S marks the spot

According to one business school professor, wind and geothermal power are now a better investment than coal. By Associate Editor Jeffrey Winters

Has there ever been a time when more energy technologies were directly competing for research and development funding? Coal power has been the recipient of money to develop carbon capture and sequestration methods as well as other so-called clean coal technologies. The Department of Energy has allocated as much as $100 million dollars a year supporting the Generation IV nuclear reactor program, which promises new reactor technologies which may be available in coming decades. Biofuels startups are tapping millions in venture capital funds. And techniques for drawing power from wind, ocean, and solar energy have also seen an influx of R&D dollars.

It goes without saying that advocates feel that their own energy technology is the most worthy of additional funding. Statements to that effect wind up in business plans and PowerPoint presentations. But sales pitches aside, is there way to assess the relative merit of additional investment in, say, fossil fuels versus that in solar thermal power? One that can suggest which technology may be poised to make a big leap in cost-effectiveness?

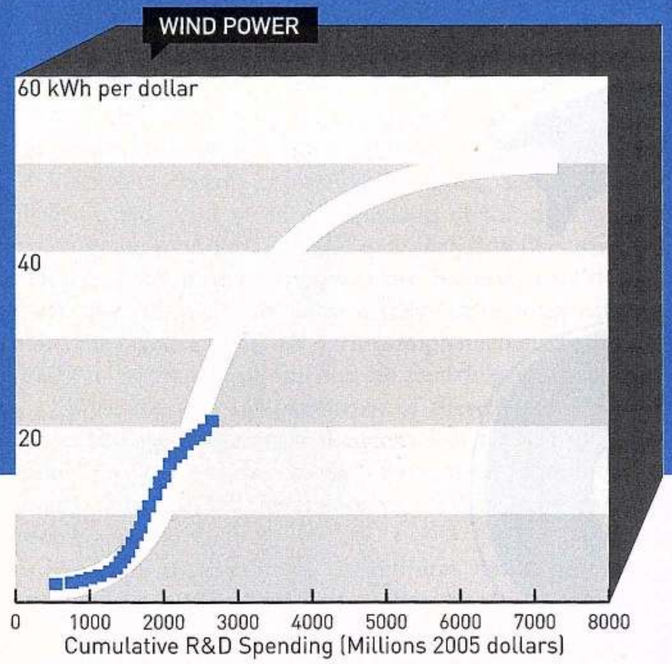
Melissa Schilling believes there is. Schilling, a professor at the Stern School of Business at New York University, recently analyzed electricity-production technologies using a method that's been applied to various high-tech industries. The results may be startling to some: According to Schilling, both wind and geothermal power are poised to become more economical than fossil fuel, needing just a relatively small infusion of additional capital.

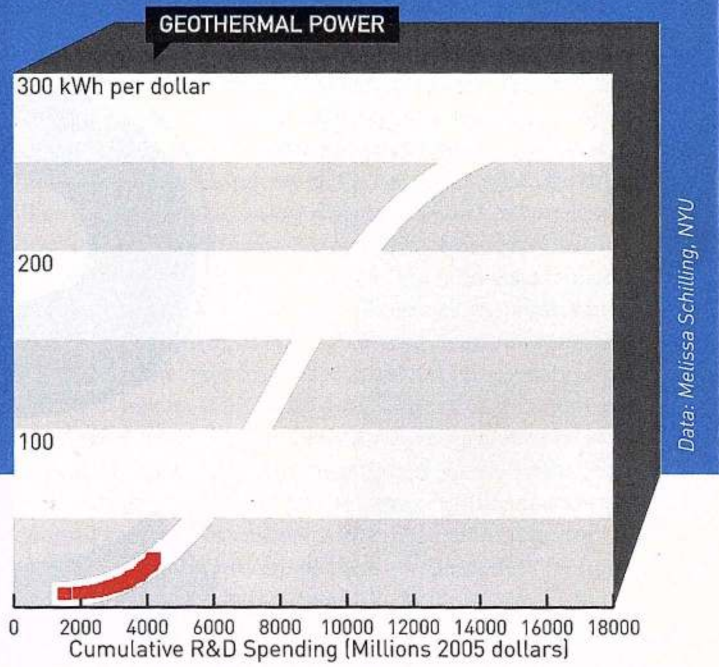
Perhaps more controversially, Schilling says her analysis also indicates that further investment in fossil fuel technologies looks to be money wasted.

Schilling's work is based on the widely held observation that the performance of a technology, when plotted against the cumulative research and development money directed toward it, follows a fairly predictable path. At first, the performance gain in the technology is negligible in spite of the R&D effort. Eventually, though, improvement in performance begins to accelerate, perhaps due to a better understanding of the technology or some unforeseen breakthrough. But after a period in which R&D yields great improvements, performance begins to level off as the technology reaches the limit of what it is capable of.

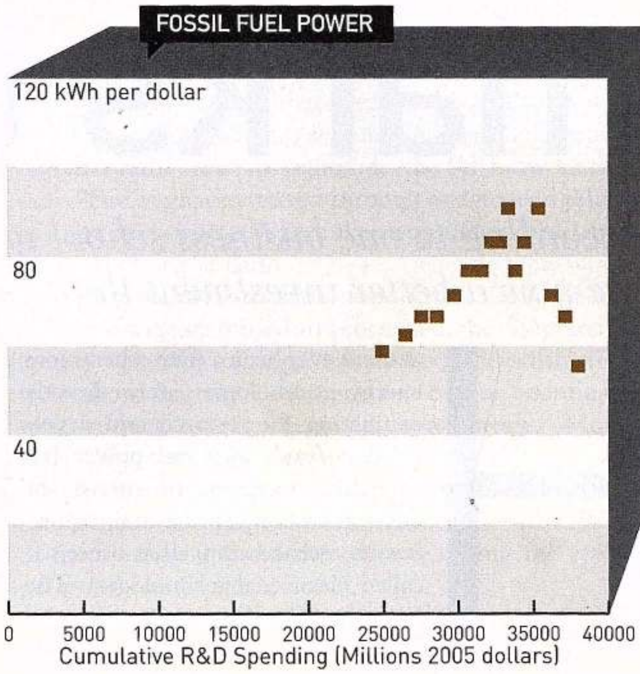
When the performance is plotted versus cumulative R&D funding, the resulting curve is S-shaped: flat at the beginning, steep in the middle and flat again at the top.

Technologies as diverse as steam engines, vacuum tubes,





The performance of many technologies follows an S-curve, when years of slow gains precede rapid improvements that eventually flatten out at a physical limit. Wind and geothermal power appear to be entering their most fruitful phase, while fossil fuel power looks to be stagnating.



and computer disk drives have followed this S-curve, Schilling says.

"When people teach innovation and strategy in economics, the S-curve is a given," Schilling said.

Firms can use this sort of analysis to determine which technologies to invest in. Mature technologies, which have had a burst of improvement but now are bumping against performance limits, are likely bad bets. On the other hand, brand new technologies can also be poor investments, since it won't be certain when the accumulated R&D effort will reach the point where great leaps in performance can be made.

U.S. Steel, Schilling said, looked at the relative technology performance trajectories when it shifted away from its traditional steel-making process to embrace the so-called mini-mills. "Initially the steel coming out of the mini-mills wouldn't meet the needs of the company's customers because it wasn't high enough," she said. "But it was clear that the performance would improve and the mini-mill steel would take over the mass market."

While such analysis has great power, it isn't foolproof. In the case of ferrite-oxide disk drives, Schilling says, IBM saw what it considered an impending performance limit and abandoned further research into it, instead focusing on a thin-film technology that the company felt had greater promise. The Japanese companies Hitachi and Fujitsu continued to invest in the older technology and were able to achieve a performance far better than what IBM thought was possible.

"So it's not set in stone," Schilling said, "but if you have S-curves that show really big differences in the trajectory of their performance, that's usually information that you can bank on."

Although electricity generating technologies are subject to different economic forces than, say, disk drives or semiconductors, Schilling says the S-curve model should apply to them as well.

Schilling's main research focus up to now has been in technology standards battles, like the one between Blu-Ray and HD-DVD video formats. But her original interest as an economist was in environmental economics. ("It's not a good area to publish in," she conceded.) So when the spike in energy prices in the mid-2000s led to renewed investment in alternative energy, she saw an opportunity to return to a topic she knew well.

"I realized it was something like a standards battle I've seen in other areas," Schilling said. "But instead of Windows versus the different types of Linux, it was fossil fuels against all these types of alternative energy technologies." With the alternatives competing against each other as well as against fossil fuels, the field was fragmented. "Would we be better off if we just had one?" she asked herself. And if so, which alternative?

Drawing on data from a number of sources, including the U.S. Department of Energy and the Electric Power Research Institute, Schilling compiled cost data for various renewable energy systems as well as for coal, natural gas, and petroleum-burning thermal plants. Cost makes a pretty good proxy for technological performance when comparing different energy technologies. The data told a familiar story: fossil fuel power was considerably cheaper than renewable, though the cost of solar, wind, and geothermal had come down markedly over the past 25 years.

Schilling then found data on the levels of research and development funding via the International Energy Agency. The most reliable data for national R&D investment was reported by Canada, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the U.S. That certainly isn't the entire world—notably absent from that list are China, France, and Germany. And the data cover only government investment, not that from private corporations. But it is, she says, suggestive of the focus of research over the past generation.

The IEA data show that since 1974 those nine governments have invested nearly $150 billion (in 2005 dollars) toward nuclear R&D. That dwarfs the almost $40 billion devoted toward fossil fuels, let alone the roughly $25 billion spent on all renewable energy technologies.

The next step was to figure out where on the S-curve of performance versus investment various renewable technologies lie. Due to hard limits of their applicability, Schilling excluded hydroelectric and biomass from her analysis. (Schilling also doesn't consider nuclear to be a renewable resource.) That left four technologies: Wind, geothermal, solar thermal, and photovoltaics.

The results for solar were not promising. Even after decades of R&D investment (though on a vastly smaller scale than what has been spent on nuclear or fossil fuels) both solar thermal and photovoltaics seem stuck on the lower tail of the S-curve.

"It was a surprise to realize that solar was improving so, so slowly," Schilling said. "If you were to plot the improvement over time, you might not realize that because a disproportionate amount of money has gone into solar over the last 40 years. That skews perceptions of what's going on in solar versus other technologies."

Wind was doing much better, Schilling found. With the cost of energy for wind power now around 5 cents per kilowatt hour and dropping fast, wind was climbing up the steep slope of the S-curve. Based on the performance data, Schilling projected that another $3 billion of R&D would get the costs of wind power to around 2 cents per kilowatt hour—within a penny of coal and cheaper than gas.

Geothermal had even more promise. Already, the cost of geothermal power was falling quite rapidly, according to U.S. DOE data. But when Schilling fit the performance versus investment data on an S-curve, the technology appeared just at the beginning of a long period of improvement.

"The numbers were so good it made me wonder why I hadn't heard more about geothermal," she said.

Indeed, if geothermal power follows Schilling's performance curve, investing $10 billion in the technology will lead to energy costs of less than half a penny per kilowatt hour. Even if that's not too cheap to meter, it is vastly better performance than any technology we have on hand.

The performance curve for fossil fuel technology was not as heartening. Indeed, it was impossible for Schilling to make a good fit of the data on an S-curve since the cost of fossil fuel energy had been getting more expensive toward the end of her data set, which cut out at 2005. This, Schilling suggests, may be because fossil fuel power technologies are at or near their technological limits. Any additional improvements would be marginal, rather than transformational.

Schilling's paper on these results, written with Melissa Esmundo, was published in the May 2009 issue of the journal *Energy Policy*.

Caveats abound, to be sure. Certainly the case could be made that nuclear ought to be added to the mix, though the size of its cumulative R&D budget compared to that of other technologies might make it hard to argue that it has been underfunded. And the sudden appearance of a breakthrough technology or the imposition of a new regulatory regime could reshuffle the deck.

That said, the analysis does point to where smart money should be invested.

"If you are technology manager at a firm and planning your new technology development portfolio, you want to find the right balance between intermediate-term and long-term projects that ensure that you can grow in the long run and eat in the short run," Schilling said.

In the near term, wind and geothermal power have the best potential for performance growth, according to Schilling's analysis, and make the best sense for additional R&D—at least from the government. (Private firms may be influenced by their existing infrastructure and the kinds of patents they hold.) Investment into biomass or solar, Schilling suggests, should be thought of as speculative.

"Someday both photovoltaics and solar thermal could turn out to be more efficient than geothermal or wind, but they are a long, long way away from that point," she said. ■