015/**

Contributed by Giorgio Rizzoni (DSCC 2015 General Chair)

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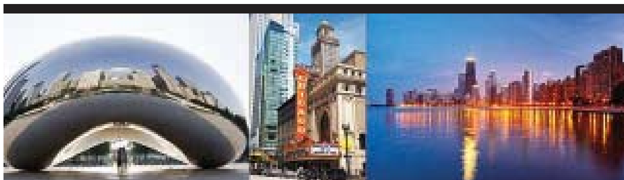

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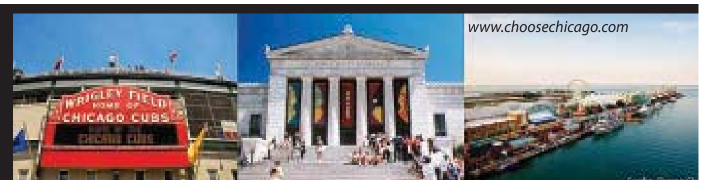

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2015 AMERICAN CONTROL CONFERENCE

Led by General Chair **Richard D. Braatz** *(Massachusetts Institute of Technology)* and Program Chair **Alessandro Astolfi** *(Imperial College and University of Rome)*, the 2015 American Control Conference (ACC) will be held in Chicago, Illinois during July 1-3, 2015. The ACC is the annual conference of the American Automatic Control Council (AACC), the U.S. national member organization of the International Federation for Automatic Control (IFAC), and is co-sponsored by several other professional societies, including ASME and IEEE.

ACC 2015
Chicago
July 1–3, 2015

While spanning all areas of the theory and practice of automatic control, this year's ACC will focus on energy, biomedical, and transportation systems, which will be the topics of a plenary lecture by **Clas A. Jacobson** *(United Technologies Systems & Control Engineering)*, and four semi-plenary lectures to be given by **Hamsa Balakrishnan** *(Department of Aeronautics and Astronautics, Massachusetts Institute of Technology)*, **Thomas F. Edgar** *(Department of Chemical Engineering, The University of Texas at Austin)*, **Benjamin Shapiro** *(Bioengineering/Institute for Systems Research, University of Maryland at College Park)*, and **J. Karl Hedrick** (*University of California at Berkeley*). In addition to regular and invited sessions, the ACC technical program offers many exciting activities including tutorial sessions, special sessions, workshops, exhibits, and outreach.

Contributed by Douglas A. Lawrence (ACC 2015 Publicity Chair)
Edited by Rifat Sipahi

Details about the conference can be found at :
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The Wireless F/T is a small wireless transmitter that streams data from as many as six 6-axis transducers simultaneously. The Wireless F/T communicates using IEEE 802.11 a/b/g/n wireless standard at 2.4 GHz or 5.0 GHz and can stream to the user's host device for data collection, real-time motion control, or user-defined signal processing. The Wireless F/T comes in two configurations, one that supports up to six transducers and one that supports up to three transducers.

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Model SPM 120AAA provides early warning of possible motor shaft seal leakages and failures. The module can help reduce the risks of premature equipment failure and downtime over 10 million mechanical cycles and fifty thousand electrical operations. Offered with choices of both fixed and adjustable sensitivities, the Model SPM 120AAA detects a pump motor shaft seal leak by sensing the position of a resistive float switch or pair of conductive probes installed within the seal cavity.

MEMS ACCELEROMETERS

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The SDI Model 1510 Series is a lower cost family of analog surface mount (LCC) MEMS variable capacitive accelerometers. They offer general purpose vibration measurements at OEM volumes, with long-term stability, across a variety of aerospace, automotive, energy, industrial, oil and gas, and test and measurement applications. Design of the SDI Model 1510 Series incorporates a micromachined variable capacitive sensing element and custom integrated circuit. The accelerometer produces two analog voltages which vary proportionately according to measured acceleration levels.

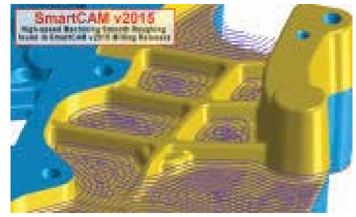
ANTI-VIBRATION MOUNTS

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

These RoHS-compliant vibration isolation mounts, also known as vibration mounts, anti-vibration mounts, vibration bobbins, or rubber bumpers, are suitable for the elastic mounting of machine units such as motors, compressors, and pumps. These mounts are simple and economical construction elements. Their broad range of different sizes and dimensions allow them to be used in many applications that require vibration isolation. GN 451.1 type has two threaded studs, GN 451.2 has one tapped hole and one threaded stud, and GN 451.3 has two tapped holes.

KNOWLEDGE-BASED MACHINING

SMARTCAMCNC, SPRINGFIELD, ORE.



The SmartCAM v2015 delivers a new knowledge-based machining repository and high speed milling strategies. High-speed machining improvements include new toolpath smoothing capabilities, which remove sharp corners from the toolpath, thereby reducing shock to both the tool and machine. New closed-profile continuous morphing and ramping strategies can also be used in combination with the new smoothing capabilities.

SIGNAL CONDITIONER

OMEGA ENGINEERING INC., STAMFORD, CONN.

The IN-USBH field calibratable inline signal conditioner adds digital high speed (1,000 readings/second) USB output to almost any mV/V pressure transducer or load cell. Free PC software takes the data from the transducer directly to the digital domain, turning a laptop or Windows tablet (with ESB connector) into a virtual meter, chart recorder, or data logger. This CE compliant product includes a 316L stainless steel case, mounting bracket, and standard USB connector cable.

INDUSTRIAL LIGHTING

CROUSE-HINDS, SYRACUSE, N.Y.

The V-spring telescoping light pole is designed to increase safety and reduce labor costs associated with installing and maintaining lights at industrial facilities. The controlled lowering pole features spring assistance to move the fixture up and down vertically. The light pole uses spring assistance to offset the pole and the light's weight and enables a worker to lower or raise the light fixture.

CLOSED FRAME DRIVE

TECHNOSOFT S.A., NEUCHATEL, SWITZERLAND.

The iPOS3604 HX-CAN is a closed-frame intelligent drive offering a compact solution for position, speed, and torque control of step motors requiring power up to 144 watts. The supply voltage range is 12 to 36 V dc with a continuous current of 4 A (10 A peak), and a PWM frequency of 20 kHz.

FLANGE FACERS

CLIMAX PORTABLE MACHINING & WELDING SYSTEMS, NEWBERG, ORE.

CE-certified, OD mount flange facers are engineered for safety. The feed control is on the outside, keeping the operator's hands away from moving parts. An emergency stop allows for quick stops and controlled restarts, while a low-pressure drop-out feature prevents unintended restarts after loss of supplied air pressure.

ALIGNMENT STAGES

OPTIMAL ENGINEERING SYSTEMS, VAN NUYS, CALIF.

Low profile XY-theta stages are designed for high-precision alignment applications. They move in an XY-plane and rotate around the center of the plane. Available in 12 models, in two precision grades, the stages have linear travels from +/- 2 mm by +/- 2 mm up to +/- 30 mm by +/- 30 mm. Four models have solid tables and the others are open frame. Typical precision repeated positioning accuracy is from +/- 0.7 μm to +/- 1.0 μm.

SUBMISSIONS

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

LINEAR MOTION SYSTEMS

LM76, EAST LONGMEADOW, MASS.

Low cost, SAIBO SB-LGB linear roller block and rail systems are available in three sizes to meet load requirements up to 1,200 N. These narrow profile linear motion systems feature low noise, smooth travel, high speed to 10 m/s, high acceleration to 50 m/s, low weight, high linear accuracy, and sealed radial low friction bearings. Because of their narrow profile they can install into new and existing applications.

UNIVERSITY OF NOTRE DAME

VITA DULCEDO SPES

The University of Notre Dame (ND.jobs) is accepting applications for Turbomachinery Positions.

Drafters

Designers

Engineers

Project Managers

Research Scientists

Technicians

APPLICATION PROCESS:

Please apply online at http://ND.jobs. For additional information about working at the University of Notre Dame and various benefits available to employees, please visit http://hr.nd.edu/why-nd. The University of Notre Dame supports the needs of dual career couples and has a Dual Career Assistance Program in place to assist relocating spouses and significant others with their job search.

The University of Notre Dame is committed to diversity in its staff, faculty, and student body. As such, we strongly encourage applications from members of minority groups, women, veterans, individuals with disabilities, and others who will enhance our community. The University of Notre Dame, an international Catholic research university, is an equal opportunity/affirmative action employer.

Milwaukee School of Engineering
MECHANICAL ENGINEERING FACULTY

Milwaukee School of Engineering invites applications for a faculty position at the Assistant or Associate Professor level for Fall 2015 teaching in the Mechanical Engineering Program.

The full-time faculty position is open to applicants in the area of Fluids/Thermal Science; however, preference will be given to applicants with expertise in the area of Fluid Dynamics.

This position requires an earned doctorate in Mechanical Engineering (or a related field), relevant industrial experience, and a strong interest in effective undergraduate teaching, integrating theory, applications and laboratory practice. A Bachelor of Science Degree in Mechanical Engineering from an ABET-accredited program is preferred. In addition to teaching duties, the successful candidate will be expected to become involved with academic advising, course/curriculum development, supervision of student projects, and continued professional growth through a combination of consulting, scholarship, and research. Excellent communication skills are required. The review of applications will begin as they are received and continue until the position is filled.

Please visit our website at **http://www.msoe.edu/hr/** for additional information including requirements and the application process.

MSOE UNIVERSITY

MSOE is an equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, religion, color, national origin, sex, age, status as a protected veteran, among other things, or status as a qualified individual with disability.

POSITIONS OPEN

THE UNIVERSITY OF SOUTHERN MAINE invites applications for a **FULL-TIME LECTURER POSITION IN MECHANICAL ENGINEERING** to begin in September 2015. See the complete notice at https://usm.hiretouch.com/view-all-jobs.

ETH zürich

Assistant Professor (Tenure Track) of Robotic Systems

→ The Department of Mechanical and Process Engineering (www.mavt.ethz.ch) at ETH Zurich invites applications for a Tenure Track Assistant Professorship of Robotic Systems. The assistant professorship is part of the National Center of Competence in Research (NCCR) Digital Fabrication on innovative building processes.

→ The successful candidate is expected to develop a strong and visible research program in the area of design, modeling, intelligent control and implementation of robot systems. The candidate should be able to bridge solid theoretical foundations, development of computational control methods, and systems design for applications to areas such as robot locomotion and manipulation in complex settings such as construction sites, unstructured industrial environments or disaster areas. The candidate is expected to make important research contributions to the NCCR Digital Fabrication, in particular to robot systems for the future construction of buildings. Candidates should hold a PhD degree and have an excellent record of accomplishments in engineering or related fields with a specialization in robotics systems. In addition, commitment to teaching graduate level courses (English) and the ability to establish and lead a world-class research group are expected.

→ This assistant professorship has been established to promote the careers of younger scientists. The initial appointment is for four years with the possibility of renewal for an additional two-year period and promotion to a permanent position.

→ **Please apply online at www.facultyaffairs.ethz.ch**

→ Applications should include a curriculum vitae, a list of publications and statements of future research and teaching activities. The letter of application should be addressed **to the President of ETH Zurich, Prof. Dr. Lino Guzzella. The closing date for applications is 31 March 2015**. ETH Zurich is an equal opportunity and family friendly employer and is further responsive to the needs of dual career couples. We specifically encourage women to apply.

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CONSULTING

SUBMISSIONS SOUGHT FOR VIDEO CONTEST

ASME FutureME Video Contest, an annual competition in which engineers share career experiences through video clips, is accepting entries on the theme, "What I wish I'd known about engineering when I entered the work force."

Contestants must create a 2-to-3-minute video and submit it before April 1. Video submissions will be accepted from an eligible individual or from the designated individual representative of a team.

Eligible individuals are those who have completed an engineering degree and are 18 years or older.

The entries will be judged in two steps. First, a pre-screening process conducted in early April will whittle down the submissions to ten. These ten semi-finalists will be posted on the ASME FutureME Video Contest Community between April 20 and May 15 for public screening and comments.

Scores from the judging panel as well as the number of "recommends" and the comments from the public will determine three winning entries.

The winning videos will be announced June 1.

The ASME FutureME Video Contest Community includes content relevant to career development topics and the video contest. There is also a means for engineers to interact with each other about their submissions and get ideas on what lessons they can share with colleagues.

For more information, go to the ASME FutureME Video Contest page at **https://www.asme.org/events/competitions/asme-futureme-video-contest.**

Bre Prettis of Makerbot, with printer winner Catherine McCoy at the 2014 AM3D event. *Photo: Teodor Lazar*

AM3D INDIA FIRST OF TWO MANUFACTURING EVENTS

Building on a successful inaugural event last year, ASME is holding two conferences this year devoted to the fast-growing field of additive manufacturing. The first event, the Additive Manufacturing + 3-D Printing-India Conference & Expo, will be conducted on Apr. 20 and 21 at the Hyatt Regency in Pune, India.

A second event, scheduled for August, will be held in Boston.

AM3D India will feature industry leaders and additive manufacturing experts from around the world discussing best practices, trends, and state-of-the-art 3-D printing technology. The event will encompass two days of technical tracks exploring developments in a range of AM-related fields, including 3-D printing materials; medical and health care; aerospace; automotive; consumer goods and retail; and research and development.

The keynote session will feature **Prabhot Singh** of GE Global Research, who will speak on "Industrialization Challenges in Additive Manufacturing." Singh, the manager of the GE Global Research Additive Manufacturing Lab in Niskayuna, N.Y., has an extensive background in additive manufacturing process development.

Also, the ASME Innovation Showcase, a competition for hardware-led social innovation, will host its inaugural India showcase at the AM3D event in Pune. Ten innovators will pitch their products and demonstrate their solutions for a chance to win a share of $500,000 in prizes. In addition to seed capital grants, innovators are competing to receive a design and engineering review from industry and technical experts.

Entrepreneurs can get more information and apply at **http://go.asme.org/ishow.** Applications close Mar. 15, 2015.

The second additive manufacturing conference, the North American AM3D Conference and Expo, will be offered from Aug. 2 to 5 in Boston. The event will be held in conjunction with ASME's International Design Engineering Technical Conferences and Computers & Information in Engineering Conference.

The poster committee for the AM3D conference in Boston is currently accepting poster abstracts. To submit an abstract, visit **https://www.asme.org/events/am3d/call-for-poster-presentations**. For additional details on the poster program, contact Israr Kabir, program manager at kabiri@asme.org.

For more information on AM3D India, visit **https://www.asme.org/events/am3d-india.** To learn more about sponsorship and exhibition opportunities at the conference, contact Raj Manchanda, director, ASME Emerging Technologies, at manchandar@asme.org. ME

HYDRAULIC FRACTURING CONFERENCE IN HOUSTON

Executives and technology leaders in the field of unconventional petroleum development will convene at the ASME Hydraulic Fracturing Conference and Expo 2015, Mar. 17-19 in Houston.

The three-day conference, to be held at the Marriott Houston Westchase, will examine the central role of mechanical engineering and surface equipment in shale-development and hydraulic fracturing. Invited talks will focus on the construction, delivery, and production of unconventional wells, associated infrastructure, and applied solutions.

The event will also provide participants with expert insights into the technological, economic, and regulatory trends driving this industry and provide a chance to meet and learn from the executives who are leading the field.

The roster of speakers participating in the conference includes more than 30 hydraulic fracturing executives. Among the featured speakers are **Paula Gant**, the U.S. Department of Energy's Deputy Assistant Secretary for Oil and Natural Gas; **Harold D. Brannon**, vice president for pressure pumping technology at Baker Hughes; **John Cadenhead**, strategy manager of Schlumberger's Unconventional Resources department; **Ehtiram Azizov**, fracturing services team leader for Trican Well Service Ltd.; and **Vishal Gahlot**, engineering manager for GE Oil & Gas Artificial Lift Systems.

Other presenters include **Alan Aitken**, director of drilling services engineering and technical support for North America at Baker Hughes; **Joe Anders**, well integrity advisor for BP; **Shane Cannon**, dual fuel market leader for Cummins Inc.; **Tim Clawson**, director of completions operations at Antero; **Philip Fusacchia**, program manager at GE Oil & Gas; **Rowlan Greaves**, project manager of Southwestern Energy's Strategic Solutions department; and **Steven A. Pohler**, senior technical consultant at Marathon Oil.

The conference will also feature approximately 35 electronic poster presentations, which will each be held following a related conference session.

To learn more about the ASME Hydraulic Fracturing Conference and Expo 2015, visit **http://go.asme.org/fracturing**, or visit **http://bit.ly/1HUlWBC** to download a copy of the conference brochure. ME

CROTTS RECOGNIZED FOR ACHIEVEMENT

Marcus B. Crotts, P.E., of Winston-Salem, N.C., was recently recognized by North Carolina State University with the Alumni Hall of Fame Award lifetime achievement award.

The honor was given to Crotts by NCSU's department of mechanical and aerospace engineering and presented at university's Centennial Campus in Raleigh.

Crotts, an ASME Fellow, founded the consulting firm Crotts & Saunders Engineering with his business partner Charles L. Saunders in 1956. The firm has worked on improved basic design methodologies in the machine tool and manufacturing industries.

Crotts graduated from NCSU with a bachelor's degree in mechanical engineering in 1953, and earned a master's degree in mechanical engineering from the University of Illinois Urbana-Champaign in 1956. He is a registered Professional Engineer in North Carolina, South Carolina, and Virginia. Crotts has been an ASME member since 1953.

SHEPPARD IS PROFESSOR OF THE YEAR

The Carnegie Foundation named **Sheri Sheppard** of Stanford University the 2014 U.S. Professor of the Year for doctoral and research universities.

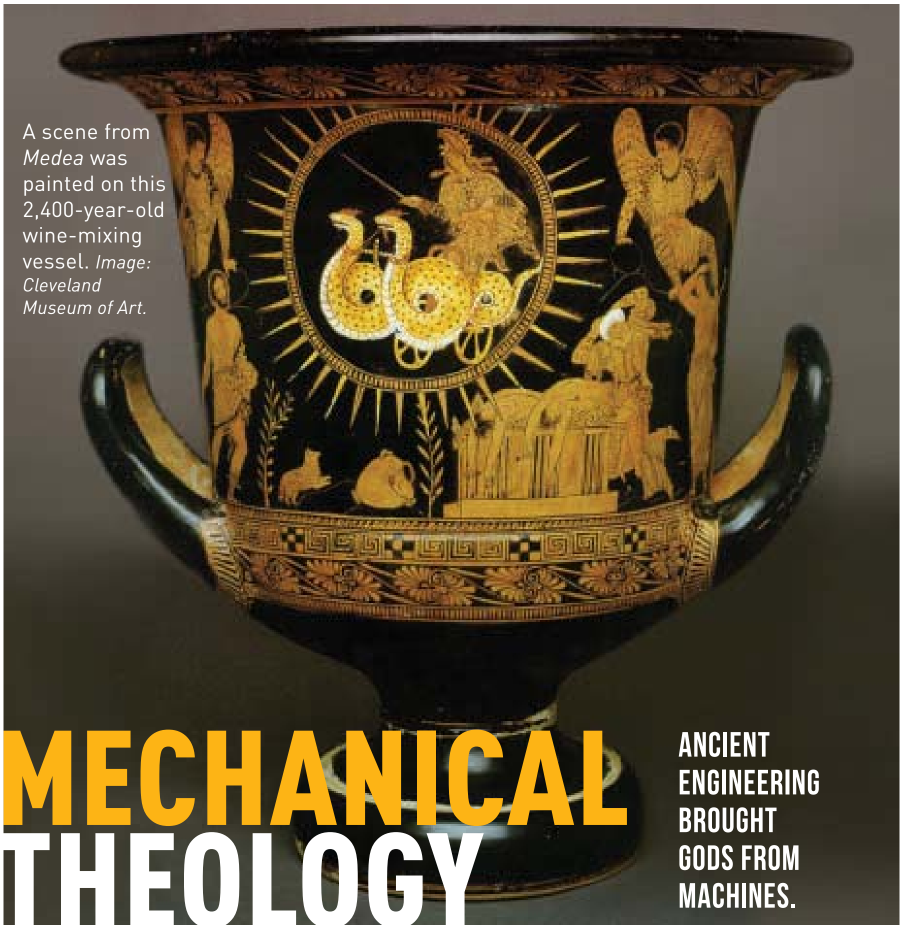
Sheppard is the Burton J. and Deedee McMurtry University Fellow in Undergraduate Education and professor of mechanical engineering at Stanford.

The U.S. Professor of the Year awards are sponsored by the Carnegie Foundation for the Advancement of Teaching and administered by the Council for Advancement and Support of Education. Established in 1981, the awards are designed to specifically highlight excellence in undergraduate teaching and mentoring. Winners are chosen from a pool of nearly 400 nominees and were selected by an independent panel of judges based on such criteria as their impact on undergraduate students and their contributions to undergraduate education in the institution, community, and profession.

Sheppard was recognized for her innovative approach to teaching undergraduate students in a hands-on, problem-solving way that transforms large classes into small group learning laboratories. She has been involved with initiatives sponsored by the National Science Foundation, including the Center for the Advancement of Engineering Education, and the creation of the National Center for Engineering Pathways to Innovation with Stanford entrepreneurship professor Tom Byers in 2011.

Sheppard received her doctorate in mechanical engineering from the University of Michigan at Ann Arbor in 1985 and joined the Stanford faculty a year later as an assistant professor, advancing to associate professor in 1993 and full professor in 2005.

Sheri Sheppard



A scene from *Medea* was painted on this 2,400-year-old wine-mixing vessel. *Image: Cleveland Museum of Art.*

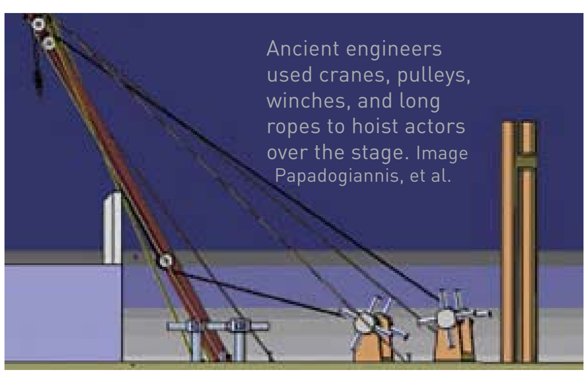
MECHANICAL THEOLOGY

ANCIENT ENGINEERING BROUGHT GODS FROM MACHINES.

ENGINEERS WHO LIVED TWO AND a half millennia ago are remembered in a figure of speech we often use today—*deus ex machina*. The phrase (Latin for "god from a machine") refers to a device used in classical Greek and Roman theaters to resolve situations or to move a plot along. A god or supernatural messenger descends to the stage to adjust human affairs.

Typically, we moderns feel cheated because we demand logic. But ancient playwrights were not similarly constrained. And since the gods of the Greek and Roman pantheon were not troubled by human restraints like the laws of physics, they often made their appearance on stage by flying.

In ancient performances *deus ex machina* involved a real *machina*, specifically a crane. Engineers assembled an elaborate assortment of hardware to lower an actor to the stage.



Ancient engineers used cranes, pulleys, winches, and long ropes to hoist actors over the stage. Image Papadogiannis, et al.

The ancients were limited to a few wooden beams, ropes, and pulleys. Probably the most challenging use of this machinery occurs in the finale of the tragedy *Medea*. If the play was produced as written, a chariot containing three passengers would disappear in the wake of a flying dragon. That would be a big order even for today's set designers.

The ancients' willingness to invest in hardware to support elaborate theatrical productions indicates how important the theater was in community life. It was more than entertainment. The theater was a religious tradition.

Ancient theaters have been the subject of a great deal of archaeological study. This includes efforts to reconstruct the wooden *deus ex machina* cranes. None of the machinery has survived, so reconstruction is based on evidence in the stones of the amphitheaters.

A January 2010 article, "Deus-Ex-Machina Mechanism Reconstruction in the Theater of Phlius, Corinthia," in the ASME *Journal of Mechanical Design* describes the remains of a theater with features that may have supported a stage machine. The authors, Argyris Papadogiannis and Thomas G. Chondros of the University of Patras in Greece and Marilena C. Tsakoumaki of King's College London, used the evidence at the theater and in literary references to work out a very convincing reconstruction of the lifting apparatus.

The paper even contains a stress and vibration analysis of the assumed structure. Reading between the lines tells a lot about the extent to which various technologies had developed in the Aegean as early as the fourth century BCE.

Rope and pulley making, which began long before in Egypt, had progressed to a point where line was obviously available in unlimited lengths and was of a quality allowing it to be bent around sheaves and winch drums. This technology, combined with a pragmatic knowledge of structures represented the ultimate state of the art at the time.

The *deus ex machina* is an example of technology serving culture. Just as electronic recording serves music today, structures and mechanics have served the theater. The presence of "*deus ex machina*" in today's vocabulary reminds us of the intimate connection that has always existed between technology and art. **ME**

ROBERT O. WOODS, an ASME Fellow and member of the History and Heritage Committee, is a frequent contributor to *Mechanical Engineering* magazine.