

The *Gathering Storm* still looms

A decade on, the situation portrayed in the influential report of a deteriorating US science and technology ecosystem has, if anything, worsened.

In 2006 a committee of what is now the National Academies of Sciences, Engineering, and Medicine issued an unusually stark warning: The US would soon be overtaken as the world's leading science, technology, and engineering power.

The report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, addressed a far broader range of topics than the dozens of reviews the academies compile each year in response to requests from Congress and federal agencies. It also attracted far greater attention from lawmakers, the media, and the science policy cognoscenti. (See PHYSICS TODAY, December 2005, page 25.)

The report's tone suggested that a crisis was close at hand, as this excerpt shows:

This nation must prepare with great urgency to preserve its strategic and economic security. Because other nations have, and probably will continue to have, the competitive advantage of a low wage structure, the United States must compete by optimizing its knowledge-based resources, particularly in science and technology, and by sustaining the most fertile environment for new and revitalized industries and the well-paying jobs they bring.

The 20-member committee that authored the report included prominent CEOs, heads of leading universities, and influential scientists and engineers and was chaired by retired Lockheed Martin CEO Norman Augustine. It noted that federal spending on research in the physical sciences as a percentage of GDP fell from 0.07% in fiscal year 1976 to 0.04% in FY 2004.

A decade later, the picture described in the report has worsened, says August-



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tine. "In my view, the federal government has had a few bright spots," he says, "but the federal story is clearly one of deterioration." In FY 2015 the physical sciences accounted for 10.2% of total federal spending on research, roughly the same as in 2004 but well below the 16.5% share in FY 1976, according to figures compiled by the American Association for the Advancement of Science.

Former representative Bart Gordon (D-TN), who chaired the House Science, Space, and Technology Committee from 2007 to 2011, is also troubled by the current state of science funding. "People just don't remember, our formula for prosperity in the second half of the 20th century was investing in education and research, which resulted in innovation, which then brought about new jobs and products and additional tax revenue to invest again." The 2009 American Recovery and Reinvestment Act (ARRA) provided a one-time funding boost for the federal science agencies, but in subsequent years the spending on research and education "simply hasn't kept up," Gordon laments.

Few would dispute that the *Gathering Storm* report was influential. "I still view the report as having a tremendous impact even though it didn't reach its full potential," says Deborah Stine, who was the study director at the National Academies. "Rarely will I go for a month without hearing some reference to the report in some major meeting on the hill or at the White House or elsewhere. It's had a long-term legacy."

Particularly notable, she says, was the

report's linkage of the four key elements of the science and technology enterprise: research; K-12 science, technology, engineering, and mathematics (STEM) education; higher education; and innovation. "It brought these disparate parts together. Usually they are each working in their own world," says Stine, now a science policy professor at Carnegie Mellon University. The committee listed 20 specific actions to be taken in those four categories. Although many were acted on, almost none have been followed at the recommended scale. And since multiple other reports have urged similar steps, the advances and new programs that have evolved in the four focus areas can't necessarily be tied directly to the *Gathering Storm* report.

In a 2010 update of the report, committee members unanimously agreed that conditions had worsened. *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5* said that deepening fiscal woes had precluded new federal investments while other nations were continuing to invest in improving their competitiveness.

ARPA-E: A success story

One manifest offspring of the *Gathering Storm* report was the 2007 creation of the Advanced Research Projects Agency-Energy, a small entity in the Department of Energy that sponsors high-risk research on innovative energy technologies. ARPA-E, a civilian analog of the Defense Advanced Research Projects Agency, received its first funding two years later with \$400 million from the

ARRA. Although widely regarded as effective, ARPA-E's budget has climbed slowly, from \$180 million post-ARRA to \$280 million in FY 2016—far short of the \$1 billion that the committee called for.

Some of the steps that the report urged for improving the US climate for innovation also have occurred, including making the R&D tax credit permanent and bolstering the US Patent and Trademark Office.

The congressional response to the report's recommendations was embodied primarily in what became the America COMPETES (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science) Act of 2007. (See *PHYSICS TODAY*, September 2007, page 34.) In addition to creating ARPA-E, the measure authorized multi-year increases in R&D spending at NSF, DOE's Office of Science, and NIST. But authorizations aren't the same as appropriations, and funding hasn't come near the act's goal of doubling the budgets of the three agencies over seven years. (For Obama science adviser John Holdren's perspective on the funding challenges, see *PHYSICS TODAY*, October 2016, page 27.)

The act did not address the *Gathering Storm* recommendation to increase funding for the tiny fraction of the Department of Defense's behemoth R&D program devoted to basic research because the congressional committees that generated the law don't have jurisdiction over DOD. Neither do they oversee the National Institutes of Health. Half of all federal dollars for basic research go to NIH, but its budget has declined 23% in real terms in the five years since the ARRA.

Since 2006 the US has fallen globally from first to seventh place in the fraction of GDP devoted to basic research, says Augustine. Today, that percentage is 0.2%. "The bad news for basic research is that very little is spent on it as a fraction of the GDP. The good news for basic research is that very little is spent on it, so it's easy to increase," he says.

The COMPETES Act did reinvigorate STEM teacher-improvement programs at NSF, notably the Robert Noyce Teacher Scholarship Program. Named after the cofounder of Fairchild Semiconductor and Intel, the program supports fellowships and stipends to attract STEM undergraduates to teaching careers. The law's call for a new presidential advisory committee on innovation



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AT A 2010 BRIEFING, former representative Bart Gordon (D-TN) (left) confers with Norman Augustine, chair of the National Academies committee that wrote *Rising Above the Gathering Storm*; the late National Academy of Engineering president Charles Vest; and former president of the National Academy of Sciences Ralph Cicerone.

and competitiveness, however, went unheeded. COMPETES also authorized NIST's Technology Innovation Program, which awarded cost-shared grants to industry and universities to develop high-risk technologies. But that program was terminated in 2011.

The COMPETES Act has taken on a life of its own and was reauthorized in 2011. That expired in 2014; House and Senate companion bills to extend it once again are pending.

Surplus or shortage?

Particularly alarming, in Augustine's view, is what he sees as the deteriorating climate for higher education in the decade since the academies' report. "We didn't foresee how much worse things would be today," he says. "We didn't foresee that states would disinvest from higher education as they have, particularly in the sciences and engineering. The idea was to get more scientists and engineers. What [the nation has] done is having exactly the opposite effect," he says, and big tuition increases have further worsened the picture.

Still, it's debatable whether the concern expressed in *Gathering Storm* over US students' lack of interest in science and engineering careers was warranted. According to the National Science Board report *Science and Engineering Indicators 2016*, the number of natural sciences and engineering bachelor's degrees awarded from US institutions rose steadily from about 242 000 in 2006 to 321 000 in 2013 (the latest year for which statistics are available), a 33% rise. Master's degrees awarded in the natural sciences and engineering increased 36% over the same period, from about 73 000 to about 99 000. The number of doctorates con-

ferred annually in those disciplines by US universities increased 14% from 28 000 to 32 000.

Former Energy secretary Steven Chu, a *Gathering Storm* committee member, welcomes the increase in undergraduate engineering majors, particularly in computer sciences. "Science has stabilized and anecdotally (perhaps) physics majors seem to be increasing," he says, pointing to millennials' interests in the risks of climate change, clean energy, and sustainability.

A 2012 report from the President's Council of Advisors on Science and Technology (PCAST), however, warned that such growth isn't enough: Given economic trends, the US would require 1 million more STEM professionals "if the country is to retain its historical preeminence in science and technology" over the next decade. The PCAST report cited one analysis by the Center on Education and the Workforce at Georgetown University showing that between 2008 and 2018, STEM occupations will increase from 5.0% of the jobs in the US to 5.3%—equivalent to 1 million jobs—and that 92% of those jobs will require at least some postsecondary education and training.

Gathering Storm itself was inconclusive on the appropriate size of the STEM labor force. "Although there is not a crisis at the moment and there are differences in labor markets by field that could lead to surpluses in some areas and shortages in others, the trends in enrollments and degrees are nonetheless cause for concern in a global environment wherein science and technology play an increasing role," it said.

A recent NSF report, *Doctorate Recipients from U. S. Universities*, said that for every broad science and engineering field,

the proportion of 2014 PhD recipients who reported definite commitments for employment or a postdoc position was at or near the lowest level of the past 15 years. Only about 65% of 2014 PhD recipients in the physical sciences reported such commitments within a year; for engineering doctorates, the rate was less than 60%.

"I believe there is a surplus of scientists," says Augustine. "But with engineers, [a surplus] is certainly not the view of the people I talk to in industry. The issue isn't too many engineers, it's too little funding. In science, that's even more so: too little funding for science and therefore not enough jobs for scientists."

Augustine argues that there will never be an engineering shortage, since plenty of engineers can be found overseas. "Engineering is quite transportable, so big companies can just open research labs and do their engineering work elsewhere," he says.

Chu worries that more than half of PhD engineering and science students in the US are foreign-born. In recent years, a growing proportion of those students have been returning to their home countries after completing their degrees.

K-12 STEM education

According to the Office of Science and Technology Policy, the nation is on track to meet President Obama's January 2011 State of the Union goal to put 100 000 additional well-qualified STEM teachers in America's classrooms by 2021. That goal is consistent with the *Gathering Storm* call for 10 000 to be trained annually.

New programs, mostly private-sector initiatives, aimed at improving the K-12 STEM education have been instituted over the past decade. President Obama's Educate to Innovate campaign, launched in November 2009, has brought in more than \$1 billion in private spending on STEM teaching. Change the Equation, a coalition of the CEOs of 33 companies, says it devotes \$750 million and millions of employee volunteer hours each year to upgrading STEM learning.

Math for America, a nonprofit founded in 2004 by billionaire hedge fund manager and mathematician Jim Simons, began by offering fellowships and courses to improve the qualifications of math teachers in New York City. Today its "master teachers" account for 1 in 10 STEM teachers there, and the program has been expanded to many other large US cities.

Augustine and some of his *Gathering*

Storm coauthors personally took on one of the report recommendations by founding the National Math and Science Initiative (NMSI) in 2007. With \$125 million from Exxon Mobil and additional support from others, the Dallas-based nonprofit has broadened student participation and performance in advanced placement classes and International Baccalaureate programs. According to Augustine, the NMSI has aided 3.2 million students to date. In some cases, he says, "we do something I find offensive but it works: We pay students to take an AP test and pass it, and we also pay their teachers."

Another encouraging development, says Augustine, has been the gradual move by teaching universities away from offering math and physics courses tailored to teachers and instead requiring more robust math and physics courses.

Still, Augustine says test scores over the past 10 years show US K-12 student performance in STEM getting worse relative to the rest of the world. In 2012, the most recent year for which statistics are available, American 15-year-olds scored 36th in math and 28th in science among 65 nations participating in the Organisation for Economic Cooperation and Development's (OECD's) Programme for International Student Assessment (PISA). On the 2006 exam, US students were 35th in math and 29th in science among 57 nations. The 2006 test did not include Shanghai, China, the top performer in both categories in 2009.

By a separate assessment, the 2011 Trends in International Mathematics and Science Study (TIMSS), US 8th graders performed 9th in math and 10th in science among 42 nations. In 2003 the US was 15th in math and 9th in science among 46 countries. In both years, Asian countries took the top four places.

The discrepancy between US students' performance on the two tests is partly because fewer wealthy nations participated in TIMSS compared with PISA, which includes all OECD nations. It also reflects the differing methodologies of the two tests: TIMSS is meant to assess knowledge of the subject matter, whereas PISA measures how well students can apply that knowledge in real-world contexts.

Summing up, Chu, referencing the 2010 *Gathering Storm* update, observes, "It is safe to say that the Category 5 has not yet landed on shore. However, the rising storm has not dissipated, but appears to be stalled nearby."

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