

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

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; re-

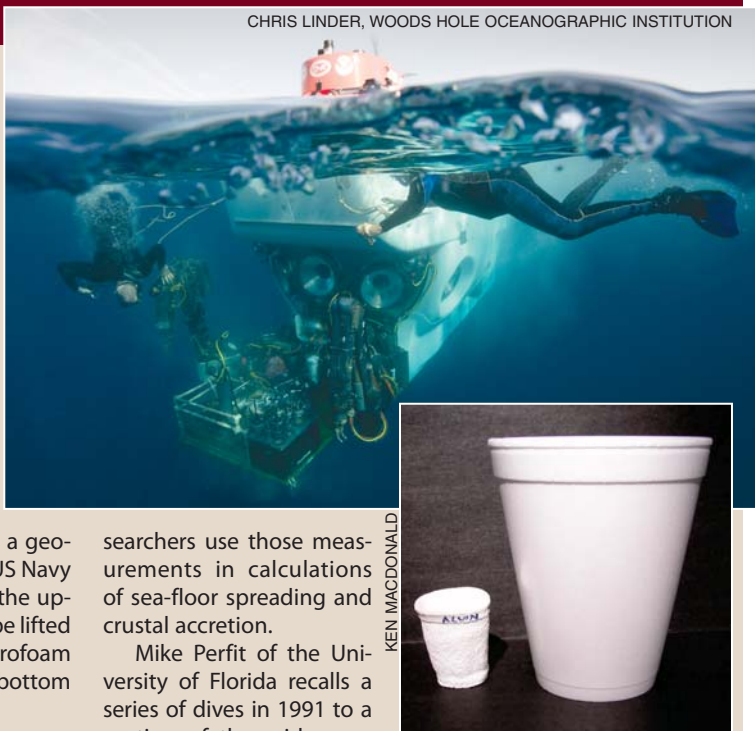
searchers use those measurements in calculations of sea-floor spreading and crustal accretion.

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 seabottom 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."

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