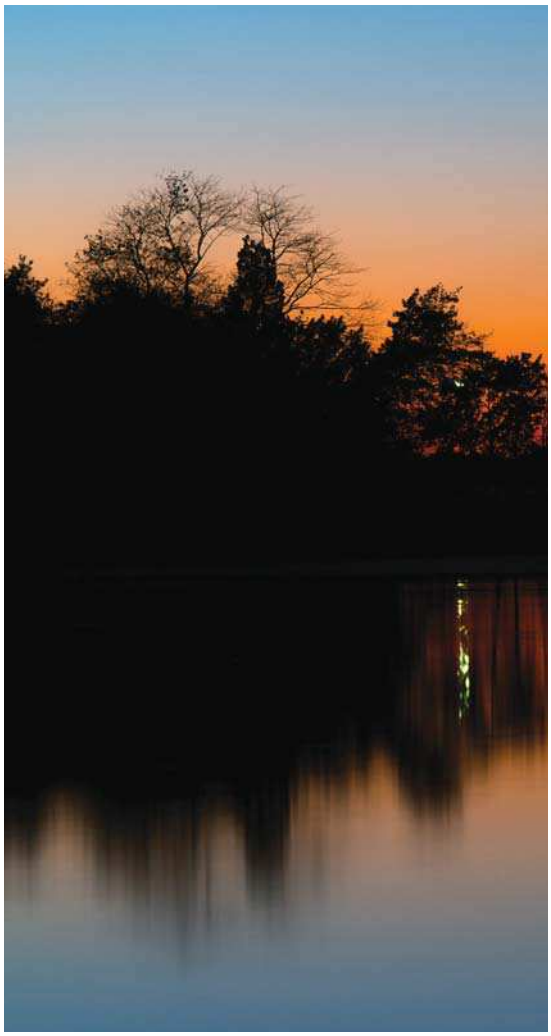
# US nuclear industry fights for survival

A glut of cheap natural gas, coupled with rapid increases in wind energy, is accelerating a decline in the US commercial nuclear industry when carbon-free energy has never been more important.



Today 98 US reactors supply just under 20% of the nation's electricity and more than half of its carbon-free power. Seven reactors have been closed in the past five years and another is due to shut down next year. Maria Korsnick, president of the Nuclear Energy Institute, the industry's trade organization, told New Jersey utility regulators in October that the shutdown of a dozen more reactors expected by 2025 will eliminate carbon-free power equivalent to two-thirds of total US wind and solar output.

Michael Wallace, a former chairman of Constellation Energy Nuclear Group, which operated five reactors, warned on 2 October that all US commercial plants could be shut down in 15–20 years. He told an audience at a Center for Strategic and International Studies event that plant closures will accelerate as suppliers to nuclear plants begin to exit the business in response to the shrinking customer base. "At some point, the continued US nuclear industry decline we're experiencing today becomes irreversible," agreed William Ostendorff, a former member of the Nuclear Regulatory Commission (NRC).

In a report released on 8 November, the Union of Concerned Scientists estimates that one-third of US nuclear plants are currently unprofitable and are likely to be shuttered over the next decade. In its annual energy outlook for 2018, the Energy Information Administration (EIA) offers a somewhat less dire nuclear decline of 20% by 2050, to 79 GW from its current 99 GW, and predicts no new nuclear plants will be built in that time. But another 24 GW of nuclear capacity could be lost in the same period should natural-gas prices fall and remain low relative to current levels, the EIA report adds.

The boom in shale-gas production has reduced gas prices by nearly two-thirds during the past decade, from an average of nearly $9 per million Btu (MMBtu) in 2008 to $3 per MMBtu in 2017, according to the EIA (1 MMBtu is about 1.05 gigajoules). Cheap gas has depressed electricity prices in the wholesale power markets to the point where many nuclear plants are unable to recover their production costs.

Exelon Corp, which with 23 reactors is the largest US nuclear power plant operator, lost $800 million over seven years in a failed attempt to keep two Illinois reactors operating, president Chris Crane told a Brookings Institution audience on 22 October. Exelon's Oyster Creek plant in New Jersey, which was the oldest operating plant in the US, closed for good in September, and its Three Mile Island plant in Pennsylvania will shut down next year following six years of losses. Crane blamed the regulators of wholesale power markets for failing to give credit to nuclear generators for the social benefits of their carbon-free output. He and other executives say that it's unfair to not provide nuclear generators a subsidy comparable to the tax credit that wind turbine operators receive for every kilowatt-hour of electricity they produce.

Some nuclear plants, particularly those having a single reactor that produces less than 1 GW, are particularly vulnerable to closure. "I'll be the first one to tell you that some of the nuclear plants are small, uneconomic, and they won't make it. And they probably shouldn't make it," said Crane.

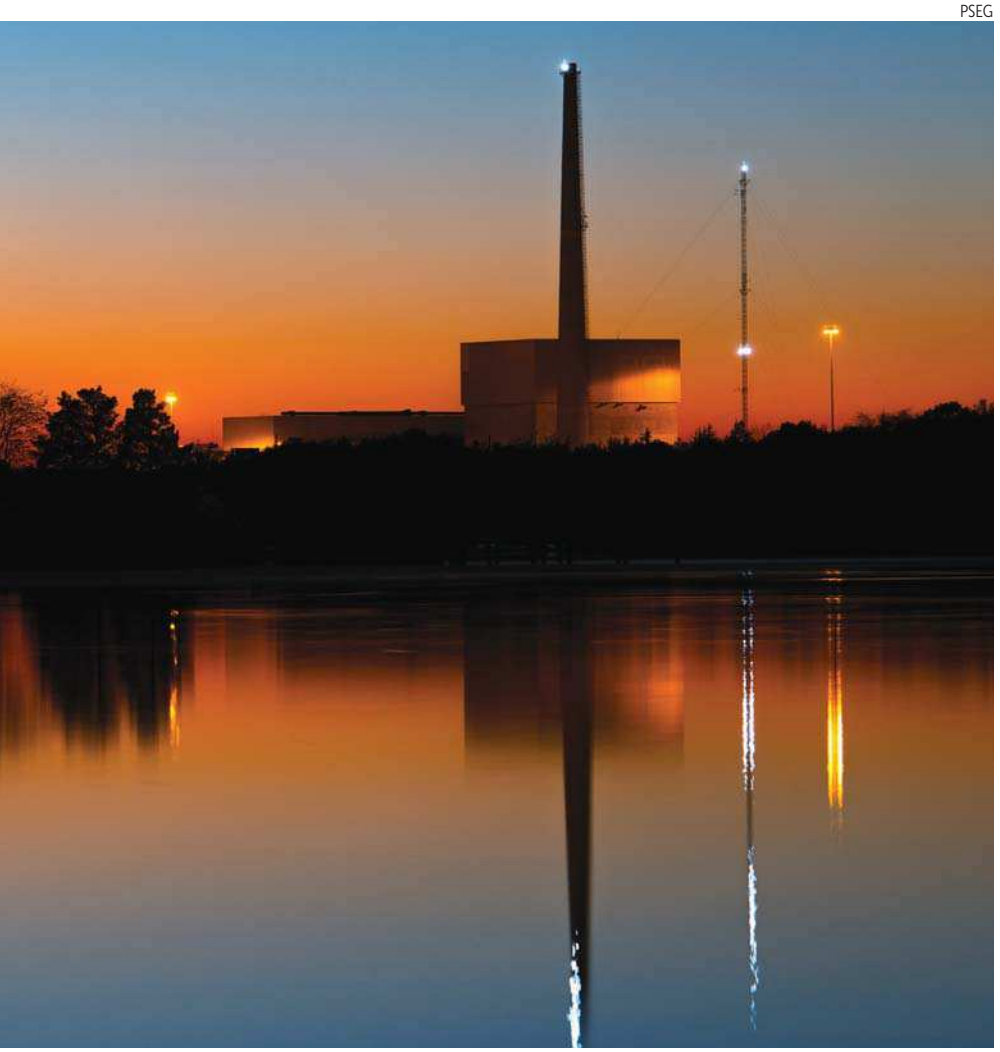
## Price takers

The bulk of the country's electricity supply is maintained by seven regional grid managers known as independent system operators (ISOs; see PHYSICS TODAY, September 2016, page 25).The largest one, PJM Interconnection, serves much of the mid-Atlantic region and part of the Midwest. Like other ISOs, PJM operates a marketplace that sells power from generating companies to local utilities. Oftentimes, nuclear power plants are not profitable because cheaper energy sources set the price paid to all generators.

Since reactors operate at full capacity and aren't readily turned on or off, nuclear generators become "price takers," says Matt Crozat, senior director of policy development at the Nuclear Energy Institute. Unless they are offline for refueling or maintenance, they operate no matter the price they receive.

About half of the nation's nuclear plants operate in competitive markets, where economic pressures are the most

PSEG



**EXELON CORP'S OYSTER CREEK PLANT** in New Jersey was shut down in September, bringing to seven the number of US commercial reactors permanently closed in the past five years.

acute, Crozat says. Other plants are located in regulated markets, such as the Southeast, where state utility commissions set wholesale power rates. Although regulators tend to dampen short-term price movements, he says, the pressures that are forcing early plant closures are largely the same. Despite losing money, many nuclear plant owners continue holding out in hopes that gas prices will rise or policy will be enacted to improve their finances.

When Department of Energy secretary Rick Perry last year proposed a rule that would compensate both nuclear and coal generators for their purported reliability and resiliency attributes, the Federal Energy Regulatory Commission unanimously rejected it. Perry unsuccessfully argued that coal and nuclear power aren't subject to fuel supply shortages that natural-gas generators have sometimes encountered during periods of peak grid demand.

More recently DOE proposed federally subsidizing uneconomic coal and nuclear plants on national security grounds while a more permanent bailout plan is developed. That proposal reportedly failed to gain the support of White House officials.

Four states—Connecticut, Illinois, New Jersey, and New York—have acted to prop up their nuclear generators. Three of them do so through zero-emission tax credits. Crane says that the state moves are a stopgap and that regional and federal

NUSCALE POWER

**A CROSS-SECTIONAL REPRESENTATION** of a NuScale small modular reactor building with five modules installed. A sixth module (left) is in the process of being loaded.

solutions are necessary. Crozat, however, notes that "Band-Aids are pretty useful when you're bleeding."

## National security concerns

Advocates of nuclear power offer another argument for saving the industry: national security. (See PHYSICS TODAY, November 2012, page 24.) A healthy commercial nuclear sector is vital to the US Navy's nuclear propulsion program, they say. All US commercial reactors and most of the world's are descended from naval reactors. Ostendorff, a former nuclear submarine commander, says that he always saw "a fair number" of ex-navy engineers at each of the 60 commercial plants he visited during his NRC tenure. Without that potential career path, today's youth will be less likely to take up nuclear engineering and positions in the nuclear navy, he says.

Nuclear proponents further argue that continued commercial decline will cause the US to lose its influence in the setting of international standards and policies in nuclear safety, security, and nonproliferation. For example, nations that have previously bought US reactors have had to accept US policies designed to keep nuclear technologies and materials out of the wrong hands. The US also led in the development of additional safety measures in the wake of the Fukushima nuclear disaster. "To engage internationally, the US must actively participate" in the industry, says Ostendorff.

But Joseph Romm, a former DOE deputy assistant secretary and senior fellow at the Center for American Progress, notes that despite the lack of a substantial US market for new nuclear plants in 30 years, "somehow our nuclear ships seem to be doing okay." As for US leadership in nonproliferation policy, he says, "If we could run the US economy on very low carbon power without nuclear, that would send a message to the rest of the world that they don't need nuclear."

Romm, an ardent renewable energy advocate, says keeping the current nuclear fleet operational for as long as possible through a $25–$30 per ton tax on carbon dioxide emissions would be "a perfectly reasonable thing to do." A July analysis by Brattle Group consultants said the economic viability of the US nuclear fleet could be ensured with an annual subsidy of $50 per kilowatt, or $5 billion a year. That's equivalent to a tax of about $20 per ton on $CO_2$ emissions. A tax of $25 per ton beginning in 2020 and escalating at 5% a year in real terms could result in nearly 60 GW of nuclear capacity being added to the existing 99 GW by 2050, according to the EIA report.

## Becoming irrelevant

"The cost of new nuclear is prohibitive for us to be investing in," says Crane. Exelon considered building two new reactors in Texas in 2005, he says, when gas prices were $8/MMBtu and were projected to rise to $13/MMBtu. At that price, the project would have been viable with a $CO_2$ tax of $25 per ton. "We're sitting here trading 2019 gas at $2.90 per MMBtu," he says; for new nuclear power to be competitive at that price, a $CO_2$ tax "would be $300–$400." Exelon currently is placing its bets instead on advances in energy storage and carbon sequestration technologies.

Two utilities last year abandoned construction of two Westinghouse-designed AP1000 reactors at a South Carolina plant. The project, which was 40% completed, had already cost $9 billion, and the mounting costs pushed Westinghouse into bankruptcy. That left two AP1000s in Georgia as the only new reactors being built in the US since the 1979 Three Mile Island accident. Their combined estimated cost has doubled to $25 billion.

In comparison to other world nuclear power developers, says Wallace, "the US has become totally irrelevant." Apart from the Georgia units, the US has no reactors under construction, planned, or proposed (the standard international nuclear industry categorization) nor do US companies have contracts or commitments to build plants abroad. By contrast, Russia, which now dominates the international market for new reactors, has 53 under construction, planned, or proposed within its own borders and another 50 in 19 countries. China is constructing, planning, or proposing to build 220 new domestic reactors, and 20 of its models

are being built or are under consideration in 12 other countries.

Russian and Chinese reactor suppliers are state-owned enterprises that finance and operate the plants they are building abroad. "It's difficult to put US designs and products on equal footing with other countries that have the full backing of their national governments behind them," says Crozat.

## Future hopes

Several US companies, however, are pursuing what they hope will be a US market for reactors that could supply electricity in relatively small increments ranging from less than 100 MW to several hundred megawatts. Any number of the so-called small modular reactors (SMRs) could be added to a given plant site should future demand warrant. (See PHYSICS TODAY, August 2010, page 25.) The major components of SMRs would be factory-built for transport to the location, where onsite construction of buildings and other site-specific components could proceed in parallel.

NuScale Power appears to be the furthest along of the SMR developers. The only one to have applied for an NRC license, NuScale is on track to gain certification for its design in 2020, says Jose Reyes, cofounder and chief technology officer. The company's first customer is a group of 29 utilities in western states that have signed up to take varying amounts of power when the plant is completed in 2026. To be located at DOE's Idaho National Laboratory, the plant will comprise up to a dozen 60 MW modules, Reyes says. Sized at 720 GW, the plant is estimated to cost $2.9 billion and scheduled to take about three years to complete, less than half the time required for a gigawatt-scale reactor.

NuScale's reactor features a stainless steel containment vessel, which eliminates the need for massive reinforced concrete containment domes that are often a major choke point during construction of conventional reactors. The power level can be quickly ramped up or down in response to changing electricity demand. That load-following feature is attractive for regions of the country that have large amounts of intermittent wind and solar generation. Like other SMR designs, NuScale's also features passive safety systems that will shut down the reactor without operator intervention should there be a loss of power or other accident. The company, whose major investor is Fluor Corp, to date has spent more than $800 million, $288 million of which came from DOE, on design and certification.

Microreactors, which are small enough to fit on a truck or train and capable of powering individual military installations or remote locations, offer another near-term hope for the nuclear industry. The act authorizing Department of Defense operations for fiscal year 2019 directs the Pentagon to draft a plan to begin operating such a reactor in 2027. In response, DOE in September requested information from interested vendors. A bid competition is expected next year.

For the longer term, developers are proposing a range of advanced, compact designs that use coolants other than water; alternatives include molten salt, helium gas, or liquid metal. In 2015 DOE established the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to

provide developers of so-called Generation Four advanced reactors with access to technical, regulatory, and financial support necessary to commercialize new reactor designs.

X-energy, which is developing a high-temperature, helium-gas-cooled advanced reactor, has received grants totaling $50 million from the GAIN program. Harlan Bowers, the company's president, says X-energy is eyeing market niches, such as remote off-grid communities in northern Canada that are currently served by diesel-powered plants. He also sees an opportunity in replacing retiring coal and natural gas plants, which generally produce less electricity than today's commercial nuclear facilities.

Bowers says all advanced reactor developers will require further engineering design in preparation for applying for an NRC license. For X-energy, he estimates that will cost $300 million–$400 million.

Some advanced reactor designs produce high-energy neutrons that can run on the spent fuel from current reactors, provided that the fission products are removed. The so-called fast reactors would reduce the nuclear waste that requires storage in a geological repository, proponents say. (See the story on page 31 and the Quick Study by David Bodansky, PHYSICS TODAY, December 2006, page 80.)

US policy since the 1970s has prohibited spent-fuel reprocessing on nonproliferation grounds. But Christina Back, vice president for nuclear technologies and materials at General Atomics, says GA is developing a new proliferation-resistant processing technology tailored to its fast-neutron reactor. The company's Energy Multiplier Module design is a compact, high-power-density variant of a gas-cooled reactor in which the helium coolant directly drives turbines. Without the need to produce steam, the design could offer efficiencies as high as 53%, she says, versus the 32–38% efficiency typical with conventional reactors.

What most advanced reactor designs have in common is that they require high-assay low-enriched uranium (HALEU), which has a level of uranium-235 close to the 20% at which fuel is considered highly enriched. Commercial reactors generally operate on 4% enriched fuel. The sole producer of HALEU is Russia. DOE, in support of its nuclear weapons program, is expected to fund construction of an enrichment plant that will be capable of producing HALEU (see PHYSICS TODAY, March 2018, page 29). In the meantime, limited quantities of the fuel for reactor development have been provided by blending down the agency's stockpile of highly enriched uranium.

A bipartisan bill introduced in September by nine senators would encourage advanced reactor development by authorizing public–private partnerships and federal power-purchase agreements. It also would authorize construction of a reactor-based fast-neutron source to test fast-reactor components.

Romm cautions advanced nuclear developers to remember that renewable and energy storage technologies are also improving. "One of the biggest mistakes that [nuclear] business plans make," he says, "is to assume that the competition remains static."

**David Kramer**