gridlines

What's next for nuclear power?

pwc

Gridlines is PwC's magazine devoted to infrastructure. Stories focus on four areas: emerging trends and technologies driving infrastructure transformation, ways to manage risks and seize opportunities, tactics that can help with day-to-day challenges, and interviews with experts at the heart of thought and action. Gridlines combines PwC's analysis and insight with reporting on critical developments and directions.

Cover photo—Construction site of the Sanmen 1 nuclear power plant.

www.pwc.com

World energy demand and nuclear power meet at a 21st-century crossroads

R. Carter Pate

Global managing partner—infrastructure and government.

Rising global populations with advanced needs make one fact certain—we are at a crossroads when it comes to energy production. On one hand, the world is going to need more electricity than ever before. A 75 percent leap in demand by 2035 is forecast by the International Energy Agency's (IEA's) *World Energy Outlook 2010*. Electricity generation is the fastest growing of all infrastructure sectors, with more than half of the $33 trillion the IEA expects to be invested in energy-supply infrastructure going to electricity. On the other hand, environmental considerations play a major part in our choices.

The question becomes: How do countries provide for massive energy demands without adding to climate problems and navigate a shift to renewable energy sources that most agree will take some time to put in place? Despite dramatic events of the last few months, with the tsunami and accident in Japan and revolts in the Mideast, world energy sources and markets will not transform easily or quickly.

"There are five major reasons that the transformation from fossil to nonfossil fuel will be much more difficult than commonly realized[1]," says Vaclav Smil, an energy and environmental scientist with whom we spoke for this issue of *Gridlines*. Smil cites "scale of the shift; lower energy density of replacement fuels; substantially lower power density of renewable energy extraction; intermittence of renewable flows; and uneven distribution of renewable energy sources" as the factors.

Right now, though, we need to take a pragmatic look at the long-term plans and actions that will be required to move the energy transformation ahead. That's where nuclear power continues to fit in, according to many scientists and policy makers. Nuclear faces challenges, of course, but how they are being met is the subject of this issue of *Gridlines*.

Vaclav Smil notes the challenges but concludes "if you are practical, you cannot say you can do without" nuclear in the long-term energy picture.

Ric Pérez, President of Operations at Westinghouse, explains the advances made by the AP1000 reactor. In China, these reactors now being built represent the first wave trying to demonstrate nuclear's resilience and reliability.

Mike Johnson, Director of the Office of New Reactors at the US Nuclear Regulatory Commission, discusses the regulatory and inspection challenges.

Buzz Miller goes into the brass tacks of building two new plants in the US from his vantage point as Executive Vice President of Nuclear Development for Southern Nuclear.

Few capital projects are as large and complicated to build as a nuclear power plant. Delays in construction have been an expensive problem. *Gridlines* focuses on two key areas that can make a practical difference.

Mission-critical management looks at creating comprehensive controls during construction, focusing on new quantitative risk analysis tools that are being used at nuclear construction sites to help contractors foresee and avoid risks.

From build to "go" zeros in on the handoff of a nuclear power plant from contractor to owner-operator that can be a painfully slow exercise in data management transfer. What's useful for a contractor is often unnecessary for an operator. The article examines enterprise asset management, a new approach geared to ensure asset configuration and facilitate long-term, reliability-centered operations and maintenance.

I hope you enjoy this edition of *Gridlines* focusing on the epochal energy shift in front of us and the role nuclear may play in it. Please contact me to discuss any of the issues raised here.

Yours truly,

1 Vaclav Smil, *Global Catastrophes and Trends: The Next Fifty Years*, MIT Press, 2008, pg. 82.

Operation excavation–Plant Vogtle construction: units 3 and 4, with the outline of a Westinghouse AP1000.

What's next for nuclear power?

An industry once poised to prove itself is put on hold as the world assesses whether it can do without it

By Mark Svenvold

As the world reevaluates the nuclear renaissance, the debate continues about nuclear energy's role in global supply. China has, indeed, temporarily suspended approval of new nuclear construction projects until it has concluded a safety inspection of current construction sites, but this has not slowed construction. China is still targeting 70 to 80 gigawatts of new nuclear capacity by the end of the decade.[1]

And while resistance to construction of new power plants is stiffening in India, five reactors are currently under construction there, another 39 more are proposed, and the government is showing increasing resolve to build enough nuclear reactors to generate a quarter of the country's electricity supply by 2050.[2] Germany has taken the most decisive action against nuclear power, deciding in late May to phase out all 17 of its nuclear plants by 2022.[3] Other countries in Central Europe like the Czech Republic, Latvia, Poland, and Hungary, are drawing an entirely different lesson and may be gearing up, by means of increased nuclear capacity, to help supply European Union countries, some grown increasingly skittish about relying on natural gas from Russia, with a steady, reliable source of nuclear-generated electricity.

Without question, the last few months have had an impact upon the industry, but many believe these effects will not nearly be as great as some have supposed. The reason? Mostly it's about the colossal scale of the fastest growing infrastructure sector in the world—electricity consumption.

Three sober realities of demand, supply, and environmental concern underlie the debate about the future of nuclear power. Indeed, much of the media coverage after the Fukushima accident has focused understandably on current developments, but that has also partially obscured certain fundamental facts about the global energy landscape.

The first has to do with the tremendous scale of the energy already provided by the sector. Indeed, nuclear power's current incumbency plays an essential role in the world energy equation today—amounting to 14 percent of the global baseload supply of electricity—and is projected to maintain that share, globally,

1 "China's Nuclear Plans to Slow but Not Shrink," Reuters, April 13, 2011, http://www.reuters.com/article/2011/04/13/us-china-nuclear-idUSTRE73C0X520110413.

2 "A Widening Nuclear Divide," Vikas Bajaj, *New York Times,* April 15, 2011.

3 "Germany, in Reversal, Will Close Nuclear Plants by 2022," Judy Dempsey and Jack Ewing, New York Times, May 30, 2011, http://www.nytimes.com/2011/05/31/world/europe/31germany.html

through 2035.[4] Regionally, nuclear's share of capacity is projected to increase to 23 percent by 2035 among member countries of the Organisation for Economic Co-operation and Development (OECD).[5] The United States gets 20 percent of its power from nuclear generation. The 17 reactors that some in Germany would like to shutter supply the country with a little more than 22 percent of its electricity.[6] Sweden gets almost half of its electricity from nuclear power. Even Japan gets 30 percent of its electricity from nuclear power.

That level of baseload supply, says Vaclav Smil, energy and environmental scientist and leading macro-risk expert, "cannot be replaced either rapidly or cheaply by any other available option, making a substantial retreat from nuclear power almost impossible to contemplate and a failure to continue with planned nuclear growth one fraught with major challenges."[7] In short, the argument can be made to get rid of 20, 22, 30, or 50 percent of a nation's baseload power now supplied by nuclear, but if that argument is made successfully, then a new source of baseload supply will be needed to quickly replace it.

But a quick transition to renewable energy isn't likely or easily doable, according to Smil, whose 30 books including *Global Catastrophes and Trends: The Next Fifty Years*, explore, among other things, the structural or systemic obstacles to technological change. "The transition to renewable energies," Smil says, "will be a protracted affair."[8] In many ways, the scale of the transition required is just too big to proceed swiftly, he argues. Even if all forms of renewable electricity increased significantly, as they are projected to do under the International Energy Agency (IEA's) New Policies Scenario, which anticipates modest climate legislation among other assumptions, renewables of all forms, including hydropower, will still account for just a third of total worldwide electricity supply, with wind and solar making up a paltry 10 percent of supply by 2035.[9]

The second reality is about the scale of projected demand for electricity globally, which will likely increase to a staggering degree. Despite recessionary declines and improved efficiencies, most observers think that electricity demand will return, post-recession, with a vengeance—demonstrating the so-called demand rebound.[10] The US Department of Energy's Energy Information Administration (EIA) projects a 30 percent jump in the United States by 2035 under its business-as-usual reference scenario, which assumes no change in energy policy.[11]

Globally, the demand rebound is also likely to happen quickly and dramatically. According to the IEA's New Policies Scenario, which assumes modest implementation of energy and carbon mitigation policies, world electricity demand is projected to increase by an average annual rate of 2.2 percent, or a total of nearly 60 percent between 2008 and 2035.[12]

It's the kind of demand that China has already anticipated. The IEA projects electricity demand in China to triple between 2008 and 2035. The country is preparing, by 2025, to accommodate 350 million people in cities that don't exist now, requiring China to add in the next 15 years an electrical grid that is the equivalent of what the United States built over 120 years.[13]

Currently China has 25 nuclear plants under construction, with 38 more planned and financed, and another 76 in the pipeline, according to the World Nuclear Association.[14] And while that may sound like a lot, for perspective it's helpful to recall that China's nuclear buildout will most likely represent a tiny share—a mere 9 percent—of the total planned generating capacity the country will need to meet a whopping projected electricity demand of 9,594 terawatt-hours in 2035—or 27 percent

"Everybody was talking about a nuclear renaissance, but nobody was really buying it. Until somebody broke the deadlock and actually bought [the AP1000], people were hesitant," according to Stephen Thomas.

4 "Figure 7.4 Share of nuclear and renewable energy in total electricity generation by region in the New Policies Scenario," IEA, *World Energy Outlook 2010*, pg 222.

5 Ibid, pg 222.

6 "Panel Urges Germany to Close Nuclear Plants by 2021, Judy Dempsey, *New York Times*, May 12, 2011, http://www.nytimes.com/2011/05/12/business/energy-environment/12energy.html.

7 Vaclav Smil, "Japan's Crisis: Context and Outlook," *The American: Journal of the American Enterprise Institute,* April 16, 2011, http://www.american.com/archive/2011/april/japan2019s-crisis-context-and-outlook.

8 Vaclav Smil, *Global Catastrophes and Trends: The Next Fifty Years,* The MIT Press, 2008, pg 77.

9 IEA, *World Energy Outlook 2010,* pg 321 and 279.

10 A growing body of evidence suggests that improvements in energy efficiency actually have the effect of increasing energy demand. "The Efficiency Dilemma," *The New Yorker,* David Owen, December 20 and 27, 2010, pp 78-85, http://www.newyorker.com/reporting/2010/12/20/101220fa_fact_owen.

11 "Electricity Demand," *Annual Energy Outlook 2010 with Projections to 2035,* pg 1, http:/www.eia.doe.gov/oiaf/aeo/electricity.html.

12 Non-OECD countries will account for 61 percent of world electricity use in 2035. Nearly 72 percent of the world expansion in installed nuclear power capacity is expected in non-OECD countries. *International Energy Outlook 2010,* pg 13 and 77, http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2010).pdf.

13 IEA, *World Energy Outlook* 2010, pg 217. See also "Dirty Coal, Clean Future," James Fallows, *The Atlantic*, December 2010, http://www.theatlantic.com/magazine/archive/2010/12/dirty-coal-clean-future/8307/.

14 "Nuclear Power in China," World Nuclear Association, updated November 18, 2010, http://www.world-nuclear.org/info/inf63.html.

First-wave foundations—Sanmen 1 is expected to be operational in 2013.

of all the electricity generated on the planet.[15] And much of China's—and the world's—electricity will be from coal-fired generation. World electricity generated by coal remains intractable, with coal's share of generation in non-OECD countries projected to double by 2035.[16] James Fallows recently quoted a Chinese energy expert who observed, rhetorically: "Will you turn off your refrigerator for 30 years while we work on renewables? Turn off the computer? Or ask people in China to do that? Unless you will, you can't get rid of coal for decades."[17] Indeed, coal and natural gas are projected to dominate electricity generation in any of the IEA's projected scenarios to 2035, with coal still accounting for 32 percent of global electricity generation in 2035 and natural gas for 21 percent of global generation.[18] The agency does not project carbon capture and sequestration technology to have much of an impact.[19] Unless this somehow changes, coal and gas will continue to move in the wrong environmental direction.

This raises the third powerful reality in the global energy landscape, the scale of which is as big as the earth itself—that is, the looming climate crisis attributed to man-made greenhouse gas emissions. Recent peer-reviewed studies have discovered threats to the carryover ice pack in the Arctic; permanent dust-bowl conditions in five global regions, including the southwestern United States; and mounting water shortages in the continental United States.[20] Such projections suggest a future filled with difficult decisions, chief among them how to satisfy global electricity demand without pumping more carbon into the atmosphere.

Against this backdrop, nuclear power remains an alternative that answers questions about current baseload supply, growing demand, and carbon emissions. "No rational long-range energy plan of any major modern economy should exclude the nuclear option," says Smil. "The debate should be about the best way to proceed, not about whether to proceed at all."[21]

Such debate seems largely academic in remote Burke County, Georgia, about a half hour's drive from Augusta, where the construction activity there resembles something from documentary films about giant utility projects like Hoover Dam. Forests of Georgia pine are suddenly interrupted by a massive swath of red clay. Scores of huge dump trucks with tires that seem as big as houses work at making a very big hole, 90 feet deep across 42 acres. Engineers, tiny human figures in hard hats, stand in groups consulting blueprints, or bend to put an eye to a surveyor's scope, or clamber over pipes and rebar, or signal to each other from towers and cranes above the general din.

15 Under the IEA's New Policies Scenario, which takes into account planned energy-security and climate policy commitments, world electricity generation is expected to grow to 35,336 terawatt-hours by 2035. China's electricity generation is projected to grow from 3,495 terawatt-hours in 2008 to 9,594 terawatt-hours in 2035. Nuclear's share of that will rise from 2 percent (68 terawatts) to 9 percent (895 terawatts). The IEA projects US generation to be 5,169 terawatt-hours by 2035, according to Marco Baroni, senior analyst at the IEA. By comparison, the total electricity generation for the United States in 2009 was 3,949 terawatt-hours, according to the EIA.

16 IEA, *World Energy Outlook 2010*, pg 217.

17 "Dirty Coal, Clean Future," James Fallows, *The Atlantic,* December 2010, http://www.theatlantic.com/magazine/archive/2010/12/dirty-coal-clean-future/8307/.

18 IEA, *World Energy Outlook 2010*, pg 217.

19 "Carbon capture and storage (CCS) technology is expected to be deployed on a limited scale in the New Policies Scenario, its share of total generation rising from zero today to 1.5% in 2035," IEA *World Energy Outlook 2010,* pg 220.

20 There will still be ice in the Arctic, but a multiyear, carryover ice pack will have disappeared. FreshNor: The Freshwater Budget of the Nordic Seas, Danish Meteorological Institute and Nordic Council of Ministers, 2009, http://freshnor.dmi.dk/handout_freshnor.pdf. See also David Ljunggren, "Multiyear Arctic Ice Is Effectively Gone," Reuters, October 29, 2009, http://www.reuters.com/article/idUSTRE59S3LT20091029?sp=true.

The National Oceanic and Atmospheric Administration study "Irreversible Climate Change to Carbon Dioxide Emissions," which projects dust bowl conditions for eight major regions in the world, reinforces two earlier studies that focused on the southwestern United States: "Human-Induced Changes in the Hydrology of the Western United States," Tim P. Barnett et al, *Science*, 22, February 2008, http://www.sciencemag.org/cgi/content/abstract/1152538, and "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America," Richard Seager et al, *Science*, May 25, 2007; http://www.ldeo.columbia.edu/cicar/documents/Sc_Express_Model_Predictionsv2.pdf.

A study commissioned by the Natural Resources Defense Council (NRDC) analyzed 16 different climate model estimates of precipitation and temperature in the United States to the year 2050 and found more than 1,100 US counties vulnerable to drought conditions, a 14-fold increase in risk from previous estimates, according to the report "Climate Change, Water, and Risk," NRDC, 2010, http://www.nrdc.org/globalwarming/watersustainability/files/WaterRisk.pdf.

21 Vaclav Smil, *Energy Myths and Realities,* AEI Press, 2010, pg 154.

This is the site of Southern Company's Vogtle Units 3 and 4, which, when placed into service as planned in 2016 and 2017, respectively, will generate a total of 2,200 megawatts of power from two Westinghouse AP1000 advanced pressurized nuclear reactors. The lead contractor for the project, the Shaw Group, of Baton Rouge, Louisiana, has a contingent of about 1,500 people working at the site at present and expects a peak of about 3,000 in a few years. The U.S. Nuclear Regulatory Commission (NRC), in an effort to streamline plant construction, granted Southern a limited work order to allow for the earth-moving operations. Component parts to be delivered include steam generators manufactured in South Korea, heat exchangers from Italy, turbine generators from Japan, 1,000-ton modular walls and floors shipped from Louisiana, and an 800-ton containment dome manufactured in Japan and assembled by Chicago Bridge & Iron.

The man at the center of all this is Joseph "Buzz" Miller. Miller, Southern Company's Executive Vice President of nuclear development, is in charge of making sure the project passes every regulatory inspection required by the NRC, of handling every problem related to the plant's intense construction schedule, and of addressing every concern of Georgia's public power commission so that Vogtle 3 and 4 go online on time and on budget.

When *Gridlines* caught up with Miller in November, 2010, he was in the middle of doing paperwork, and like all things nuclear, it was a mighty piece of paperwork—the 18th revision of a 23-chapter application called the Design Control Document, a tome covering every safety system in the Westinghouse AP1000 reactor and all of the minutia—of its construction.

Teams of engineers from Southern, Westinghouse, and elsewhere had been working since 2005 preparing this document to submit to the NRC, which was due in a month's time, in early December. That deadline was met successfully. It was a critical step on the way to receiving a combined operating license (COL), which will allow construction to begin in earnest. Already, modular pieces of the power plant had arrived from South Korea and were being offloaded in the Port of Savannah—the early shipments of 58 iron plates that will form a massive bowl-shaped structure, the bottom half, or bottom-head, of a containment dome for the power plant.

While the plates are welded together to form the bottom-head, the lower floors of a concrete building meant to house it will be constructed, saving time. When the bottom-head bowl is finished, all 800 tons of it will be crawled over to the finished building on a slow-moving track and then lifted into place. "We'll have a lot of big lifts," Miller said.

The widespread use of modular assembly, Miller explained, is a big change from how nuclear plants were assembled 30 years ago, when the last reactor was built in the United States. So-called Generation III designs include the ESBWR (Economic Simplified Boiling-Water Reactor) from GE-Hitachi, the US-APWR (US Advanced Pressurized-Water Reactor) from Mitsubishi Heavy Industries, and the EPR (European Pressurized Reactor) from Areva. Westinghouse's AP1000 is part of that next-generation-design revolution. "Modular construction and a standard plant approach," said Miller, "have proven to be vastly superior to stick building."

But none of this would happen until the paperwork was done. That paperwork—seeking preapproval of almost 100 percent of the AP1000 reactor design prior to construction, another big improvement over the past—has become an abiding preoccupation. "We're deep in the licensing process," Miller said, dryly.

It would not be an exaggeration to say a great deal was riding on the success of Miller and Vogtle. But success depends partly on events happening thousands of miles away, in China, where four AP1000 power plants, some of them nearly half finished, have a three-year head start on Buzz Miller's construction schedule.

In China, real iron is in the ground. In the spring of 2007, after a fierce competition between Westinghouse and French-owned Areva, China's State Nuclear Power Technology Corporation, SNPTC, selected Westinghouse's AP1000 power plant to become the standard nuclear reactor design for many of its projects. It was a technology transfer agreement that had some scratching their heads. The deal effectively gave the blueprints for the AP1000 design to the Chinese, something that Areva had balked at. Why would Westinghouse give away the crown jewels, as it were?

The short answer, according to Stephen Thomas, professor of energy policy at the University of Greenwich, England, is that Westinghouse had in the AP1000 a revolutionary design, but that design wasn't going anywhere unless someone bought and built it. "Everybody was talking about a nuclear renaissance, but nobody was really buying it," Thomas told *Gridlines*. "Until somebody broke the deadlock and actually bought something, people were hesitant. Companies like Westinghouse wanted their new generation of power plants demonstrated."

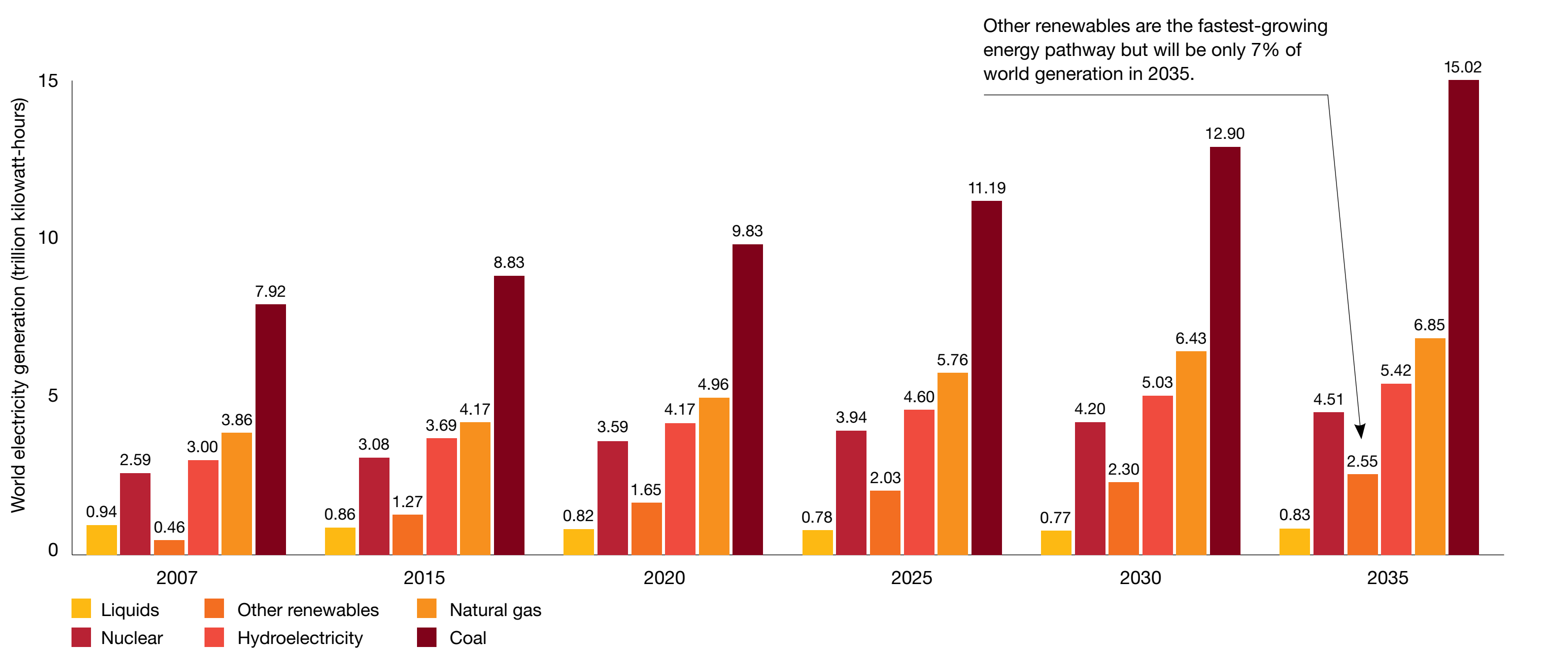
But there was a deeper strategy as well, according to Richard A. Gabbianelli, Westinghouse's vice president of finance. "We knew that China's nuclear build-out would be very big," says Gabbianelli, who anticipated dozens of plants in the near term. "With a build-out on that scale, China would need help. There's no way they would be able to do it alone. Westinghouse would continue to be in the picture for a very long time." Indeed, within months, the technology transfer strategy seemed to be paying off when China announced that it wanted to build 100 more AP1000 reactors by 2020.[22]

Today, Westinghouse's big bet is being tested on the only stage that matters: in real time, with real concrete being poured, real steel stretching into the sky, and the real daily challenges of a construction site. Much has been written about a nuclear renaissance, but in China, the contours of that abstract idea are taking shape

22 "China wants 100 Westinghouse reactors," Bonnie Pfister, *Pittsburgh Tribune-Review,* June 28, 2008, http://www.pittsburghlive.com/x/pittsburghtrib/s_575073.html. That figure has since been reduced by about half. China plans to build roughly 75 gigawatts of new nuclear power by 2035, which is the equivalent of about 57 nuclear plants of roughly 1,300 megawatts capacity, a significant portion of them of the AP1000 design—still an impressive target by any measure. "Figure H-5, World Installed Nuclear Generating Capacity, by Region and Country," U.S. Energy Information Adminstration (EIA), http://www.eia.doe.gov/oiaf/ieo/ieoecg.html.

A look at the energy landscape:

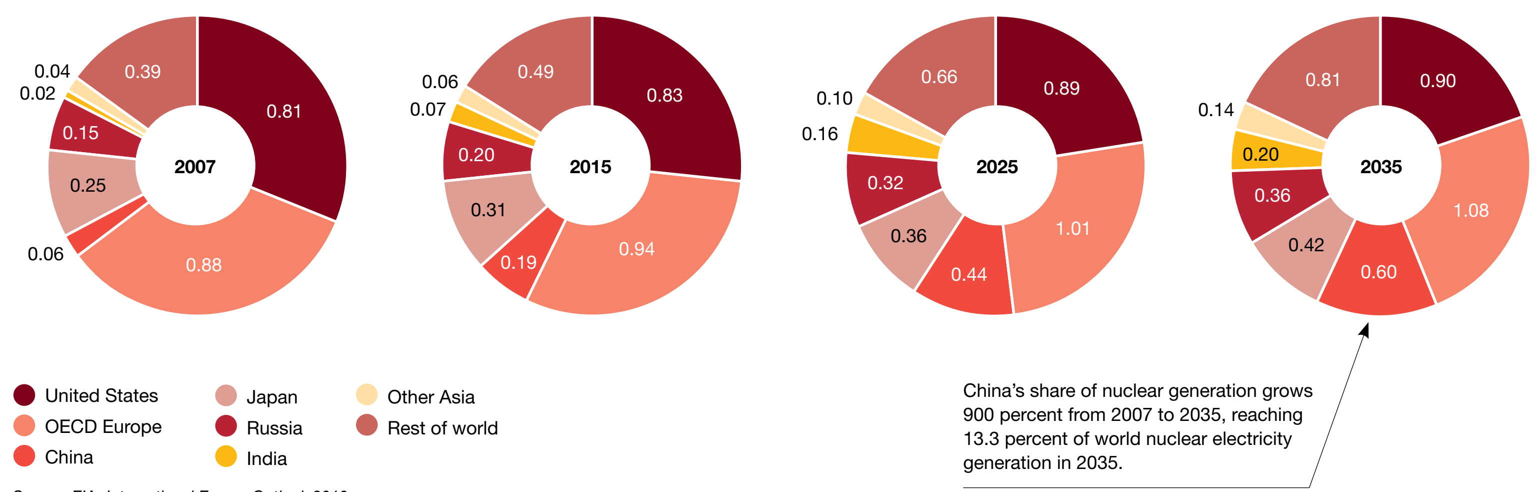
Renewables are the fastest growing, but coal will still fuel the largest share of the world's electricity in 2035



Source: EIA, *International Energy Outlook 2010*

China's share will skyrocket: World net electricity generation from nuclear power by region, 2007–2030

(trillion kilowatt-hours)



Source: EIA, *International Energy Outlook 2010* in the skyline itself. Indeed, China has become the world's de facto proving ground for any number of energy pathways, because China is pushing hard in all of them, from advanced coal with carbon capture and sequestration to next-generation natural gas, to wind, solar, and nuclear power.

"You can think of China as a huge laboratory for deploying technology," a US government official who works in China said recently. "We have advanced ideas. They have the capability to deploy it very quickly. That is where the partnership works."[23] The Vogtle projects illustrate this point. Southern Company has its engineers in China and has brought Chinese engineers to Georgia. Westinghouse has had an engineering team, led by John Pierpont, observing construction of the AP1000 bottom-head containment dome at the Sanmen project in the eastern coastal province of Zhejiang, according to Ric Pérez, Westinghouse's president of operations.

When Sanmen's bottom-head was finished, Pierpont and his team were reassigned to Vogtle, taking with them the lessons learned in China. "Those lessons," says Pérez, "hundreds of them—how to dress the modules, how to make them easier to assemble at the site—these lessons were written into the Design Control Document for the Vogtle plants in Georgia." This spring, other construction milestones have been met—the reactor vessel at Sanmen 1 has been completed and is undergoing hydro-testing; the second ring of the containment dome at Haiyang 2, in the northeastern coastal province of Shangong, has been installed. Those lessons in construction are being captured in China and are expected to help develop—for the overall industry and the institutions that finance construction—a baseline sense of how long it will take to build Generation III plants like the ones planned in Georgia and elsewhere in the world.

Part of the compelling interest in nuclear generation is the concern of countries in Western Europe and Central Europe, over continuity of supply. Russia, whose state-owned Gazprom supplies roughly a quarter of the European Union's natural gas, has been willing to enforce its price on countries. For example, during a pricing dispute over natural gas, Gazprom simply turned off its supply to Ukraine during the bitterly cold winter and spring of 2008–09. "That event," says Luis Echavarri, Director General of the Organisation for Economic Co-operation and Development's (OECD) Nuclear Energy Agency, "really drove home the need to have stable and secure supplies."[24] And, as Westinghouse's Pérez notes, if Germany phases out its nuclear fleet, something is going to have to make up

Story continues on page 33

23 "Dirty Coal, Clean Future," James Fallows, *The Atlantic*, December 2010, http://www.theatlantic.com/magazine/archive/2010/12/dirty-coal-clean-future/8307/.

24 "Nuclear Option Is Back on the Table," Aude Lagorce, MarketWatch, May 20, 2010, http://www.marketwatch.com/story/the-nuclear-option-is-back-on-the-table-2010-05-20.

"[Current levels of nuclear generation] cannot be replaced either rapidly or cheaply by any other available option, making a substantial retreat from nuclear power almost impossible to contemplate and a failure to continue with planned nuclear growth one fraught with major challenges."

Vaclav Smil

A few words with with Ric Pérez …

President of Operations at Westinghouse, focusing on all facets of commercial nuclear energy production in Europe, Asia, and South America. *Gridlines* met Pérez at Westinghouse headquarters, outside Pittsburgh, where he had just returned from a quarterly meeting in China with the State Nuclear Power Technology Corporation (SNPTC). The SNPTC is funding the construction of two Westinghouse AP1000 reactors, Sanmen I and II, and runs another 17 reactors.

How has Fukushima affected the nuclear industry?

I think it has fostered an appropriate level of revalidation of safety features and procedures for the existing fleet and for the next generation of new build. Both US and EU regulations, post-9/11, required some assumptions relative to external events—the so-called LOLA, or Loss of Large Area requirements. Under these LOLA requirements you have to assume that for whatever reason there's an external event—a plane strike, for instance—that takes a large area of the plant out. The NRC just revalidated those requirements to the 104 operating plants, required them to validate that all those systems and coping mechanisms were valid, asked them to drill and train on them again, and so those were all done. We expect a report out in a few months from the NRC that will, in part, address new plant design as well. But I can tell you—and obviously we want to get this right—that our own initial assessment is that our design features really provide a safety net for the Fukushima-type event. In short, we're seeing in this process a validation of the AP1000 design.

If you're asking me, five weeks after the event, what are the fundamental takeaways? I'd say one of them is that there's been an acknowledgment that the Generation III path is the right path to go for nuclear, because Generation III is defined, in a large measure, by its emphasis on providing extra margins of safety in the design of the plant. For the AP1000 reactor, that means a million gallons of water are already positioned inside the containment building; passive cooling systems that operate automatically with air-powered valves and do not depend on outside power; battery and diesel generator backup power supply; two separate methods for mitigating hydrogen gas; and hardened spent fuel pools with a dozen different redundant systems to insure that water stays in those pools.

Have the events in Japan affected construction of the first two AP1000 reactors in China—the reactor at Sanmen 1, and Haiyang 2—or construction at Plant Vogtle in Georgia?

We have not stopped anything at Haiyang or Sanmen. In fact, we just achieved two of the of the key milestones we had planned for this year at Haiyang this past week. On April 6, we finished the CA01, which forms the refueling canal, steam generator compartments, and the pressurizer compartment. And we set the second ring on the containment vessel on April 28th. As far as Sanmen 1 is concerned,

Unit 1 cover ring, Haiyang, China.

the reactor vessel is finished and is being hydro-tested at the factory in Korea. It will be shipped soon and will arrive at Sanmen in May. That's a big milestone—it's the first big nuclear island component that will go into the reactor—and it is fundamentally on schedule. Right now, the construction sites look like a swarm of ants—it's the classic large-scale construction scene.

At Vogtle, there's been no letup on construction—on what we've been allowed to build under the NRC's limited work authorization. All the back-fill is finished for the plants, the first part of the foundation, the construction of the support facilities. And work continues all down the supply chain—with all the manufacture of equipment, so all the reactor vessels, steam generators, and reactor cooling pumps are all continuing to be fabricated. In fact, I just saw a bunch of them the other day when I visited our facility that is manufacturing the pumps.

China seems to be the real proving ground for nuclear power in general and for the AP1000 design in particular. Is it safe to say that China is, in essence, the first wave for a new build in nuclear power? If so, what are the lessons you're learning about actually constructing the AP1000 for the second wave which would happen elsewhere—in the United States, for instance?

The first big lessons are about modular construction—mostly about how to handle the structural modules at the site. Some of these are very big. There's a module called the CA-20, which is essentially a 10-story building. We're learning many lessons at Sanmen about how to dress a module like that on-site, better ways to lift components. Some of these are very big lifts, of up to 1,000 tons.

James Fallows reports in the December issue of The Atlantic that China is preparing, by 2025, for 350 million people to live in cities that don't exist now.[1] In short, China is in a hurry on all fronts.

That's right. And so, when it comes to putting up structural modules, they sometimes manhandle the pieces into place. We're learning from that. We're learning how to lift heavy structures better, how to brace walls when pouring concrete, and how to better test the pour to ensure full penetration of the modules. That sort of thing. We're seeing what can be done, and in how much time. Sanmen 1 will meet its 54 months construction schedule, and begin generating electricity by 2013. Fifty-four months will become our baseline time to beat—and I expect to beat that time on all the remaining projects.

Some might challenge the China-as-first-wave idea. The argument would be that the situation in China is so dramatically different from anywhere else, that any comparison to China amounts to a false analogy. In effect, just because a nuclear plant is built in 54 months in China doesn't mean you'll be able to do the same elsewhere. How would you answer that?

It's a fair question. And I'll say that when you talk about commodity installation—laying pipe, cable—all the small-bore stuff—China may be 10 to 15 percent more productive than a comparable workforce in the United States. Having said that, what seems very clear on a daily basis is that our modular construction system—the advantages of modularity—are playing to the dominant strengths of the United States, where there has been a long-standing, high level of experience in factory/modular construction in other industries—like petrochemicals, fossil fuel generation, refineries, oil extraction.

A game changer in the United States comes in the form of Part 52 of the NRC regulatory process—the advance approval of design right down to the specs for bolts and threads at the attachment points between rebar in the structural modules.

We've essentially adopted the model of the Japanese. The cost of construction labor in Japan is what really drove them out of the hole, as it were, and they developed a factory/modular model. So did the United States, and this has made US skilled labor in modular construction more competitive than it is in China. And we expect significant improvements in this area over China. So, in short, when it comes to modular construction, instead of the China-as-first-wave being a false analogy, we see it as really a direct and usefully predictive analogy.

The general design of the Westinghouse AP1000, with its emphasis on passive systems, raises safety margins and reduces the overall footprint of the nuclear island—and a smaller footprint goes a long way in reducing construction time. What else seems to be helping reduce construction costs?

You mentioned the maturity of the AP1000 design, which is really important. It's easily three times more efficient than the designs of the '80s. But the other game changer in the United States comes in the form of Part 52 of the NRC regulatory process—the advance approval of design right down to the specs for bolts and threads at the attachment points between rebar in the structural modules. All of this gets approved—before construction—in something called the Design Control Document. We're finishing one of those right now. In fact, we're in the process of taking all of the important, time-saving lessons learned in the construction of the AP1000 in China—I'm talking about hundreds of lessons learned—and writing those design lessons directly into the Design Control Document for Vogtle Plants 3 and 4, the two reactors that will be built for Southern Company in Georgia.

1 "Dirty Coal, Clean Future," James Fallows, *The Atlantic*, December 2010, http://www.theatlantic.com/magazine/archive/2010/12/dirty-coal-clean-future/8307/.

We expect the Chinese analogy to carry over to the United States. We expect the AP1000 design to be a game changer for how nuclear can make an impact in the world.

Scale model of the Sanmen nuclear power company facility.

As you may know, Southern is currently doing advance construction, preparing its site to receive the bottom-head of the containment domes for the AP1000. In China, all of this work has been completed. We sent a team from Westinghouse to observe that construction, and these people have now been sent to advise and consult in the bottom-head construction process at the Vogtle plants. Currently at Vogtle, the big non-safety-related buildings are up—the concrete batch plant, warehouses, the modular assembly building is done. All the excavation is done, and now the backfill is finished.

What other countries, aside from China, seem intent on new build for nuclear?

There are two that come readily to mind for different reasons. Number one is Brazil, a country that already has two nuclear units in operation and another one being built, and as you know they're hosting the World Cup and they're hosting the Olympics and have unbelievable economic growth. So they've indicated that they will not modify their current plans for going out to bid, and that is clearly one of the places we're very, very positive about just because they are a known nuclear operator with a good history and with a very developed infrastructure.

Historically, countries that reacted strongly against nuclear build in the aftermath of Chernobyl—an event that bears very little resemblance to Fukushima, by the way—those countries that constrained themselves against nuclear power ended up buying a lot of electricity from outside their own country. The very same thing may happen to Germany, which has reacted strongly against nuclear power post-Fukushima. Some countries haven't forgotten that lesson and may be positioning themselves to become suppliers of nuclear-generated electricity to places like Germany. In other words, energy security, energy markets, and continuity of supply remain a strong pull for many countries especially in places like the Czech Republic where they stated an intent to buy two more plants at Temelin 3 and 4, but also Lithuania, Poland, Slovakia and Hungary. If anything, they're more positive than ever about the need for them to build large baseload units not only for their own consumption and growth but also to support export of energy and export of their industries to places like Germany and places in the West.

Many observers have said that the world will continue to move forward with nuclear power; that, in many ways, the world has no choice but to keep pushing forward in just about every pathway including nuclear. There's too much of a demand rebound in the coming years, and the issue of global warming has to be answered in some way. Would you agree with this?

Yes. Your point about the world demand and the world direction on nuclear—even though a lot of countries have taken a pause to take a breath and analyze the situation—the situation is exactly as you have described it. If anything, we feel that this incident may actually engender a new build outside the United States toward Gen III reactors—and away from the Gen II designs that the Chinese were doing in the past and some other countries were embarking on. So, despite this cautionary moment in history, we think that the Gen III style like the AP1000 design, will emerge from all of this very well.

As someone deeply involved in current construction of nuclear power plants, what would you say is the takeaway about nuclear power?

The AP1000 was designed with two basic premises. First, to provide large-scale electricity safely, and second, to do it reliably, with the highest standards, with indigenous labor forces, and at a pace that will make a difference in decarbonizing the world. We've seen that much of this is already happening. It's being done. So far, in China the use of the AP1000 design has, in some ways, been about their pressing need for speed: they need to provide for a demand that is colossal. In the United States, the pressing issue has been about economics—and much of that is about hitting your construction milestones. We're hitting ours in China. We're hitting the schedule, we're hitting the time frames. And because it's modular construction we're talking about, we expect the Chinese analogy to carry over to the United States. We expect the AP1000 design to be a game changer for how nuclear can make an impact in the world. ■

A few words with Vaclav Smil …

"The fortunes of nations," Vaclav Smil writes in his 2008 book *Global Catastrophes and Trends: The Next Fifty Years*, "are not determined primarily by strategic designs or economic performance but by the magnitude and efficiency of their energy conversions."

We are now in the midst of just such a grand transition from fossil fuels to renewable and alternative energy sources. This evolution, Smil observes, is "the most fundamental future shift in the global economy. It is not, as one might think, further globalization but rather the coming epochal energy transition," which Smil discusses here in the context of nuclear power.

Smil's abiding focus is on the deep structures that have shaped history and that drive future trends. Born in 1943 in what is now the Czech Republic, Smil is Distinguished Professor in the Faculty of Environment at the University of Manitoba, where he has taught since 1972. The first non-American to receive the American Association for the Advancement of Science Award for Public Understanding of Science and Technology, Smil has published 32 books on energy, the environment, the history of technology, and global risk assessment and most of the recent ones have been reviewed by Bill Gates on his website. His next book, *(Not) Made In USA,* (MIT Press),

"To attack this in the simplest way, you would point to the singular problem of scale."

is an assessment of the rise and fall of American manufacturing.

Smil has given briefings and testified on wide-ranging risk and energy issues at the White House, the US House of Representatives, and the US State Department. He is a regular consultant to agencies and associations including the World Bank, the Rockefeller Foundation, the CIA, and the Department of Defense. In 2010 Smil was named by *Foreign Policy* as one of the Top 100 Global Thinkers.

Let's talk about nuclear power. You've written that "no rational long-range energy plan of any major modern economy should exclude the nuclear option. The debate shouldn't be about whether to proceed but about how to proceed."

I'll tell you why I say it. It's here. It's a fundamental part of the energy mix, embedded into the baseload supply of electricity. People don't realize this. In the US nuclear power provides 20 percent of the power generation. In Canada, nuclear's share of electricity generation is 30 percent. In Japan 30 percent. This is a huge

Getting [to a world without fossil fuel] will be expensive and require considerable patience. Coming energy transitions will unfold, as the past ones have done, across decades, not years.

percentage. People think about France, which generates 75 percent of its electricity via nuclear power, but no, think about others also—Belgium, 50 percent rate, for instance.

The typical Western countries are 20 to 40 percent. This is not two or four percent. It's a baseload, it's factual, it's embedded. And nuclear can deliver the power at a large scale—one gigawatt, two gigawatts, three gigawatts. The biggest nuclear power plant in Japan provides 10 gigawatts of electricity. So it has this potential for scale already built in. It can deliver power to the emerging megacities of the world. So why don't we use third or fourth generation nuclear? Why not do that? Because otherwise [if we do not] we are cutting 30, 40 percent of our juice, and this is not an option. Nuclear power fits the scale that's needed.

The IEA projects electricity demand to grow most rapidly in non-OECD countries like China, which is projected to triple its demand by 2035 to 9,594 terawatt-hours—or 27 percent of all the electricity generated on the planet.[1] And that of course doesn't include the rest of Asia. In other words, world demand for electricity will grow at a scale that is staggering.

Exactly. You put one nuclear power plant and it could serve a megalopolis and it could do that reliably for 30 years. These plants are up and running all the time. They are very efficient, with load factors [a percentage measure of efficiency over time] of 95 percent, many of them. We do not have any other large-scale generation of electricity as reliable—I'm not saying as economical, because economics have been a barrier. But if you are practical, you cannot say you can do without it.

You visit and lecture at Tokyo University regularly and have written extensively about Japan and China. You said you were writing about the Fukushima accident. It seems like the nuclear industry would be extremely sensitive to that kind of fatal discontinuity. What's the impact? Is this "game over" for the nuclear sector?

No. I've been corresponding with many, many people who are extremely knowledgeable about nuclear design, and it appears that this was very largely preventable, actually. They butchered the first day, basically. Fukushima, as you know, is a problem that is now about one-tenth of Chernobyl in terms of total radioactivity released into the environment. So it's a serious thing, but if they would have taken the right steps in the first day, the radiation released could have been one-tenth of what was actually released, one-tenth, so it could have been only like one percent of Chernobyl. So it would have been a "disaster" but very much more manageable. This was a natural catastrophe, but still it was largely human error that caused its extent.

And these were old plants. Fukushima is 40 years old. It and other plants like it will have to be replaced. Japan will build some new nuclear power plants. There may be some delay and they may build fewer of them than planned. But this is not the end of nuclear power for Japan. What alternative do the Japanese have, after all? To import more coal? Or to import more liquefied natural gas to generate electricity?

What effect will Fukushima have on the nuclear industry in China?

This is just a postponement for the nuclear industry, which will continue to grow. Two years from now, it will be business as usual. Again, like Japan, the Chinese have no choice because of the mind-boggling demand statistics you mentioned. Imagine in 2000—I think it was three years altogether if not four—I think 2004, '05, '06—each of these years

1 Under the IEA's New Policies Scenario, which takes into account planned energy security and climate policy commitments, world electricity generation is expected to grow to 35,336 terawatt-hours by 2035. China's electricity generation is projected to grow from 3,495 terawatt-hours in 2008 to 9,594 terawatt-hours in 2035. Nuclear's share of that will rise from 2 percent (68 terawatts) to 9 percent (895 terawatts). The IEA projects US generation to be 5,169 terawatt-hours by 2035, according to Marco Baroni, senior analyst at the IEA. By comparison, the total electricity generation for the United States in 2009 was 3,949 terawatt-hours, according to the EIA.

The scale of human aspiration and the energy required to provide it are the things that somehow most advocates of green technologies do not want to talk about.

the Chinese built more coal-fired electricity capacity than the total electricity-generating capacity of Germany or France for the same period. And practically all of it in coal. So there's that option. Again, the Chinese need to build something on the order of 60 gigawatts of electricity capacity every year. So, yes— they'll be building nuclear.

You're obviously not against renewable energy, but why are some of the leading renewable alternative energy pathways insufficient to address the world's need for energy?

To attack this in the simplest way, you would point to the singular problem of scale—the sheer scale of the world population that will soon be aspiring to a middle-class way of life and to levels of consumption and consumer activity that are made possible by electricity [That breaks down to] seven billion people of whom one billion are filthy rich compared to the rest, another billion already are getting there, and the rest want to be there eventually. All of them, quite reasonably, want what we have [in terms of quality of life and comfort], and what we have is made possible, to a large extent, by electricity. This—the scale of human aspiration, and the energy required to provide it—are the things that somehow most advocates of so-called green technologies do not want to look at. And much of this has to do with where people will be living. A couple of years ago, we passed a great milestone in human history. Half of the people live now in cities. And not just in cities, they live increasingly in megacities.

A typical city in Asia has one to two million people. China before long will have dozens of cities with five, eight million people. How do you run a city like that on a wind turbine or a photovoltaic cell? How do you run modern megacities where most of the population would be housed in high-tower structures, how do you run them on renewable energy sources?

You're a realist about the pace of large-scale energy transitions, and this one—the transition from fossil-fuel based energy to alternative and renewable energy—will take place over generations, and not, as some proponents have claimed, over a single decade. Why is that?

By the late 1890s, when combustion of coal (and a bit of oil) surpassed the burning of wood, charcoal, and straw, each of the two resource categories supplied annually an equivalent of about half a billion tons of oil. If during the coming decades we sought to replace worldwide only 50 percent of all fossil fuels with renewable energies, we would have to displace fossil energies equivalent to about 4.5 billion tons of oil, a task equal to creating an almost entirely new industry whose energy output would surpass that of the entire world oil industry that took more than a century to build.

Al Gore proposes to replace the two nonrenewable forms of generation in the United States—fossil fuel and nuclear—which now amount to about 900 gigawatts of installed capacity and took nearly 60 years to build, but this poses some spectacular challenges. America's wind turbines and solar photovoltaics now add up to less than four percent of the total electricity generating capacity of more than 1,000 gigawatts. Even if all the transmission lines were in place, which they are not, because of significantly lower load (capacity) factors of renewables (typically no more than 25% compared to 75% for fossil and more than 90% for nuclear stations) the country would have to build more than 2,500 gigawatts of new wind and solar capacity to replace today's thermal (coal, gas, nuclear) generation—and under no imaginable scenario could this be done in a decade.

In addition, this would mean, of course, writing off, in a decade, the entire fossil-fuel and nuclear-generation industry, an enterprise whose power plants alone have replacement value of at least $1.5 trillion. Another $2.5 trillion would be spent to build the new replacement capacity and the requisite high-voltage lines. Where will deeply indebted and financially precarious America get $2.5 trillion to invest in this new infrastructure within a decade?

But you've written favorably about solar—and some have argued that committing a large enough area to solar could actually achieve the kind of replacement of fossil fuel generation that many seek.

Right. Put enough solar panels in a little square somewhere the size of Arizona and you can power the country, but then you have to build high voltage transmission lines from that little square to everywhere in US — and still to find what to do after the sun sets, not a trivial challenge given that we have no practical way to store electricity on gigawatt scale. Trillions of dollars will need to be spent on financing to rebuild the infrastructure to support that. It's an infrastructural problem. People live in big cities so you have to bring the juice to them on a scale which is amazing.

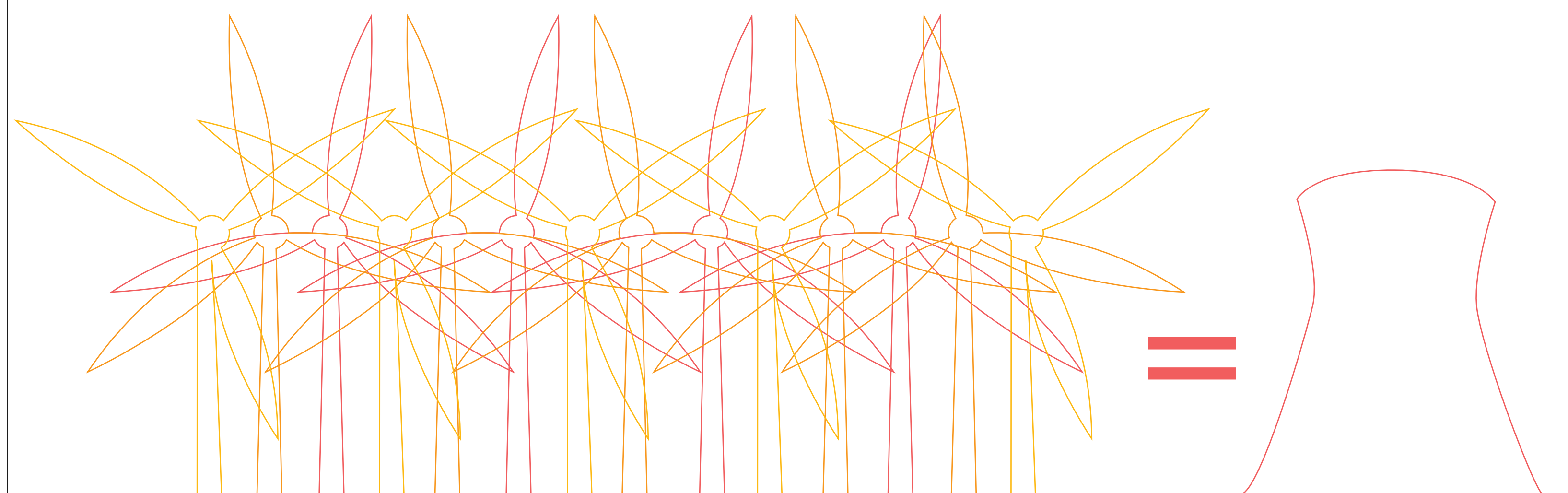
You build the one nuclear power plant—like them or hate them—and one plant easily equals 2,000 megawatts. You build one big wind turbine, it's two megawatts or three megawatts. So again, you have to build thousands of wind turbines to equal one nuclear plant.

Then there are the many unforeseen risks. We don't know how long these things last, say after 20 years when solar and wind are installed in millions of units and have accumulated the working lifetime of hundreds of millions of hours. Do we have any experience with giant solar panels working for 20 years? Do we have any experience with giant offshore wind farms working reliably for 20 years?

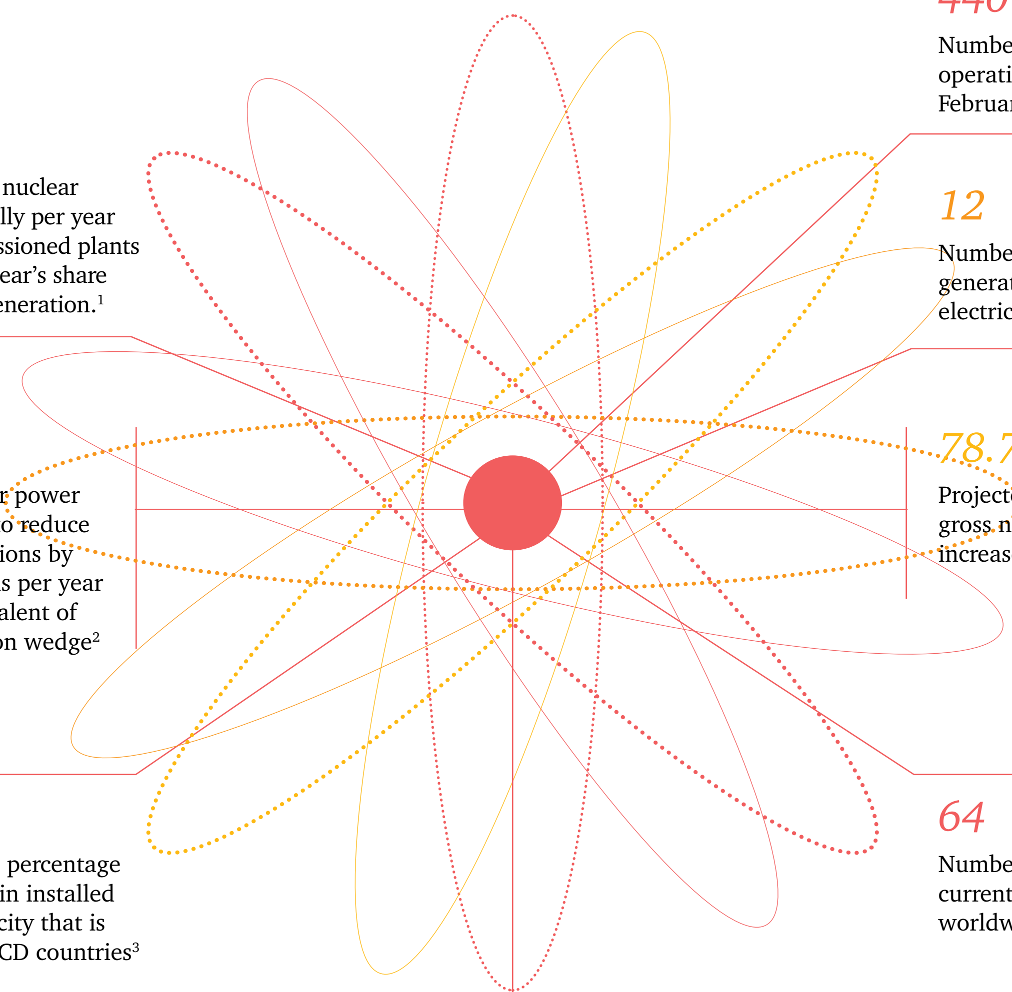
What will happen to a wind turbine farm if a massive ice storm comes, as it sometimes does in parts of the northern US, and literally grows a thick coating of ice on every surface out there?

You've seen these recent tornado outbreaks in the [US] south—170 tornadoes touching within a few hours over six states. What will happen to these mega-wind farms in Oklahoma or Texas when they'll be touched by mega-tornadoes? That's a rare event, but it happens again and again.

These are just some of the reasons why energy transitions in large economies and on a global scale are inherently protracted affairs. A world without fossil fuel combustion is highly desirable, and, to be optimistic, our collective determination, commitment, and persistence could accelerate its arrival. But getting there will be expensive and will require considerable patience. Coming energy transitions will unfold, as the past ones have done, across decades, not years. ■



*Nuclear power at a glance**



23–54

The number of new nuclear plants needed globally per year to replace decommissioned plants and to increase nuclear's share of total electricity generation.[1]

1,500

Gigawatts of nuclear power needed worldwide to reduce global carbon emissions by at least 1 billion tons per year by 2060—the equivalent of 1 carbon stabilization wedge[2]

72

From 2007 to 2035, percentage of world expansion in installed nuclear power capacity that is expected in non-OECD countries[3]

440

Number of nuclear plants in operation worldwide as of February 2011[5]

12

Number of countries that generate over one-third of electricity by nuclear power[6]

78.7

Projected percentage of global gross nuclear power generation increase from 2008 to 2035[7]

64

Number of new nuclear plants currently under construction worldwide[8]

Rankings of the nations generating the greatest percentage of electricity from nuclear power[4]:

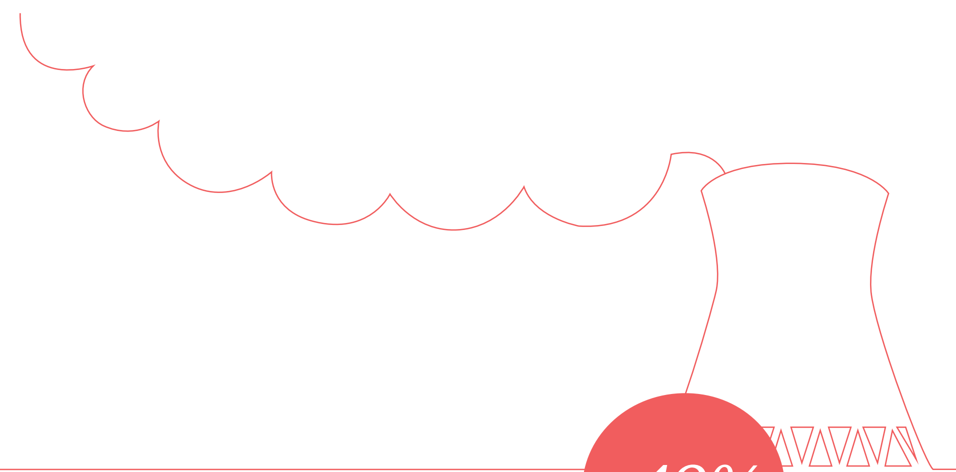
#1	#2	#3	#4
Lithuania	France	Slovakia	Belgium

United States

104	Number of nuclear units in the United States
20.2%	Electricity production provided by nuclear in the United States in 2009[9]
4	Number of new nuclear units currently under construction in the United States[10]
$8.3 billion	Amount of federal loan guarantees made available to these plants[11]
$10 billion	Amount of federal loan guarantees that remain undistributed

China

27	Number of nuclear plants under construction in China[12]
42%	Percentage of active worldwide nuclear construction taking place in China[13]
75 gigawatts, 57 plants	Projected installed nuclear capacity in China by 2035 and its equivalent in 1,300-megawatt nuclear power plants[14]



Rankings of the top 3 countries generating the most electricity from nuclear power:

#1	#2	#3
United States	France	Japan

14%

Percentage of world electricity production provided by nuclear power in 2009

+49%

Estimated change in world electricity production by nuclear power by 2030, if carbon legislation and other inducements are adopted[15]

*Source: IAEA, as of May 24, 2011. http://www.iaea.org/programmes/a2

1 The figure, 54 new reactors per year, assumes, among other things, that clean coal technology is not very successful, that installation of renewable generation is lower than expected, and that carbon-trading schemes are widely adopted, "Chapter 3: Projections to 2050," *Nuclear Energy Outlook*, Nuclear Energy Agency, OECD, 2008, pg 104.

2 Carbon Mitigation Institute, Princeton University, http://cmi.princeton.edu/wedges/intro.php. And from a presentation by Professor Alex Glaser, "Great Issues in Energy: The Nuclear Option," April 9, 2010, Dartmouth College, http://engineering.dartmouth.edu/news-events/lecture-series/issues-in-energy/ (cue to 1:03:30). Glaser's rough calculation uses projections by Robert J. Goldston, "Climate Change, Nuclear Power and Nuclear Proliferation: Magnitude Matters," in "Energy Policy," http://www.pppl.gov/pub_report/2010/PPPL-4502.pdf. Goldston projects a threefold increase in worldwide growth in energy demand from 2,000 gigawatts to 6,000 gigawatts a year/per year by 2060. Glaser's figure of 1,500 gigawatts assumes a growth in the share of nuclear generation worldwide to roughly 25 percent of the current share.

3 *International Energy Outlook 2010*, pg 77, http://www.eia.doe/oiaf/ieo/pdf.o484(2010).pdf.

4 Nuclear Energy Institute, http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/.

5 Power Reactor Information System (PRIS), International Atomic Energy Agency (IAEA), http://www.iaea.org/programmes/a2/, and Nuclear Energy Institute, http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/.

6 According to the Nuclear Energy Institute, in 2009, 16 countries relied on nuclear energy to supply at least one-quarter of their total electricity. Countries generating the largest percentage of their electricity in 2009 from nuclear energy were Lithuania*: 76.2%; France: 75.2%; Slovakia: 53.5%; Belgium: 51.7%; Ukraine: 48.6%; Armenia: 45.0%; Hungary: 43.0%; Switzerland: 39.5%; Slovenia: 37.8%; Sweden: 37.4%; Bulgaria: 35.9%; Korea, Rep.: 34.8%.
*Lithuania's last operating unit was shut down in 2009. http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/.

7 Projections are based on the International Energy Agency's New Policies Scenario, which assumes a cautious implementation of some carbon reduction measures such as, in the United States, a 15 percent federal renewable target for electricity, extension of renewable subsidies like the production tax credit, and modest carbon legislation, or some version thereof after 2020, *World Energy Outlook 2010*, http://www.iea.org/weo/index.asp.

8 PRIS, IAEA, http://www.iaea.org/programmes/a2/.

9 "Table 6. NUCLEAR ELECTRICITY PRODUCTION AND SHARE FROM 1980 TO 2009, Nuclear Power Reactors in the World, 2010," International Atomic Energy Agency, IAEA, pg 19, http://www-pub.iaea.org/MTCD/publications/PDF/iaea-rds-2-30_web.pdf.

10 Construction activities for two Westinghouse AP1000 reactors designated as Vogtle, Units 3 and 4, began in March 2010. Construction is being conducted under a limited work authorization, which allows for the placement of engineered backfill, concrete mudmats, and a waterproofing membrane to prepare the nuclear island base for the foundation work. Preconstruction activities (excavation) are under way at the V.C. Summer site in South Carolina. Official construction activities will not begin until the combined license is issued (currently expected in fourth-quarter 2011). Office of New Reactors email, 1-10-11.

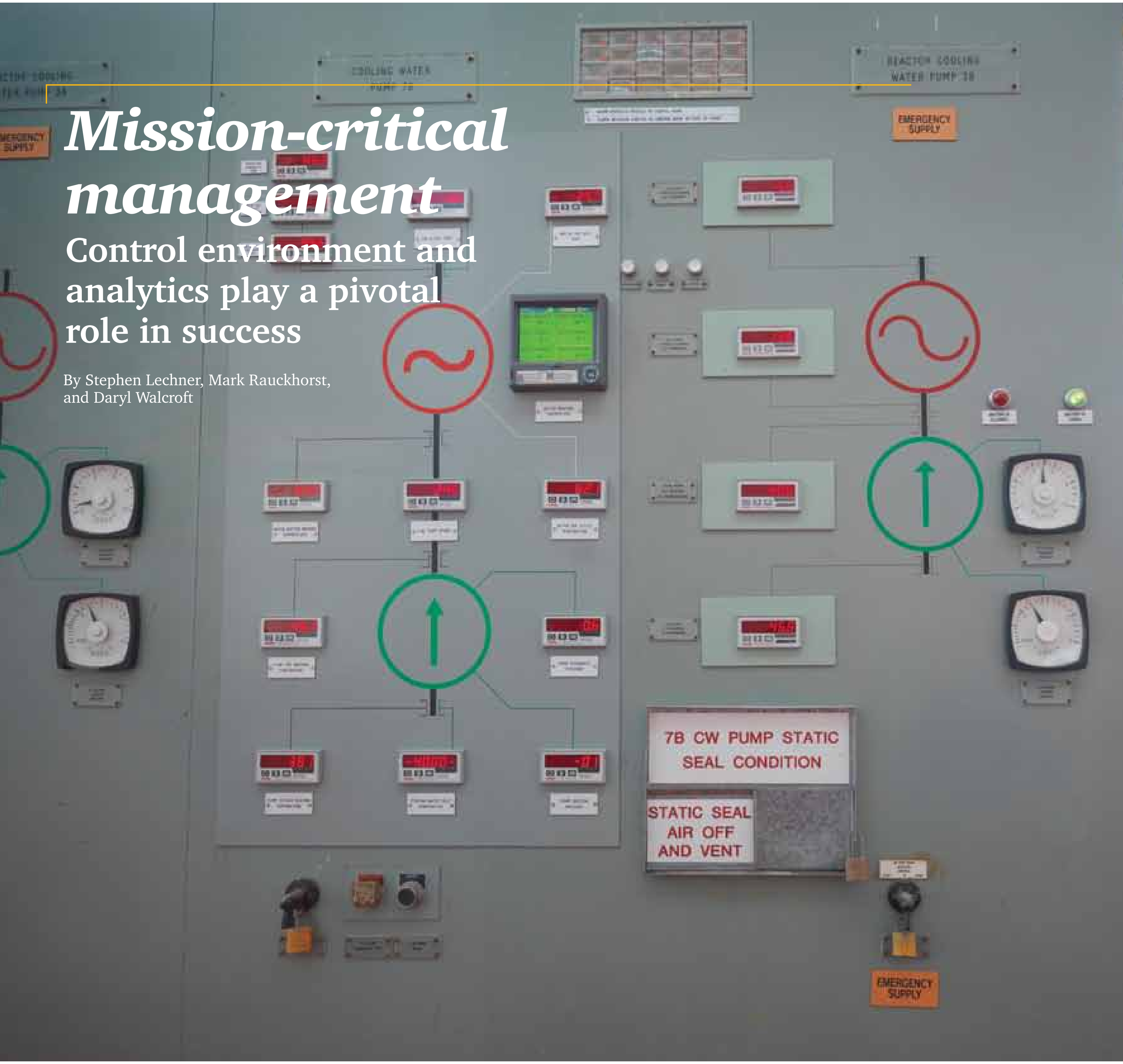
11 "DOE Delivers Its First, Long-Awaited Nuclear Loan Guarantee," Peter Behr, *New York Times Energy & Environment*, February 17, 2010, http://www.nytimes.com/cwire/2010/02/17/17climatewire-doe-delivers-its-first-long-awaited-nuclear-71731.html.

12 PRIS, IAEA, http://www.iaea.org/programmes/a2/, and Energy Information Agency, *International Energy Outlook 2010*, pg 80, http://www.eia.doe/oiaf/ieo/pdf.o484(2010).pdf.

13 Ibid.

14 "Figure H-5, World Installed Nuclear Generating Capacity, by Region and Country," http://www.eia.doe.gov/oiaf/ieo/ieoecg.html.

15 That is, a projected 49 percent increase in world electricity production from nuclear power by 2030 under the IEA's 450 Scenario, as compared with the business-as-usual Reference Scenario, *World Energy Outlook 2009*, Table 9.2, "World Energy Demand and Electricity Generation," International Energy Agency, pg 324.



Mission-critical management

Control environment and analytics play a pivotal role in success

By Stephen Lechner, Mark Rauckhorst, and Daryl Walcroft

Engineers in a nuclear power station, Scotland.

"Project control tools have been quite valuable. They're an independent set of eyes to check for where we might need some focus."

Large capital projects fail to achieve cost, schedule, and quality objectives for reasons that are well-known: unclear definitions and objectives, loosely defined delivery and contracting strategies, and absence of robust communication and reporting lead the list. But of the many areas of concern, none are more important, when it comes to building a new nuclear power plant, than developing a transparent governance structure and a comprehensive control environment.

Of course, all major capital projects need to have a strong governance structure and a control environment, but with nuclear construction the control environment is critical. It must stand up to intense regulatory and public scrutiny and include the required processes and tools to manage the extreme complexity of nuclear permitting, licensing, and construction along with the difficult transition from construction to start-up and operations. It must also be able to adapt to the ever-shifting, multidimensional aspects of these projects, and it requires the use of agile and unique systems and controls to enable management to deliver the promised value.

A comprehensive control environment includes the common control tools and procedures used on construction projects, including detailed planning and scheduling, active change management, cost controls, risk management, quality controls, safety management, and contract administration tools. However, on a large, complex project like a nuclear plant, project management teams should also incorporate detailed control analytics to supplement the standard project control tools and procedures.

The effective deployment of control analytics could be a pivotal point of leverage for the nuclear industry. With control analytics, a project management team can proactively analyze the performance of a project and its associated risks through the use of modeling techniques and identify those risks that have the highest potential for significant adverse consequences to project execution. With timely identification of project risks, the project management team is able to take mitigation measures, enhancing project performance and thereby attracting more attractive project financing and reducing regulatory risks.

Equally and perhaps more important, the use of control analytics must be seen against the backdrop of an approaching, massive demand for baseload generating capacity. Many analysts now say that world markets are poised for an economic rebound. When this happens, the demand for energy will increase and owner-operators in the energy sector will face major pressures to build baseload generating capacity.

Renewed construction of large capital projects like new power plants will require greatly improved capital project efficiency and sustainable cost reductions. In short, it will be more important than ever to manage the development and operations of capital assets in order to increase cash flow and optimize the ROI [return on investment] delivered by big capital projects.

The toll taken by poor or lax scheduling controls—a key feature addressed in the controls analytics landscape—is clear both in the field and in quantified results. According to a 2007 study by McGraw-Hill Construction, poor project integration can add 3 percent to a project's total cost. Scheduling problems are compounded in large capital projects where multiple stakeholders use different project schedules with varying standards, software, and approaches.

Often, these detailed schedules are then linked to more-summary-level schedules that management uses to make important project management and financial decisions. But summary reports can misrepresent actual project status, which in turn can draw management down the road of flawed strategic decision making. Standard scheduling software, moreover, is not designed to perform comprehensive analytics and detailed metric trending on multiple schedules.

Maintaining a clear view of project costs is also a challenge for a project management team. The sheer number of different price escalators—for instance, the complexity of refinancing as projects advance, capital budgeting, cost forecasting and cash flow, rate-making policy, and O&M [operation and maintenance] budgeting—are among the many factors that complicate the determination of an accurate forecast cost at completion.

Compounding problems is the matter of large-scale risk factors that can loom over a project management team: potential supply chain challenges (such as supplier backlogs, global tariffs, and value-added taxes that make the procurement of large-scale equipment difficult); interaction with a complex variety of country and export requirements; the failure of contractors to deliver on time and budget; and, for regulated utilities, the risk of public service commission cost disallowances.

The effective deployment of control analytics could be a pivotal point of leverage for the nuclear industry.

What's needed is a targeted suite of tools that offers a comprehensive analysis of schedules, of cost and financial parameters, and of other risk data—merged into a comprehensive view of likely risks and outcomes. Quantitative risk analysis (QRA) combines all three of these main elements—schedule, financial, and risk for a given construction project. It establishes date trends and metrics and can analyze risks over tens of thousands of computer-generated iterations using probabilistic methods of analysis. The result offers a comprehensive view of likely risks moving forward and quantitative parameters to aid in management decision making.

QRA enables a project team to integrate cost, schedule, and risk data to model numerous permutations of possible project outcomes. Cost, schedule, and risk data are entered into a computer simulation that runs several thousand random iterations. Managers are then able to see the discrete impacts upon the cost and scheduling of specific risks and threats. Typical QRA output highlights cost and schedule estimates with degrees of certainty—raising management's level of confidence for current projects and providing a platform for better decision making regarding future actions.

To address extremely complex problems, QRA is already being used by agencies and companies constructing large capital projects. For example, we observed one company using QRA to analyze the construction schedules of a number of liquid natural gas (LNG) plants around the world to highlight potential delay risks on a new LNG project and to respond to the risks by using recovery plans and work-around schedules before the risks became problems. That project finished two weeks ahead of the planned completion date.

QRA has also been used in new nuclear construction to integrate schedule, cost, and risk data and to assist with the development of a risk- and issue-management system as well as develop a master schedule of project work and establish a reporting framework for communicating project metrics to management and regulators. "These project control tools have been quite valuable," according to one project manager at a new nuclear construction site. "They're an independent set of eyes to check us for where we might need some focus."

When it comes to new nuclear construction, setting up a proper control environment is critical. Although there is no one tool or technique to ensure successful project execution, a clear focus on schedule, cost, and risk management can establish the foundation for an effective control environment. Active processes and controls to measure, monitor, and assess project status and potential impacts, along with tools to analyze and quantify project risks, provide management with the information needed to prioritize its actions. Without this information and knowledge, projects have the potential for missing many if not all of the desired objectives.

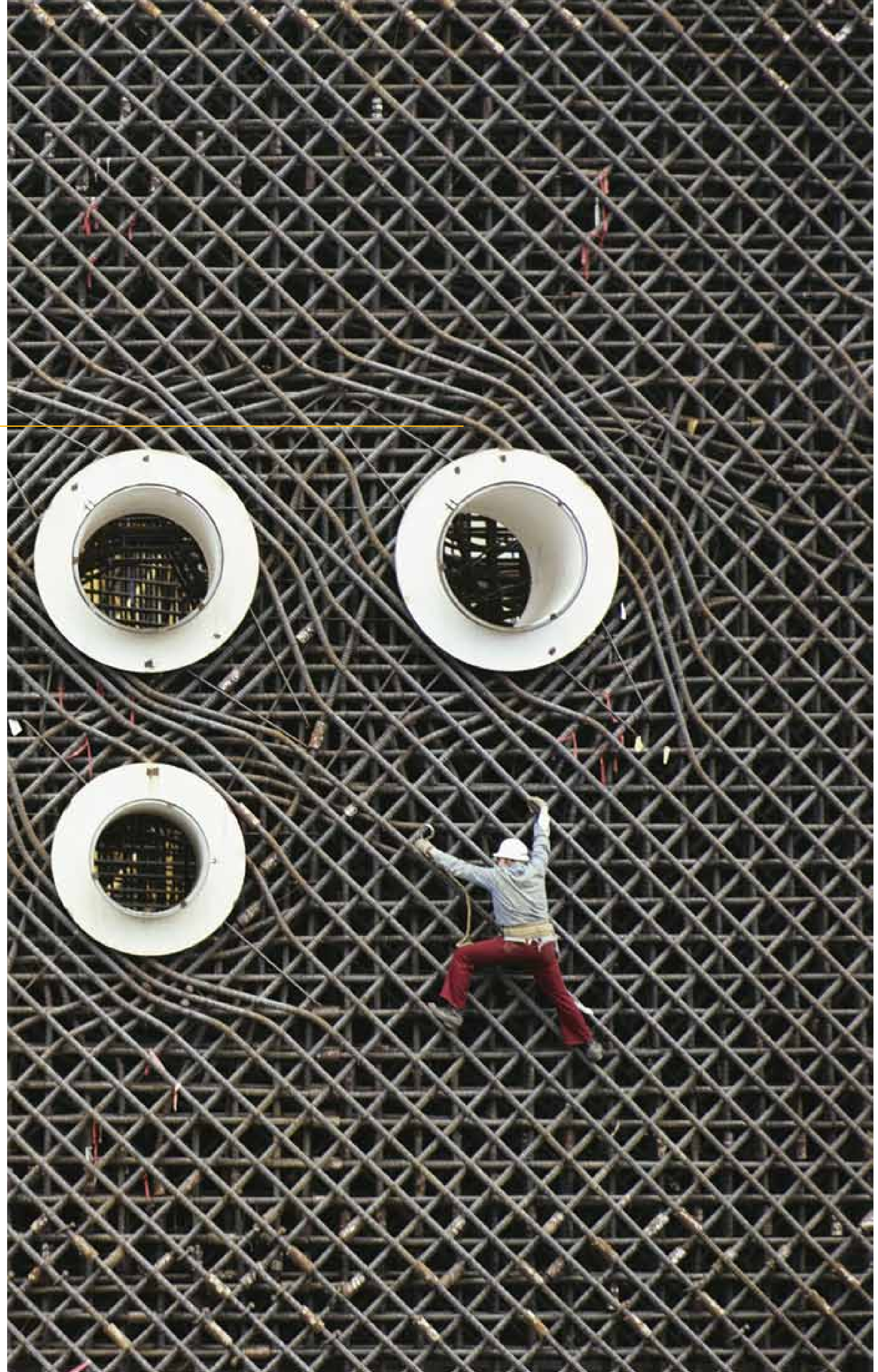
New nuclear can and should be an important part of the world's energy solution when it comes to addressing the need for more energy while mitigating adverse climate impact. If nuclear is to be part of the solution, however, it will require projects that are executed in a structured and predictable manner. Having the proper control systems and tools in place helps management execute the plan.

About the authors

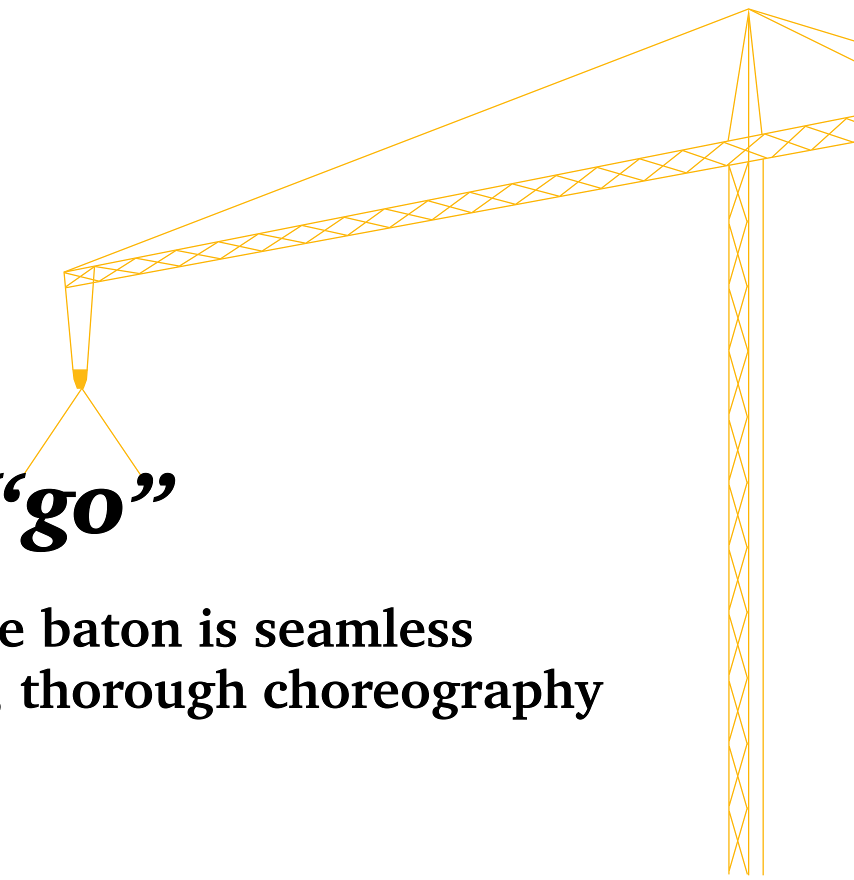
Stephen Lechner and **Daryl Walcroft** are based in San Francisco and **Mark Rauckhorst** in Atlanta, for PwC's capital projects and infrastructure practice (stephen.p.lechner@us.pwc.com, +1 415 498 6596; daryl.walcroft@us.pwc.com, +1 415 498 6512; and mark.rauckhorst@us.pwc.com, +1 678 419 2087).

From build …

By Chris Fynn and Jeff Briner



A worker scales a lattice of steel rods, Hanford, Washington.



… to "go"

Passing the baton is seamless with early, thorough choreography

Taking delivery of a large capital project like a nuclear power plant—the turnover and commissioning—barely resembles the process of picking up a new car at an automobile dealership, but it could be a lot closer with systemic management of information flows that can make a tremendous difference in efficiency and effectiveness.

Commissioning involves a massive transfer of responsibility, risk, and data from the builder to the new owner. With a nuclear plant, many different contractors and vendors will have spent years installing several hundred thousand components of interest—large and small. Ultimately, it is the owner's responsibility to be able to prove that what was designed is what was built and that what was built is what is being operated. Over the life of the construction process, this data often gets scattered among different construction units, different vendors using different software platforms, different data for the same object, and containing data arranged for a builder's needs but not an owner's. A car builder, for instance, will be deeply interested in the tensile strength of an automobile frame, but the owner just wants to know the frame is solid.

Call it the "Library of Babel" effect— too much information, scattered over too many different sources and too many languages that don't communicate. Stakeholders may be eager to get the plant up and running, but all the data are in the wrong systems and there are always conflicting data values for the same item. The car manufacturer may recommend tire pressure at 35 psi, but the tire manufacturer recommends 32 psi. Which is correct? The problem, then, in part, is one of data consolidation and reconciliation—how to ensure that the owner of a new plant receives an accurate, complete, consistent, and useful "manual" for the plant's operation. Obviously, no book or physical

Safety is the guiding first principle of asset configuration management and the guiding first principle of the nuclear industry itself.

Engineers inspect an array of steel cable tailings, Scotland.

manual is big enough for a nuclear plant. Rather, in the case of a nuclear power plant, an entire suite of software systems, often called enterprise asset management (EAM) tools, is needed to bring all the disciplines and languages of operation into one cohesive and living set of operating guidelines. EAM systems provide a range of advantages for nuclear plants and, in fact, any large capital project.

Safety comes first, of course. And asset configuration lays the groundwork for achieving it. During Senate hearings into the causes of the Deepwater Horizon disaster, a pattern emerged. It became clear that in day-to-day operations on the oil platform, there was a disconnect in what engineers call the rig's "design basis." Over time, the parts and components that were supposed to be operational or the parts listed in the computer systems as operational were, out on the actual platform itself, broken or nonfunctioning, or they had been replaced by different parts. In some cases, the parts were simply nonexistent. Safety, then, is the guiding first principle of asset configuration management and the guiding first principle of the nuclear industry itself. Nuclear operators need to know exactly what assets they have in order to manage and operate them safely, and that's the bottom line for nuclear power. EAM-related applications must accurately reflect what is on the ground in the plant itself. Beginning with the foundational principle of One Asset, One View goes a long way toward avoiding complexity, opacity, and the missteps that can come with building, testing, turning over, and commissioning.

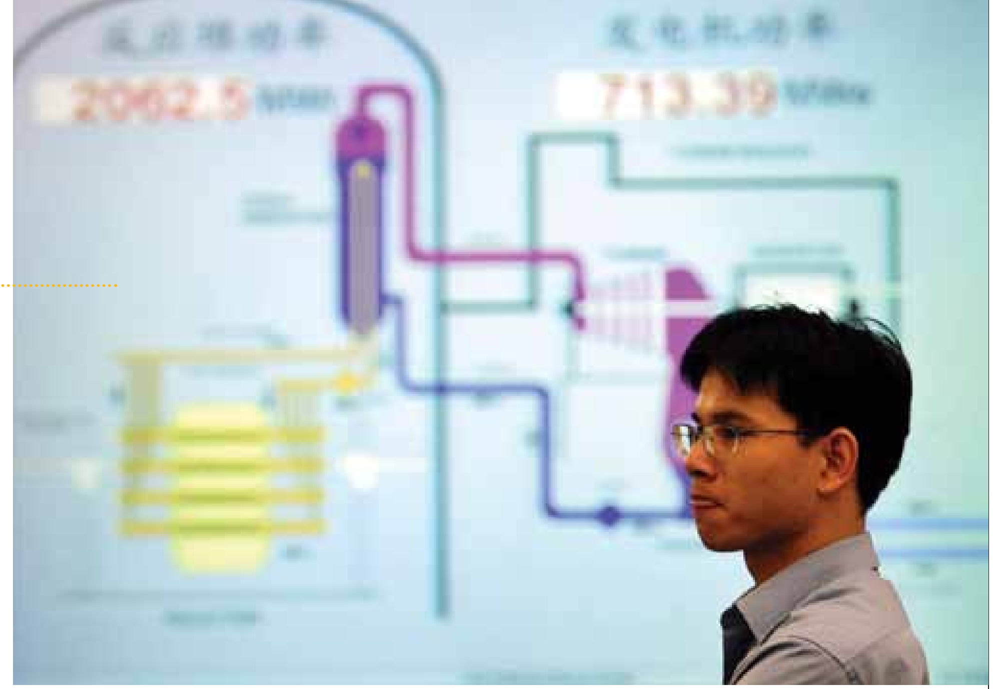
To hit the ground running, establishing asset configuration during the design-build phase of the project is safer, faster, and cheaper. Most people think of EAM systems, if they think of them at all or even know they exist, as part of operations and maintenance, and they are. However, many owners begin thinking about gathering the asset data for their new plants fairly late in the turnover and commissioning process. This often leads to a less-than-efficient movement of asset data from the construction computer systems into the operators' computer systems—eating up valuable time and scarce resources before the plant can be confirmed compliant to regulatory standards for safe operation. The current practice is equivalent to buying and picking up a new car and having to figure out for yourself what size engine you have, what replacement spark plugs are needed, what type of tires were put on, and what gas to use—all at your own expense. In the case of regulated energy markets, this cost must be passed on to the consumer.

Establishing an enterprise asset management system early during the design-build phase of a project is key to not missing a step or risking a problem when the handoffs occur between builders and operators. It greatly reduces, or in many cases eliminates, an entire sequence of data translation, validation, verification, and reloading.

The design-build phase is exactly where the "Library of Babel" problem starts in the first place, so installing an EAM system during that phase facilitates the consolidation of all asset data into a single source. Having that single source enables accurate asset configuration to be managed regardless of which process makes updates to the asset. A single source for all asset data makes for a faster transition between builders and owners—and the sooner owners can get their plants up and running safely, the better for everybody. The fact that an expensive step can be removed lowers the total cost of ownership, lowers energy rates, and improves profitability. Because installing EAM in the design-build phase needs to be considered early, the asset owner-operator should address this in the contracts with the engineering, procurement, and construction (EPC) vendors. But the owner is not the only beneficiary. Indeed, having a single asset repository populated by EPC vendors can also reduce their cost of doing business, support their warranty services, and deliver reliability and construction feedback to their internal resources.

Efficiency rises with reliability-centered maintenance. From a business perspective, the most important aspect of EAM is to run the plant at the highest level of efficiency possible—to keep the plant running and to do it as safely and cost-effectively as possible.

Even with redundancy, expensive failures occur that could have been prevented. The opposite is true as well. Some maintenance can be unnecessary, ineffectual, and expensive.



A worker stands in front of a control monitor at the Qinshan No. 2 nuclear power plant in Zhejiang, China.

What EAM allows a plant owner to do is execute operations and maintenance with reliability. This emphasizes preventative maintenance, reduces risks of costly failures, and reduces less manageable corrective maintenance, which is often. At a macro level, of course, nuclear plants are designed to be very safe. Engineers have added multiple layers of redundancy. But at a micro level, when it comes to specific systems, components, and protective devices, it is rare that strong reliability analysis is performed on how these components might fail and how they should be maintained.

Even with redundancy, expensive failures occur that could have been prevented. The opposite is true as well. Incorrect maintenance can be unnecessary, ineffectual, expensive, and in some cases damaging. Well-executed EAM processes supported by reliability-centered maintenance (RCM) practices can help ensure that microlevel designs are fully optimized to avoid needless and expensive work. Integrated RCM and EAM practices build knowledge and lasting value into the asset repository to link failure modes for a given plant design and define how to manage those failures. As a result, from turnover to operation, EAM provides a plant with a fully optimized maintenance program at the most effective cost and with maximum safety.

Finally, the proof can be found in the nuclear construction occurring in China, where early and optimized installation of EAM in the design-build phase is happening faster and more broadly than anywhere else. At China's Daya Bay nuclear power station, for instance, the Daya Bay Nuclear Power Operations and Management Company (DNMC) is implementing SAP's EAM solution in three existing power plants operating six reactors. The EAM solution lays the foundation and planning for the coming rapid expansion in nuclear power—establishing an SAP EAM template that will operate systemwide across a fleet of 16 new units in various phases of construction, turnover, and commissioning, as well as another dozen plants under design. PwC implemented our standard SAP EAM template across Daya Bay's large nuclear fleet to help mitigate the risks associated with rapid expansion.

Installation of EAM tools early in the design phase of the nuclear asset life cycle will reduce the transfer time from contractor to operator, reduce costs for all involved, and offer Daya Bay's management a single EAM overview of its entire fleet of reactors, coordinating everything from daily plant operations to supply chain to asset maintenance to finance. At the end of the day, the handing over of a major nuclear power plant will always require a great deal of science as well as art. However, the use of EAM systems during engineering design can avoid many missteps along the way.

Installation of enterprise asset management tools early in the asset life cycle during the design will reduce the transfer time from contractor to operator and reduce costs for all involved.

Cars are designed, built, and delivered to meet industry safety standards and individual driving needs. Designers constantly use real-world failure information to improve their designs for safety and reliability. A car comes fully documented with recommendations on how it should be safely operated and maintained. The documentation about the car (asset) is mostly captured when the car is designed, and much of that gets included in the owner's manual. This is the safest and most cost-effective way to own a car. The nuclear industry needs to continue to adopt similar practices and continue its focus on designed safety that comes with efficient and effective configuration management across all asset lifecycle phases.

About the authors

Chris Fynn, based in New York, and **Jeff Briner**, who alternates between Cleveland and China, serve in PwC's enterprise asset management practice (christopher.c.fynn@us.pwc.com, +1 646 471 1266; and, jeffrey.d.briner@us.pwc.com +1 859 466-6222).

Daya Bay nuclear power plant, Guangdong province.

A few words with Michael Johnson …

Director, Office of New Reactors, U.S. Nuclear Regulatory Commission. You don't have to look far to find an ex-submariner in the nuclear power sector. Michael Johnson, who graduated from the US Naval Academy in 1979 with a Bachelor of Science in Ocean Engineering, served on a nuclear submarine for 10 years. He's been in the regulatory field for 24 years, starting in the Office of Inspection and Enforcement. He began his current position as the Director of the Office of New Reactors in May 2008.

To what extent has Fukushima affected the Office of New Reactors and the regulatory environment?

Well, since Fukushima, in addition to supporting our around-the-clock coverage, for example, of our operations center and the site team that is in Japan, we have been continuing our licensing reviews of new reactors. One of the actions the NRC took as a result of Fukushima was to stand up an internal task force headed by Charlie Miller. Gary Holahan, who is a deputy of the Office of New Reactors, is on that task force, which was chartered by the NRC to look at lessons learned from Fukushima. It's that task force that would identify potential things that the Office of New Reactors would need to consider and adjust as appropriate.

The technical requirements that exist for new reactors are largely the same technical requirements that exist for operating reactors, and the guidance that we use to apply those requirements in review of designs and license applications are the same, so, in short, we're continuing those reviews for new reactor licenses, even as we look to identify lessons learned and any potential changes that we might make to those requirements going forward.

Do you anticipate any slowdown of the ongoing reviews for the plants in Georgia or South Carolina—the Vogtle and the V.C. Summer plants, respectively?

We are continuing with our reviews for those plants, and the task force that I mentioned is working on near term and longer term actions that might be taken. Should those actions have implications for new reactors we would then have to catch up with the process, if you will, to make sure that the designs that we certify or the licenses that we approve reflect any adjustments. We'll have to wait and see how that unfolds. But today I would say we're continuing on.

The designs of the new reactors that are being built in Georgia, South Carolina, and China—they're part of what's been called Generation III. Against the backdrop of recent events, talk to me about the Generation III design.

We're actively reviewing 12 combined license applications and we're reviewing a number of Generation III designs—the AP 1000, the ESBWR, the USAPWR and the EPR design.[1] These designs are exciting in that they are built upon lessons from the past—upon operating experience—and every one of them has changes that improve the safety of the design. From a regulatory perspective we think that's very exciting. Some of the changes are more evolutionary, such as—redundancy additions and added diversity between systems. Other designs are actually what you might call revolutionary—plants like the Westinghouse AP1000, for instance, which uses greatly enhanced passive features in its safety functions.

We're looking at a new generation of plants that were designed and will be built to be safer. So we have a sense of comfort with respect to the new reactor designs. Of course, I'm not going to say that there will be nothing for new reactors—we'll have to wait and see—but I feel very comfortable about where we are. The Generation III design represents a different era that has incorporated so many new improvements to safety. Against the backdrop of Fukushima, this new generation seems to address a lot of the risks that existing reactors don't necessarily have in their design.

1 All are names of so-called Generation III advanced nuclear reactor designs, which feature, among other things, simplified design, passive features, improved redundancies, smaller construction footprints, and modular construction elements—the AP1000 is a pressurized water reactor design from Westinghouse; ESBWR, or Economic Simplified Boiling Water Reactor, is from General Electric–Hitachi; the USAPWR, Advanced Pressurized Water Reactor, designed to satisfy regulatory requirements in the United States and abroad, is from Mitsubishi; and EPR, or European Pressurized Reactor, is from Areva.

The designs for the current generation of reactors are exciting in that they are built upon lessons from the past … and every one of them has changes that improve the safety of the design. [From] a regulatory perspective we think that's very exciting.

What other big issues are out there for the new reactor field? And what are you most focused on—what are your worries?

My big concern is making sure that we complete this initial round of reviews for the design certifications in front of us in a way that ensures that what we approve is safe. If they're built, we expect that they'll be in operation a long time—so I want to make sure that we're doing it in a way that's safe. And to be candid, I want to make sure that we also do it on schedule. Both safety and scheduling are major drivers for me.

Many have pointed to scheduling delays in the licensing process as one reason for the high cost of nuclear power. Does the Office of New Reactors work in a proactive way to streamline the permitting process and, if so, how does one balance streamlining with safety and oversight?

We are the safety regulator, so we're primarily interested in making sure that whatever designs we approve are safe. But while that is a focus, we also have paid a lot of attention to the regulatory process because we want that to be as streamlined and as efficient as we can possibly make it. In fact, the entire licensing process that we use—Part 52 of our regulations, the so-called one-step licensing process—builds on lessons that we learned from the last time we did licensing reviews and it is a much more efficient process.

What would you say are the key things that you have changed from a few decades ago—the last time nuclear power plants were being built—to help streamline the regulatory process and help lower the cost?

Most of the changes reside in Part 52 of the licensing process, a one-step process, which has us review and approve the design before construction begins. Part 52 also has provisions for an applicant to submit and receive approval for a particular site without applying for a specific plant to be built on that site. So, for instance, 20 to 25 years ago, nuclear plants being built in the old two-step process could spend 10 to 12 years getting through the wickets of the construction permit and then the operating license. Now, however, many of the issues that once cropped up late in the old two-step process get resolved up front and early so that licensees can proceed expeditiously through construction. And if they construct that plant as it was designed, they can proceed expeditiously to operations.

For applications currently under review, who's going to be the first to be issued a license?

We've just recently issued schedules for the completion of reviews for Vogtle and for Summer. If we hold to these schedules and ultimately approve them, they will be the first to be issued licenses.

The nuclear industry, like many others, is prone to problems in the supply chain—especially for this industry, quality component parts are key. Is the nuclear power supply chain something that the Office of New Reactors is concerned about?

The supply chain is something that we've been focused on, and it's something that the industry is focused on, too. We look at key vendors around the world to make sure they have quality assurance programs that are up to our expectations. Of course, the primary responsibility for quality rests with the applicant and the licensee, but we do inspect a sample of vendors. We can't monitor every vendor around the world, obviously, so we'll visit a sampling of vendors. As an example, I was in Japan Steel Works, which fabricates the major forgings for the world, and ran into Westinghouse folks who were out inspecting the component that they're actually going to receive from Japan Steel Works.

What about the issue of fraudulent or counterfeit parts in the nuclear power supply chain? This would seem to be a serious issue for the sector. Are you addressing this?

Counterfeit and fraudulent parts are not a new issue. The industry worried about this the last time around, and we've continued to be concerned about counterfeit and fraudulent parts. We are actually working to strengthen our activities to address counterfeit and fraudulent parts as a result of a recent inspection by our Office of the Inspector General. So a program that I think was good is going to get better.

What other top concerns do you have?

It's critically important that the operating fleet remains safe while we're focused on new designs. That's why the NRC created a separate office for new reactors, so new reactor licensing doesn't distract from oversight of the operating fleet. We must always recognize that an accident, or a significant incident at an operating plant, would be the surest way to imperil what is potentially going to be real movement with respect to the renaissance for new reactors.

Once a facility receives its license, we will verify that the new plant is built in accordance with the design before they can load fuel and begin operation. Once again, responsibility for ensuring the plant is built in accordance with the approved design and the regulations rest with the licensee. [Southern Nuclear's] Buzz Miller will tell you, he won't sleep until he can actually begin operations. So he's going to be up a lot of nights between now and construction to operation.

It seems like the US is going to be getting maybe a handful of new reactors—not 20, but a handful—to see whether they come in on time and on budget. Does that make sense to you?

I think you're right. I think that's the way it will play out. These folks who will be first, including Vogtle and Summer, will get through the process and begin construction. And I think if that works well, you'll see others begin construction, and you'll see perhaps others coming forward with new applications. ■

A few words with Joseph A. "Buzz" Miller …

Executive Vice President of Nuclear Development, Southern Nuclear. Miller is responsible for overseeing nuclear-generation expansion for Southern Company and for Georgia Power, including the only two nuclear plants currently under construction in the United States—Vogtle plants 3 and 4 in Georgia. At the time of this conversation, in November 2010, Miller and his team were in the final push to complete a major regulatory milestone for the Vogtle plants.

Among all your concerns, what's the most pressing right now?

It's an important time in our licensing process, which is crucial for us to maintain schedules. The Westinghouse Design Control Document is a massive, complex document that essentially is the approval from NRC [the Nuclear Regulatory Commission] for the operating and construction license—the new, one-step process by which an operator obtains a license to construct and operate a nuclear power plant. There are 23 chapters in the Design Control Document that cover every safety system in the AP1000 [reactor].

You are moving dirt around. There is extensive construction going on at Vogtle. Right now there are something on the order of 1,300 construction workers there. Can you break that down? What are they doing in particular?

There are about 1,500 workers now—most of them from the Shaw Group, the main contractor. We had to do a major excavation about 90 feet deep covering an area of about 42 acres—21 acres each for Unit 3 and Unit 4 that we're building. That's a massive amount of earth work. We actually have to backfill all of that about halfway, and we have to compact all of that because that dirt will be under the nuclear island. We have seismic analyses that are performed that address how the site would respond in an earthquake.

Southern's Buzz Miller on-site in Georgia.

Can you explain the seismic work?

There are assumptions in the seismic analyses about how the earth under the nuclear plant will behave during an earthquake. You want to avoid soil prone to liquefaction, where during an earthquake the ground behaves like a fluid. To do that, we have to have the right kind of dirt and we have to compact it to meet the assumptions in our analyses. All this backfill work requires NRC approval. We have two full-time NRC resident inspectors at Vogtle right now, and they can go anywhere, at any time, to inspect any safety-related activity to ensure that procedures are being followed, that quality requirements are being handled appropriately, and that we're meeting the codes and standards that we've said we would use.

> *In nuclear we like to say we're a learning organization. So we're learning on all kinds of fronts right now. We've learned about dirt, for instance—all dirt is not created equal.*

Right now you're preparing the landscape for the bottom-head of the containment vessel. How much does one of those things weigh?

You saw panels—plates—that are going to be welded together. Those plates are going to form a giant bowl that's going to be picked up and put inside the hole. The whole vessel, which is like a giant kettle, weighs about 800 tons. Then we're going to build three rings that one by one get set and welded on top of that lower part. And then there'll be an upper head that is built, and that will be picked up and put in. We have a lot of big lifts.

And modularity is an example of how things have changed since 30 years ago?

That's right. Two major changes from the past are, first, getting the design work to nearly 100 percent complete prior to doing the major construction. Second is this modular construction and standard plant approach, which other industries have shown to be vastly superior to stick building.

There are four AP1000 plants in China that are a year and a half, two years ahead of your construction schedule. You have a memorandum of understanding with the Chinese—they've come over here, you've gone over there. What have you learned so far from their construction process?

Let me say this about the Chinese: they're on a very aggressive schedule. Shaw, the lead construction contractor, has learned lessons related to the handling of big structural modules. Certain modules that are being built on the ground, horizontally, in China, for example, will be constructed vertically at the Vogtle site.

Like one of those 1,000-ton walls?

That's right. Shaw is learning that the fewer times one has to reposition something like that, the better.

What about the supply chain? You've got pressurizers being made in Italy; and in Japan, turbine generators. That would seem an incredibly complex thing to manage. What's your biggest concern there? What keeps you up at night?

It's a great question. And I'll tell you: with the components, quality is the most important thing, period. And safety. The safety of our people and the quality—the nuclear quality. And we want to build that quality into the plant. So we created a surveillance group specifically for Vogtle 3 and 4. We've come up with a risk-based approach where we've analyzed components based on their nuclear function, their difficulty in fabrication, our fleet operating experience, and schedule issues. As a result, we have a full-time person in Italy. We have a full-time person in Korea. We have full-time people in Lake Charles, Louisiana, where modules are being built.

What about unforeseen problems at the Vogtle construction site?

Well, in nuclear we like to say we're a learning organization. So we're learning on all kinds of fronts right now. We've learned about dirt, for instance—all dirt is not created equal. We excavated, and then backfilled, millions of tons of earth, but that backfill needed to have certain specific characteristics to pass the NRC's seismic requirements—so much sand in relation to so much clay in order to avoid liquefaction during an earthquake. A lot of our backfill didn't have the right qualities.

So we needed to get a license amendment through the NRC regulations for the right kind of backfill. And we've worked out a lot of minor unforeseen issues—paperwork issues—and other shortcomings. It's been sort of like preseason before the regular season starts.

Many have pointed to the regulatory structure in the southeast United States and the difference between that structure and the more deregulated market up in Maryland and elsewhere. They note that as being a key point of leverage that has allowed Southern to capture early cost recovery from the ratepayers, for instance, to help finance nuclear construction. Is that correct?

It is a key factor. Our regulatory structure helps us do that. We're recovering finance costs during construction, which, while it is on the front end, over time will save our customers money. So it's actually an economic way to build. But it's a combination of things—a regulatory structure that allows for things like early rate recovery to help finance projects, good management focus, solid financial integrity on Wall Street, and an exemplary operating nuclear fleet.

How important is carbon legislation to you?

Carbon legislation might be a boon to the nuclear industry. But Southern is like a microcosm of the United States. Our nuclear generation is a reflection of the national picture for nuclear. So too with our coal generation. We are certainly aware of and involved in the debate on carbon legislation, but frankly, I don't worry about it. We are all about executing the Vogtle project, which is part of a diverse fuel supply for our customers. We clearly believe that nuclear has a role in the future or we wouldn't be doing this. And we're not in this to just build one and be done. We're going to execute this, and then we'll look at building additional nuclear units in Southern.

In some ways the nuclear industry has taken a couple of recent hits with big projects coming to a stop, but Vogtle 3 and 4 are actual concrete examples of huge projects that are moving forward. So it seems like you're carrying the standard for an industry that really does need to prove itself. Is that right?

I think that's fair. And we didn't race to get in that position. We've been methodical but realistic about our approach, and we intend to execute this. And, yes, it's a big project. We're aware of our standing, particularly on the nuclear side, but we recognize the strength of our company and of our people—and that's just the way it is. If it's our role to lead within the industry, then that's where we're headed. ■

See the Web at www.pwc.com/gridlines for the full interview with Joseph A. "Buzz" Miller.

Two major changes from the past are, first, getting the design work to nearly 100 percent complete prior to doing the major construction. Second is the modular construction and standard plant approach, which other industries have shown to be vastly superior to stick building.

First containment vessel plates arrive for Plant Vogtle Units 3 and 4, September 8, 2010.

Routine inspection of an outer-chamber reactor vessel at the Kruemmel nuclear plant near Geesthacht, Germany.

Story continues from page 8

the difference. "That demand is not going to vanish," says Westinghouse's Pérez, "and some countries in Central Europe may, by dint of new nuclear construction, become nuclear electricity exporters—to countries like Germany." Such a geopolitical landscape may in part explain why a company like GE-Hitachi is planning sales in Europe of 10 to 15 new reactors in the next decade, and why Pérez sees countries like the Czech Republic, Lithuania, Poland, Slovakia and Hungary as likely regions for new nuclear construction in the near future.[25]

All of this has been encouraging for the nuclear sector as a whole, though little reported. Rather, in addition to new concerns about safety, one is more likely to hear, in the United States especially, about other very real challenges to nuclear power: high-risk premiums for loan guarantees and the long-term projections of low-price domestic natural gas and its effect on the nuclear industry in the states—or on price escalation for new nuclear construction. These factors were cited in the October 2010 canceling of watershed projects like Constellation Energy's Calvert Cliffs 3 in Maryland and the April 2011 cancellation of NRG's South Texas Project.[26]

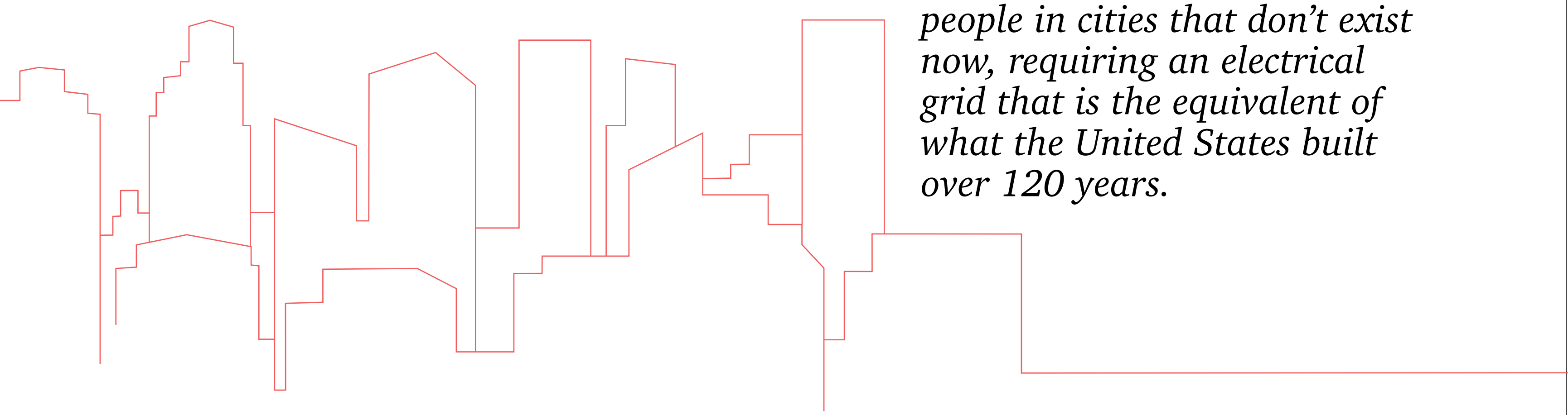
Indeed, in the United States, the Vogtle project in Georgia and the V.C. Summer project in South Carolina are the lone US standard-bearers for the nuclear industry. But few have written about the broader scene: about how useful the juggernaut of Chinese nuclear power plant construction will be as a rough baseline reference to construction elsewhere or how South Korea plans to export 80 nuclear power reactors by 2020, acquiring a 20 percent share in the world market.[27] Even less known is that some of the sharpest critics of nuclear power and some of the most respected critical studies of the sector acknowledge that the industry should be given a chance to demonstrate the ability to build new reactors on time and on budget.

A quiet chorus of assent has been rising. In April 2010, Ernest J. Moniz, Director of the Laboratory for Energy and the Environment at MIT's Department of Physics, spoke at

25 Ibid, http://www.marketwatch.com/story/the-nuclear-option-is-back-on-the-table-2010-05-20.

26 "NRG Abandons Project for 2 Reactors in Texas," Matthew L. Wald, *New York Times*, April 19, 2011, http://www.nytimes.com/2011/04/20/business/energy-environment/20nuke.html?src=busln.

27 "South Korea Bets on Nuke Exports to Power Economy," Kiyohide Inada, *Asahi Shimbun*, May 7, 2010, http://www.asahi.com/english/TKY201005060259.html, and "Asia Powers Up Its Nuclear Ambitions," Myra P. Saefong, MarketWatch, May 20, 2010, http://www.marketwatch.com/story/asia-powers-up-its-nuclear-ambitions-2010-05-20?pagenumber=2.



China is preparing, by 2025, to accommodate 350 million people in cities that don't exist now, requiring an electrical grid that is the equivalent of what the United States built over 120 years.

Dartmouth College's annual Great Issues in Energy Symposium. While allowing for certain caveats, Moniz's conclusions were favorable.

"Nuclear power looks like a credible candidate for expansion in the decade after this one," Moniz said, "after we see whether we can actually build these plants in the US successfully."[28] At the same symposium, Princeton University's Alex Glaser, who focuses on issues surrounding nuclear proliferation, cited a study from the National Research Council last year that concluded, among other things, that nuclear power be given a chance to prove itself commercially viable within the next decade.[29]

Peter Bradford, of the Union of Concerned Scientists and author of several recent articles challenging the nuclear power industry, also weighed in last year at an Environmental Policy Forum on nuclear power. "Prove that these advanced reactor designs work in five or six plants with federal help," Bradford said, "and then we can talk about an expansion."[30] Even one of the most stringent critics of nuclear power, Joseph Romm of ThinkProgress who also addressed the Dartmouth symposium, still counted nuclear power—a projected 700 gigawatts of new nuclear power globally by 2050—as one of 13 significant carbon wedges that will be needed to forestall a global warming crisis.[31]

What all of these people—nuclear advocates and skeptics alike—recognize is that nuclear power will remain an important part of the global energy mix.

The devils and the angels of nuclear may still lie in the details, however. Taking a step back from the big picture of global energy need and nuclear construction, the nuts and bolts of getting it all done present a separate set of challenges. First among them is ensuring a solid controls environment during construction. Second is incorporating an asset management system as projects rise to smooth the transfer of design data between contractors and plant owners and operators, and to help keep plants running smoothly and effectively.

For the nuclear sector, construction costs, an abiding challenge faced by the industry, are also thought to be completely within the industry's control. That's the general feeling on the Westinghouse corporate campus just north of Pittsburgh, where *Gridlines* spent a day touring the AP1000 control center, visiting the new plant training facilities, and speaking with executives like Ric Pérez, president of operations, who had just returned from one of his quarterly visits to China.

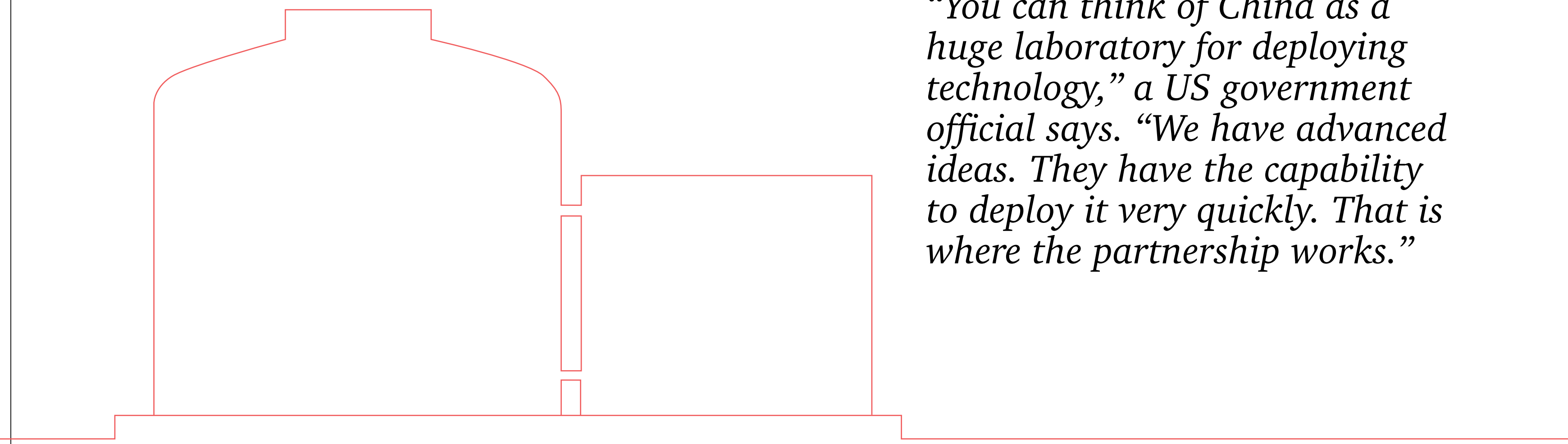
"Sanmen will be finished in its targeted time of 54 months," Pérez says. "That will become our baseline time to beat—and I expect to beat that time on all the remaining projects in China." After Sanmen 1 and 2 are completed, four more AP1000 reactors will be built on the site. Farther north, at the Haiyang site, six AP1000 reactors will be added upon completion of Haiyang 1 and 2. For Pérez, safety always comes first in his discussions. But solving the construction time puzzle is also a pivotal issue for the industry moving forward. Achieving this will take a coordinated effort between vendors like Westinghouse, utilities like Southern, and regulators like the NRC. Most observers agree that with a baseline case in hand, new construction in the United States should gain the scheduling advantages of standard design. And this will in turn reinforce a positive cycle—potentially making for a shorter review schedule for the NRC, according to William E. Cummins, director of regulatory affairs for Westinghouse.

28 "Great Issues In Energy: Nuclear Power, Panel Presentation and Q & A", Dartmouth College, April 2010, http:// engineering.dartmouth.edu/news-events/lecture-series/issues-in-energy/.

29 "America's Energy Future: Technology and Transformation, Summary Edition, National Academy of Sciences, 2009, Executive Summary, pg 5, http://books.nap.edu/openbook.php?record_id=12710&page=5.

30 *The Environmental Forum,* Volume 27, Number 1, January/February 2010, pg 53, http://www.ferc.gov/media/statements-speeches/wellinghoff/2010/01-04-10-wellinghoff-sec.pdf.

31 "Great Issues In Energy: Nuclear Power, Panel Presentation and Q & A" Dartmouth College, April 2010, http:// engineering.dartmouth.edu/news-events/lecture-series/issues-in-energy/.



"You can think of China as a huge laboratory for deploying technology," a US government official says. "We have advanced ideas. They have the capability to deploy it very quickly. That is where the partnership works."

"The basic AP1000 design will not change from plant to plant," Cummins explains. Different locations will pose different construction challenges, but the economies of standard design should serve the industry well. Each new plant will not require, in effect, the reinvention of the regulatory wheel, "so regulatory approval times should be reduced," says Cummins. The NRC's Office of New Reactors concurs, and it also points to China as a proving ground for improvements in regulatory efficiencies.

"We are taking advantage of the [AP1000] construction going on in China to test parts of our construction inspection program and incorporating any lessons learned into our [US] program," says Donna Williams, Technical Assistant at the Office of New Reactors. "We anticipate that the number of on-site inspection hours will decrease for each subsequent plant that we inspect."

"The regulator is not the major issue that needs to be addressed," says Dale Klein, former Chairman of the Nuclear Regulatory Commission (2009), who spoke to *Gridlines* recently. "I think the regulator can obviously be a little bit more efficient without compromising safety and security. But what I would like to see is a more articulated national energy program of where nuclear fits in, and then the next question will be, How do we finance and develop these very capital-intensive plants that are going to be around for literally decades, so that we don't end up losing the opportunity for the American people to have a clean baseload supply of electricity?"

Problems always crop up with large capital projects. The key for the nuclear sector may lie in a new generation of analytical tools—schedule analytics, project finance modeling, and quantitative risk analysis—that can help the Buzz Millers of the world forecast construction headaches. So-called Monte Carlo modeling tools have been around ever since John von Neumann coined the term to describe a method of calculation that uses random samplings run on computers many thousands of times. Monte Carlo methods were used in the Manhattan Project and have been developed for broad application across many fields.

Why would such analytical systems work for nuclear power plant construction? Consider the issue of scheduling. The sheer volume of activities required for a big capital project is staggering. One typical activity, for instance, might be to install a foundation for a building. Another might be as small as installing a pipe. A third might be to excavate a 180-foot hole.

But the count keeps going, to reach hundreds of thousands of key activities, each with as many as hundreds of subtasks. Scheduling tools are now part of a new generation of quantitative

“No rational long-range energy plan of any major modern economy should exclude the nuclear option,” says Vaclav Smil. “The debate should be about the best way to proceed, not about whether to proceed at all.”[34]

Workers pour concrete at a nuclear construction site in southeast China’s Fujian province, June 2009.

risk analysis. Schedule analytics form one data set. Another data set includes financial tools that help managers predict price escalators that vendors will charge owners over the life span of the project. For instance, time-phase analyses take two or three years’ worth of data and cast that forward so that managers can project future trends and make adjustments where needed. A third data set consists of the long-term risks for large capital projects, including supply chain delays and even regulatory risks. These three sets of data are then run through a specialized Monte Carlo–type application, the data spinning out calculations many thousands of times.

The result is that managers like Buzz Miller have a comprehensive view of what’s happening on a construction site. They can determine production rates, predict whether milestones will be reached, learn whether more people will be needed to achieve targets, know where supply chain vulnerabilities lie, and even determine the likely risk tolerance of regulatory agencies.

It may be that disciplined blocking and tackling is more needed than the stuff of rocket science, and in the red clay of Georgia, control analytics, like almost everything else in the nuclear sector, are being put to the test.

While there’s no single solution to the challenges of an entire industry, there is a desire—within the industry and within the utilities it serves—to make nuclear work to play an important role satisfying the world’s increasing energy appetite as the epochal shift occurs from fossil fuels to renewable sources.

“We are the ones that innovated the technology,” Duke Energy’s CEO Jim Rogers said in May of last year.[32] In January 2011, Duke Energy made a bid to purchase Progress Energy, a merger that many observers acknowledged would make financing for both companies’ proposed nuclear plants easier. “Our size and scale, once combined, position us well for nuclear generation,” Progress Energy’s CEO Bill Johnson said after the merger was announced.[33]

This kind of activity, the practical experience being gained in other sites rising worldwide with a completely new generation of reactors, and a universe of advanced control analytics may offer the hope that the industry’s Gordian Knot—bringing plants in on time and on budget—may soon be met and mastered, unlocking the tremendous energy potential of nuclear power.

About the author

Mark Svenvold writes about energy and environmental issues for *Gridlines* as well as *The New York Times* magazine and many other print and online news sources. His latest book is *Big Weather*.

32 “US Nuclear Power Build-up Taking First, Tentative Steps,” Steve Gelsi, MarketWatch, May 20, 2010, http://www.marketwatch.com/story/americas-nuclear-buildup-takes-first-steps-2010-05-20?pagenumber=2.

33 “Duke Energy–Progress Energy Behemoth Covets Nuclear Power Amid Soaring Costs,” Robert Trigtaux, *St. Petersburg Times,* January 11, 2011, http://www.tampabay.com/news/business/energy/duke-energy-progress-energy-behemoth-covets-nuclear-power-amid-soaring/1144673.

34 Vaclav Smil, *Energy Myths and Realities,* AEI Press, 2010, pg 154.

To discuss the issues

Global and US Leader
Carter Pate
Tel +1 646 471 5330
carter.pate@us.pwc.com

Australia
Joseph Carrozzi
Tel +61 2 8266 1144
joseph.carozzi@au.pwc.com

Canada
Brian Pawluck
Tel +1 604 806 7701
brian.k.pawluck@ca.pwc.com

Central and Eastern Europe
Tibor Almassy
Tel +36 1 461 9644
tibor.almassy@hu.pwc.com

China/Hong Kong
Hongbin Cong
Tel +86 10 6533 2667
hongbin.cong@cn.pwc.com

Brazil
Mauricio Girardello
Tel +55 11 3674 2469
mauricio.girardello@br.pwc.com

Hazem Galal
Tel +55 21 3232 6168
hazem.galal@br.pwc.com

Germany
Hansjörg Arnold
Tel +49 69 9585 5611
hansjoerg.arnold@de.pwc.com

India
Bharti Gupta Ramola
Tel +91 124 4620 503
bharti.gupta.ramola@in.pwc.com

Italy
Guido Sirolli
Tel +390 6 57083 2125
guido.g.sirolli@it.pwc.com

Japan
Kenji Yoshida
Tel +81 90 5428 7652
kenji.k.yoshida@jp.pwc.com

Malaysia/Vietnam/Thailand/Cambodia/Laos
Andrew Chan Yik Hong
Tel +60 3 2173 1219
andrew.yh.chan@my.pwc.com

Mexico
Francisco Ibañez
Tel +52 55 52 63 60685
francisco.ibanez@mx.pwc.com

Middle East
Neil Broadhead
Tel +971 4 304 3199
n.broadhead@ae.pwc.com

Charles Lloyd
Tel +971 56 682 0617
charles.lloyd@ae.pwc.com

Netherlands
Martin Blokland
Tel +31 8879 27586
martin.blokland@nl.pwc.com

Russia
Artem Petrukhin
Tel +7 495 967 6224
artem.petrukhin@ru.pwc.com

Singapore
Mark Rathbone
Tel +65 6236 4190
mark.rathbone@sg.pwc.com

South Africa
Mark Ally
Tel +27 11 797 5049
mark.ally@za.pwc.com

Vishal Agarwal
Tel +254 20 2855000
vishal.agarwal@ke.pwc.com

Spain
Guillermo Masso
Tel +34 915 684 353
guillermo.masso@es.pwc.com

Sweden
Lars Tvede-Jensen
Tel +46 8 555 33 403
lars.tvede-jensen@se.pwc.com

UK
Tony Poulter
Tel +44 20 780 45814
tony.poulter@uk.pwc.com

Nuclear contacts

Chris Fynn
Tel +1 646 471 1266
christopher.c.fynn@us.pwc.com

Philippe Girault
Tel +33 1 56 57 8897
philippe.girault@fr.pwc.com

Chris Green
Tel +44 161 245 2339
chris.j.green@uk.pwc.com

Stephen Lechner
Tel +1 415 498 6596
stephen.p.lechner@us.pwc.com

Contributors

Strategic Direction
Richard Abadie
Sondra Chrusciel
Sotiris Pagdadis
Carter Pate
Tony Poulter
Peter Raymond

Marketing, Operations + Outreach
Lee Ann Ritzman
Becky Weaver
Jennifer Wiley

Online
Adiba Khan

Editor
William Sand

Design
Odgis + Company
Janet Odgis
Rhian Swierat
Banu Berker

See the Web at www.pwc.com/gridlines for the full interview with Joseph A. “Buzz” Miller.

www.pwc.com

The papers and printer used in the production of this study are certified to Forest Stewardship Council (FSC) standards, which promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests. The cover for this publication was printed on paper containing 10% postconsumer waste material, and the text was printed on paper containing 10% postconsumer waste material.

By printing at a facility utilizing 100% wind energy and using postconsumer recycled fiber in lieu of virgin fiber:

- 4 trees were preserved for the future
- 10 lbs of waterborne waste were not created
- 780 gallons of wastewater flow were saved
- 172 lbs of solid waste were not generated
- 340 lbs net of greenhouse gases were prevented
- 2,603,125 BTUs of energy were not consumed
- 1,974 lbs of GHG emissions were not generated
- 2.1 barrels of fuel oil were not used
- 2,230 cubic feet of natural gas were not used
- equivalent of not driving 1,952 miles
- equivalent of planting 134 trees