ITER project has to respond to all of those management assessment recommendations, has to come up with an action plan, and has to execute." Poneman joined Moniz at the Senate hearing because Moniz has recused himself from fusion matters. Moniz was previously a physics professor at MIT, which is a DOE fusion-program contractor.

The Obama administration has capped the US annual contribution to ITER at $225 million, but it has never come close to including that much in a budget request. Congress appropriated $199 million for ITER in fiscal year 2014. Edmund Synakowski, associate director of fusion energy sciences at DOE's Office of Science, told an advisory committee in April that the $150 million requested for ITER in FY 2015 was appropriate in view of the lack of a baseline schedule. But Ned Sauthoff, director of the US ITER Project Office, told the same meeting that next year's request will cause the project schedule to slip further.

Iotti says the ITER project needs to "demonstrate substantial real progress by the middle of 2015; then the project is not only salvageable but will be successful." At that point, components will start to show up at the site, buildings will be constructed, and, he says, "people will start to think differently, thinking that this is actually going to happen." **David Kramer**

Nuclear energy output slows as climate warms

New reports from the Intergovernmental Panel on Climate Change and the US government say the window is closing for actions to avert the worst effects of warming.

Despite emission reductions by the US, Russia, and some other nations, worldwide anthropogenic greenhouse gas emissions accelerated at an annual rate of 2.2% from 2000 to 2010 and reached a record high of 49 billion metric tons of carbon dioxide equivalent in 2010, according to the fifth assessment of the Intergovernmental Panel on Climate Change (IPCC). By comparison, emissions grew at an annual average rate of 1.6% during 1970–2000. Carbon dioxide equivalent is a unit of measurement used to convert the heat-trapping effects of other greenhouse gases such as methane.

A separate report released on 6 May by the US Global Change Research Program (USGCRP) says that the effects of climate change are already being felt in the US. Effects include longer summers, rising tides, more prolonged heat waves, heavier downpours, and regional changes in the varieties of plant and bird species.

Without any further policy actions to control emissions of greenhouse gases, the world is likely to see a rise of up to 4.8 °C in the average global temperatures by the end of the century, according to the IPCC. That is more than double the 2 °C rise from preindustrial-era temperatures that scientists have estimated to be the upper limit if the worst impacts of climate change are to be averted.

The USGCRP assessment, which was based on the results from 16 climate models, predicts that if emissions from fossil-fuel combustion are left unchecked, temperatures could increase by up to 5.6 °C by the end of the century. Even with substantial reductions in CO_2 emissions, the temperature could rise as much as 2.8 °C by 2100, says the report.

Viewed against that backdrop, the recent closures of five US nuclear reactors and the threat of additional plant retirements caused by economic pressures on an aging nuclear fleet jeopardize the Obama administration's commitment to reduce US greenhouse gas emissions to 17% below 2005 levels by 2020.

The US is the world's second largest emitter of greenhouse gases, behind China. The IPCC estimates that global emissions will need to be slashed by up to 70% by midcentury in order to remain below the 2 °C threshold.

Worldwide, energy production is the largest source of manmade greenhouse gases; it accounts for 35% of total emissions. Also the fastest-growing emitter, energy supply contributed 47% of the increase in emissions in the 2000–10 period, said the IPCC assessment, the third installment of which was released in mid-April.

Low-carbon sources—nuclear, renewables, and fossil fuels coupled with carbon capture and storage—must grow from their current 30% share to 80% of world electricity production by 2050, the IPCC says. But nuclear's global share has been declining, from 17% in 1993 to 11% currently, according to the International Atomic Energy Agency.

Off the table

"If you read the IPCC reports, they are clear that maybe we are out of time, but certainly we have little time" to reduce greenhouse gases in earnest, said Carol Browner, former Environmental Protection Agency administrator, at a Washington, DC, conference hosted by the Center for Climate and Energy Solutions (C2ES) on 28 April. "I used to be antinuclear until after I left EPA and started to realize the single biggest problem the world needs to address is climate change, and that you can't take off the table a technology that is basically carbon free," Browner said.

Nuclear reactors provide 60% of the nation's current supply of zero-emissions energy, more than four times the amount generated by wind and solar combined, according to the Energy Information Administration (EIA) of the Department of Energy. About one-fifth of all US electricity is nuclear generated. Since 2005, US CO_2 emissions from the electric-power sector have fallen by 15%, largely due to a shift from coal to natural gas, the economic recession, and increases in energy efficiency and wind generation, according to C2ES. But the EIA forecasts that in the absence of new policies, the proportion

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The Vermont Yankee nuclear power plant is one of five US commercial nuclear reactors whose owners have recently announced closures.

of fossil-fuel and zero-carbon energy sources in the US will remain relatively stable through 2040.

"The bottom line is that if we keep shutting down nuclear power plants, it will be that much tougher to meet even our near-term climate goals," said Eileen Claussen, C2ES president. Since late 2012 four US power companies have unexpectedly announced the retirement of five reactors, representing 4.2% of the country's total nuclear generating capacity. The owners of two of those plants, Kewaunee in Wisconsin and Vermont Yankee, blamed the closures on low natural gas prices and other economic issues. The other closures, of Crystal River in Florida and the two reactors at San Onofre, California, were attributed to maintenance issues, specifically problems related to replacing their steam generators, according to C2ES. Peter Lyons, DOE assistant secretary for nuclear energy, said that mechanical fixes were available for those three units, and the owners likely would have paid for them in a more favorable economic environment.

The EIA, in its *Annual Energy Outlook 2014*, forecasts another 6 GW of US nuclear generating capacity—roughly six reactors—will be shut down by 2019, as higher-cost units face continued economic challenges. Five reactors are currently under construction in the US, but the EIA forecasts that beyond those five, no additional nuclear plants will be built through 2030.

David Kramer

Researchers get back to the deep

CHRIS LINDER, WOODS HOLE OCEANOGRAPHIC INSTITUTION

KEN MACDONALD

Alvin, the US's only manned research submarine that can explore the sea floor, is back in service after a three-year, $41 million upgrade. This spring it was used in the Gulf of Mexico to assess effects on marine life of the 2010 Deepwater Horizon oil spill.

The titanium personnel sphere is now 18% larger—but with an inside diameter of 2 m, it's still close quarters for a pilot and two scientists on a typical 8- to 10-hour dive. The new, 8-cm-thick sphere has five windows, two more than before. *Alvin* also has more and better cameras, provides better lighting, and can carry more instruments down and more samples up.

Most of the new components are designed to withstand dives down to 6500 m. But extending *Alvin*'s depth rating beyond 4500 m would require powerful, fire-safe batteries; a new variable ballast system; and funding. "At 4500 meters you get 68% of the global sea floor. At 6500 meters, you get 98%," says Daniel Fornari, a geophysicist at Woods Hole Oceanographic Institution. The US Navy owns *Alvin*, WHOI operates it, and NSF funded most of the upgrade. (The top photo shows *Alvin* as divers prepare it to be lifted from the water after a test dive. In the bottom photo, a Styrofoam cup shrunken by pressure when *Alvin* carried it to the sea bottom stands alongside one that stayed on Earth's surface.)

In its 50 years, *Alvin* has had a significant impact on deep-sea research—and revolutionized deep-sea biology by discovering hydrothermal vents, says Fornari. Before the latest upgrade, the sub had made 4664 dives. They were for studies in biology (about 38% of dives), geology and geophysics (32%), and chemistry (13%); the other 17% of dives were for engineering and equipment tests, training, and education.

Peter Girguis, a Harvard University deep-sea microbiologist, designed an underwater mass spectrometer that he takes down on *Alvin*. "I care about measuring chemicals in relationship to the organisms I am studying," he says. "The biomass in the deep ocean is modest compared to the upper ocean, but the diversity of life in the deep sea is way larger. Understanding microbes is key if we want to have a sense of how humans affect the biosphere—acid rain, ozone hole, climate change."

Alvin is also used to measure geophysical properties of the sea floor and ocean crust. Localized gravity measurements, for example, can distinguish sub-sea-floor areas of dense rocks from porous lava flows or sediments and can identify zones of mineralization created at hydrothermal vents. "Underwater hot springs have high amounts of copper, gold, and even platinum," says Girguis. "That's spurring a renewed worldwide interest in deep-sea mining." And magnetic field measurements can map reversals of Earth's magnetic field that are recorded in volcanic rocks; researchers use those measurements in calculations of sea-floor spreading and crustal accretion.

Mike Perfit of the University of Florida recalls a series of dives in 1991 to a section of the mid-ocean ridge southwest of Mexico. The team could not find features that had been previously mapped with a deep-sea camera towed from the sea surface. "Fresh black glassy basalt covered everything and white bacterial floc that looked like snow [was] coming out of cracks and holes in the sea floor," he says. Postdive analysis of short-lived radioisotopes in lava samples confirmed that they had seen a volcanic eruption. After studying the site for more than a decade, Perfit and colleagues were surprised to discover that such eruptions occur on decadal time scales, rather than hundreds to thousands of years as had been thought.

Often observations with autonomous or tethered robotic sea-bottom vehicles complement research with *Alvin*. With robotic vehicles, says Susan Humphris, a WHOI geochemist and the principal investigator for the *Alvin* upgrade, "you are looking at a TV screen, and you don't get the context of the rocks. You don't understand the relation of things to each other in the same way as you do with the human eye."

Alvin is more responsive than tethered robotic vehicles, says Ken Macdonald, a University of California, Santa Barbara, geophysicist who has been on about 50 dives. "It's more efficient for taking samples and deploying instruments." And, he says, "there is the exhilaration. I can't emphasize enough how important that is. Being down there is profound."

Toni Feder