

one of several such strategies (including energy efficiency, carbon sequestration, and renewable energy resources), all of which deserve increased governmental support, this point was lost in the magazine's review, which appeared to present an either-or choice of fossil fuels or nuclear power.

The MIT study itself consciously sidesteps the most important question: Which strategies deserve the most governmental support based on their promise to minimize the total societal costs of energy? To answer that question, we urgently need more *comparative* studies of all greenhouse-gas reduction strategies that consider both the raw cost of power generation and so-called external costs (emissions, nuclear waste disposal, proliferation risks, and so forth). External costs are notoriously difficult to quantify, but comparative studies do exist.² The MIT study considers the effect of a "carbon tax" to quantify the external costs of CO₂ emissions from fossil fuels and proposes a fee for nuclear waste disposal. But it does not attempt to quantify the full external costs of these strategies or compare such costs

with those of other strategies.

The raw generation cost of leading renewable sources such as wind and solar energy dropped 80% from 1980 to 2002 and will continue to fall as economies of scale and new technologies take hold.³ The cost of wind power at the most favorable sites (\$0.05 per kilowatt hour) already makes it nearly competitive with fossil fuel sources on a raw-cost basis. Given that the external costs of wind power are probably much lower than those of fossil fuels and nuclear power, wind power should be getting much more support than it currently receives. Denmark generates 15% of its electricity from wind, compared with 0.3% for the US. What are we waiting for?

References

1. Massachusetts Institute of Technology, *The Future of Nuclear Power*, available at <http://www.mit.edu/afs/athena/org/n/nuclearpower>.
2. US Congress, Office of Technology Assessment, *Studies of the Environmental Costs of Electricity*, available at http://www.wws.princeton.edu/cgi-bin/byteserv.prl/~ota/ns20/alpha_f.html.
3. US National Renewable Energy Labo-

ratory, *Renewable Energy Cost Trends*, available at http://www.nrel.gov/analysis/docs/cost_curves_2002.ppt.

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Dawson replies: PHYSICS TODAY contacted Ernest Moniz, cochair of the MIT study, for a response.

Moniz comments: Both the Norbeck and Clark-Phelps letters contain some valid observations, but they fail to note additional key considerations.

Edwin Norbeck's assertion that the nuclear waste management problem "should be regarded as insignificant" underestimates both the technical and political challenges if considerable growth in nuclear deployment is to be realized. The MIT report states that "geological disposal is technically feasible but execution is yet to be demonstrated or certain." The issue of execution should not be minimized. Second, he emphasizes the economic value of actinides and fission products in the spent fuel but does not acknowledge either economic or proliferation concerns. Several countries today separate plutonium and uranium from irradiated fuel for recycling. However, this is not economically competitive, and an accumulation today of about 200 tonnes of separated plutonium is a clear proliferation risk (the International Atomic Energy Agency defines "significant quantity" as 8 kg). Further partitioning of commercial-reactor spent fuel to extract specific fission products is not currently performed, has been explored for some elements, and faces major economic hurdles.

Robert Clark-Phelps correctly asserts the importance of comparative studies of alternative greenhouse-gas reduction strategies. However, all carbon-free technology pathways are likely to be needed in a robust response to the daunting greenhouse-gas challenge, and comparative studies should be grounded in objective, in-depth multidisciplinary analyses of each pathway. Nuclear power, the starting point for the MIT group, is in many ways the most contentious, but all others face significant challenges at the terawatt scale. Wind, for example, has a substantial tax credit, and its deployment should continue to show strong growth, but many issues, such as intermittency, long-distance transmission, energy storage, and public ac-



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ceptance, must be resolved to enable truly large-scale deployment.

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Data Volume Is Fourth Frontier in Astrophysical Observation

Martin Harwit's article "The Growth of Astrophysical Understanding" (PHYSICS TODAY, November 2003, page 38) was enjoyable and insightful. The author names three frontiers in observation: angular resolution, timing, and spectrometry. I propose a fourth: expanding data volumes. This frontier has progressed steadily, from paper-and-pencil catalogs, to photographic plates, to large-format CCDs and robotic survey telescopes.

Each advancement brings new discoveries. Some examples: Tycho Brahe's measurements of the planets were precise, but also voluminous; he had 85 data points on Mercury's orbit, for example—a great advancement on the state of the art. The volume, as much as the precision, made Johannes Kepler's analyses possible. John Goodricke discovered one variable star in 1784, but Henrietta Leavitt, working with thousands of stars on photographic plates, discovered the Cepheid period–luminosity relation. Today, in one of many superb examples, a huge observing project called the Sloan Digital Sky Survey is making precision measurements of large-scale structures. The project's resolution and spectroscopy are up to date, but its multiterabyte data set is really new and exciting.

Bigger and bigger surveys are absolutely necessary for advancing our knowledge of astrophysics. They provide the opportunity to discover extremely rare phenomena and to find surprising statistical properties of known ones.

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Harwit replies: Benjamin Monreal is quite right. Expanding data volumes have had an enormous impact on astronomical discovery. Although my article could not include it, my book *Cosmic Discovery* (Basic Books, 1981) provides a plot of the eight orders of magnitude improve-

ment over the naked eye, in sensitivity and data gathering rates, made possible by 1980 through increased telescope apertures, more sensitive photo-response, and increasingly large numbers of spatial resolution elements on photographic plates and photoelectric arrays. The recent discovery, by the DENIS and 2MASS all-sky surveys, of a few dozen extremely low-mass brown dwarfs among hundreds of millions of more ordinary stars, shows the added value of machine data processing.

Martin Harwit

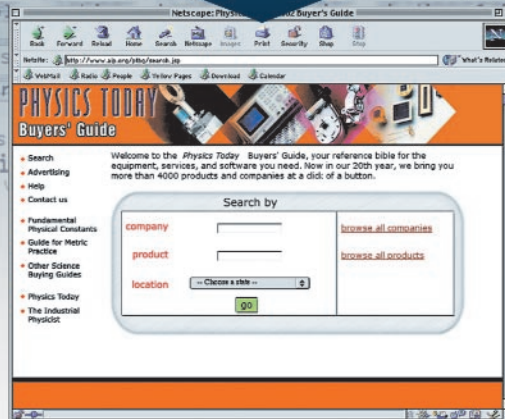
Washington, DC

Tevatron's Complex Collider Cousins

According to Bertram Schwarzschild's story "Disappointing Collider Performance and Tight Budgets Confront Fermilab With Tough Decisions" (PHYSICS TODAY, November 2003, page 22), "The Tevatron collider is, by far, the most complex accelerator ever to reach the operation stage." This is not so—other accelerators of comparable complexity exist, if complexity is measured by the technologies used, the numerical

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