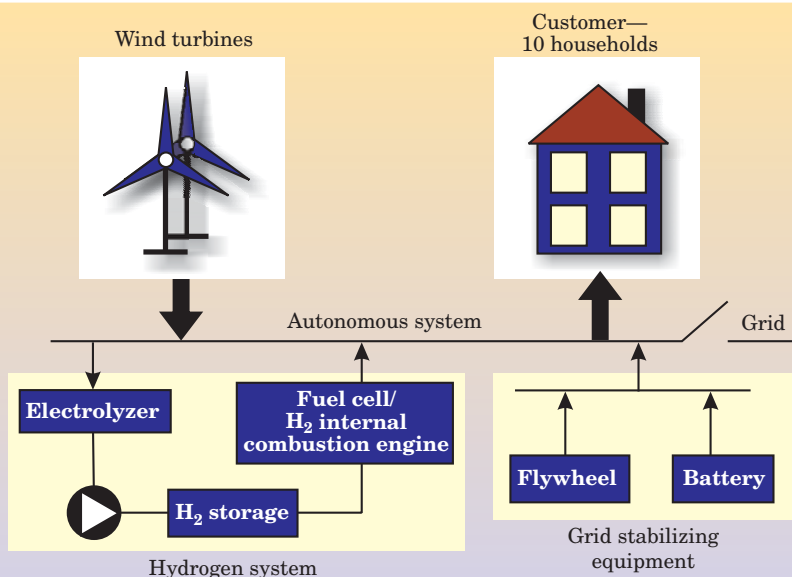




Two 46-meter-tall wind turbines on Norway's island of Utsira (right) are part of a prize-winning experiment in renewable energy. Excess energy is stored as hydrogen (diagram) and used when the wind doesn't meet demand. The turbines' production is sufficient to export energy to the mainland grid.



actually delivers reliable, robust, high-quality power to customers all the time."

"The problem with renewable energy—solar, wind—is that it is intermittent," says Nakken. "To have a stable supply, so you can deliver even when you don't have wind, storage is key. Hydrogen is one way of storing electrical energy."

The Utsira setup consists of two 600-kW wind turbines, an electrolyzer that uses excess energy to break water molecules into oxygen and hydrogen, a generator and fuel cell to reconvert the hydrogen into electrical energy, and a stabilizing system. Says Nakken, "You measure wind production and power demand. As long as the production is larger, we serve customers directly." That, he adds, is 80–90% of the time.

When wind energy production dips below demand, the system automatically draws on backups. That happens when the winds are too weak or too strong; to protect from mechanical damage, the turbines slow down for wind speeds greater than 25 m/s, and stop above 34 m/s. Fluctuations in wind energy production are smoothed over by tapping kinetic energy from a flywheel (see diagram). For gaps longer than a few minutes, energy is recovered from hydrogen. The system stores up to 12 m³ (at a pressure of 200 bar) of gaseous hydrogen, enough to supply power to participating Utsira residents for two or three days. If that were to fail, the mainland grid would serve as a backup.

Actually, only about half of the energy from one of the turbines is dedicated to the pilot test; the rest feeds directly into Norway's main electrical grid. The peak demand has been 50 kW, says Nakken. Half of one wind turbine gives 300 kW. That's oversized, he says, "because you want to minimize the hydrogen part for technical and financial reasons. Instead of a large storage capacity, you want to have a large turbine."

For the hydrogen conversion, the combustion engine is established technology based on the diesel engine. The Utsira experiment also has a 10-kW fuel cell. Says Nakken, "Without a doubt, the biggest unknown lies with the fuel cell. They are costly and their reliability for such applications is not proven. We decided we wanted a small fuel cell as a demonstration. It may be the choice of the future." The combustion engine, he adds, "is noisier and not that efficient. But at least you know it works—and the cost is not more than one-tenth of a fuel cell."

Bringing down costs "is vital" if the

wind-hydrogen system is to be scaled up, says Hammervold. John Olav Tande, a scientist at SINTEF Energy Research in Trondheim, Norway, says testing the combination is a good idea. "You can learn a lot, and assess the ability of industry to build such systems." But, he adds, "hydrogen is not necessarily the answer."

The autonomous wind-hydrogen system might be an answer for remote areas, says Nakken. Less than halfway through the two-year experiment, he adds, "we have already had inquiries from Siberia and the Azore Islands." The Utsira experiment dovetails with nonbinding goals of the European Union (Norway is not a member) to get 12% of energy from renewable sources by 2010 and 20% by 2020.

Utsira's roughly 250 residents "are excited," says Jostein Austrheim, the farmer who leases the land to the wind-energy project. "We don't know when the power comes from the grid, wind, or hydrogen. It's fantastic. Maybe [the experiment] will attract tourists."

Toni Feder

US High-Tech Economy Slipping

In the wake of the Bush administration's fiscal year 2006 budget proposal that left federal support for most basic research flat or declining, a coalition of industry, academic, and science groups has developed a broad set of benchmarks to persuade policymakers that US leadership in technological innovation is slipping.

The Task Force on the Future of

American Innovation, formed last year to cast in economic terms the political discussion of federal funding of basic research, released benchmarks in mid-February with the hope of influencing this year's science funding debate on Capitol Hill. "The object of this is to try to get policymakers in Congress to understand how the competitive world economy has changed," said Doug

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Comer, director of legal affairs and technology policy for Intel Corp, an industry member of the task force. "The US government is falling behind in its commitment to basic physical sciences research, which is a critical part of our competitive future."

Nils Hasselmo, president of the Association of American Universities, another task force member, said, "We have trend lines and they are disturbing as far as US leadership in research and innovation are concerned. We have downward trends in the participation of American citizens in science and technology while at the same time there is a dramatic increase in [S&T] competition from elsewhere. The handwriting is on the wall and in the statistics."

Although the president's basic research funding proposal was causing angst in the science community, Nobel physicist Burton Richter attributed science funding woes to both political parties. Speaking on behalf of the task force, Richter said, "What they [political leaders] are doing to the physical science budgets is bipartisan shortsightedness. It was no different under the Clinton administration than it is under the Bush administration, and we'll suffer for it in the long run because the rest of the world is accelerating their R&D while we seem to be decelerating ours."

The benchmarks include "signs of trouble" indicators for education, the US workforce, knowledge creation, R&D investment, and the high-tech economy. Several other benchmarks focus on specific high-tech research fields, including nanotechnology, information technology, energy, aerospace, and biotechnology. David Peyton, director of technology for the National Association of Manufacturers, called the benchmarks "the latest iteration of a process that's been going on for a number of years, but this is the most comprehensive set of numbers and we've tried to be careful to present the state of the world in a snapshot and in trend lines." They will be used, he said, to "work the hill" and to persuade policymakers in both Congress and the administration to provide stronger funding for basic science.

The benchmarks, created with data from a host of studies and reports, include the following findings:

Education

► Undergraduate science and engineering degrees are being awarded in the US at a lower rate than in other countries. The ratio of college undergraduate degrees in the natural sciences is only 5.7 per 100 college students in the US, while Finland, France,

Entrepreneur Launches Low-Cost Space Rockets

Elon Musk will be keeping his fingers crossed later this month when his latest venture, a low-cost rocket called *Falcon I*, launches from Vandenberg Air Force Base in California. Musk, a 33-year-old South African former internet entrepreneur who has a physics degree from the University of Pennsylvania, says that launch costs are a major reason why humanity has not yet successfully exploited space. "At the current rate, it will never happen," he says.

Musk created and bankrolled Space Exploration Technologies Corp (SpaceX) three years ago, after selling his stake in Paypal, the online payment system, to internet auction house eBay for hundreds of millions of dollars. With his first rocket, *Falcon I*, each launch costs \$5.9 million to put a 520-kg payload in low-Earth orbit. A bigger medium-lift rocket, *Falcon V*, is expected to put payloads in geosynchronous orbit for \$15.8 million, compared to \$60 million for Boeing's Delta medium-lift launch rocket.

The cost savings come from reducing the launch team from hundreds of people to 15–20, making the first stage reusable, building most of the rocket in-house, and deploying the latest technologies. Unlike current rockets, *Falcon V* is designed to be able to lose an engine and still deliver a payload to the correct orbit. SpaceX, based in El Segundo, California, already has signed customers such as the government of Malaysia and the US Department of Defense, and interest from the science community is growing. Researchers from the University of Washington, MIT, and the University of Queensland hope to launch the *Mars Gravity Biosatellite* on a *Falcon* in 2007. Musk has received dozens of inquiries from potential customers. "I would be happy if *Falcon I* achieved a four-to-six launch rate per year. It looks like we will probably do even more launches of *Falcon V*, once that gets going."

Paul Guinnessy



Falcon I could be the start of low-cost access to space.

Ireland, Spain, Sweden, and the UK award between 8 and 13 degrees per 100 students. In Asia, Japan awards 8 per 100, and Taiwan and South Korea each award about 11 per 100.

► The US has a smaller share of the worldwide total of science and engineering doctoral degrees awarded each year than either Asia or Europe. In 2000, about 89 000 of the 114 000 doctoral degrees given in science and engineering were earned outside the US.

Workforce

► From 1994 to 1998, the number of Chinese, South Korean, and Taiwanese students who chose to pursue PhDs in their own countries nearly doubled. By contrast, over that same period, the number of students from those countries pursuing PhDs at US universities dropped 19%, from 4982 to 4029.

► Since 1980, the number of science and engineering positions in the US has grown at almost five times the rate of the US civilian workforce as a whole.

Knowledge creation

► The US share of science and engineering papers worldwide declined

from 38% in 1988 to 31% in 2001. Europe and Asia are responsible for the bulk of the growth in scientific papers in recent years.

► From 1988 to 2001, the US increased its number of published science and engineering articles by only 13%, while Western Europe increased its article output by 59%, Japan by 67%, and East Asia by 492%. Though both Japan and East Asia started from a far smaller base in 1988 and still do not publish as many articles as the US, their dramatic growth rates are striking.

R&D investment

► From 1995 through 2001, China, South Korea, and Taiwan collectively increased their gross R&D investments by about 140%, while the US increased its by 34%.

► US federal funding of basic research in engineering and physical sciences has experienced little to no growth over the last 30 years. As a percentage of gross domestic product, funding for physical sciences has been in a 30-year decline.

High-technology economy

► From 1980 to 2001, the US share of worldwide high-tech exports fell from 31% to 18%. At the same time, the global share for China, South Korea, and other emerging Asian economies increased from 7% to 25%.

► During the 1990s, the US maintained a trade surplus for high-tech products even as the trade balance for other goods plummeted. But since 2001, even the trade balance for high-tech goods has fallen into deficit.

The benchmarks note that even in nanotechnology, a heavily supported US research priority, Japan and China may have already surpassed the US. While the US is "supplying 25% of the global federal funding for nanotechnology," the benchmarks say, "Japan makes certain that its national nanotechnology initiative meets or exceeds the funding levels approved in the US. The European community is doing the same."

In energy research, the benchmarks state that the US significantly scaled back its fusion-energy science program in the mid-1990s, "essentially ceding scientific dominance in fusion research to Europe and Japan." The US has fallen behind in traditional nuclear power as well. "Current expansion and growth prospects for

nuclear power are centered in Asia," the benchmarks say. "Twenty of the last 29 reactors to be connected to national grids are in the Far East and South Asia, and, of the 31 units under construction worldwide, 18 are located in India, Japan, South Korea, China, and Taiwan." In the US, no nuclear power plants have been ordered since 1978.

Peyton said the benchmarks will be updated annually to keep the connection between basic research and economic growth in front of policymakers. Intel's Comer said that clari-

fying that connection is critical. "The idea, of course, is to put more resources in the physical science research, but it goes beyond money," he said. "The whole problem in Congress is the leaders often say, 'We put all of this money into research and what good does it do?'"

The benchmarks, Comer said, "go to raising the level of consciousness and understanding on the part of members of Congress about the key connection between research and new ideas, new technology, new industries, and high-value jobs." **Jim Dawson**

US Students Retain Middle-of-the-Pack Status

Eighth graders in the US improved in both math and science, according to the recently released 2003 Trends in International Mathematics and Science Study (TIMSS) rankings, but US fourth graders scored virtually the same as they did in 1995 and lost ground to several other countries. The scores show that US students rank above the international average of nations participating in the testing, but are only in the middle of the rankings among what NSF describes as "those nations that are most advanced or . . .

that have taken part in TIMSS consistently since the study's first assessment in 1995."

Students from Singapore outperformed students from all other countries in both math and science at both grade levels. Different numbers of countries participated in different categories in the 2003 study, but overall more than 360 000 students from 46 countries were involved. The TIMSS testing was conducted by the International Association for the Evaluation of Educational Achievement and was

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