detritus. They can cause significant decline in zooplankton abundance (*8*). (iii) They grow fast and reproduce quickly (*9*). (iv) Because all fishes forage on planktonic organisms during their early life-history stages, bighead and silver carp have the potential to compete for food with every species of fish, and some native fishes are filter-feeders as adults.

Thus, the possible impacts of introduced bighead and silver carp on local fish communities urgently need to be assessed, especially in those waters (e.g., the Mississippi River) where the carp have successfully established reproducing populations.

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4. Lake Xingyun is located in the Yunnan-Guiyang Plateau, surface area 39 km^2, mean depth 9 m, 1723 m above sea level, N24°17′ to 24°23′, E102°45′ to 102°48′.
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9. In the Yangtze River, the weight of a 3-year-old fish reaches 3.6 kg for silver carp and 7.4 kg for bighead, the maximum size of bighead is 35 to 40 kg, and the mean egg number per adult female is 1.07×10^6 for silver carp and 2.0×10^6 for bighead carp (*3*).
10. This research was supported by the State Key Basic Research and Development Plan (G2000046800) and a key project of the Chinese Academy of Sciences (KZCX2-403). J. K. Liu, Y. F. Shen, and W. X. Cao gave useful suggestions on the draft of the letter.

The Real Cost of Wind Energy

THE COST OF ELECTRICITY FROM WIND IS about 4 ¢ per kilowatt-hour (kWh) according to M. Z. Jacobson and G. M. Masters' estimate in their Policy Forum "Exploiting wind versus coal" (*Science*'s Compass, 24 Aug., p. 1438), making wind energy competitive with new coal-fired generation. There is a 1.5-¢/kWh federal credit for wind energy producers, and, in addition, consumers are willing to pay a premium for wind. Given this credit, and a conservative 0.5-¢/kWh green power premium (*1*), one might expect wind producers to break even at ~6 ¢/kWh. If their costs are 4 ¢/kWh, producers should make large profits and wind should dominate new electric capacity. No such boom is observed; wind generates only 0.1% of U.S. electricity and accounts for only 1% of capacity additions in the last 5 years (*2*). Two factors—transmission and intermittency—raise the real cost of wind and explain the discrepancy between simple estimates of cost and observed installation of capacity.

Jacobson and Masters propose replacing ~60% of coal capacity with wind farms in North Dakota that have an average power of ~130 GW. At this scale, wind is a significant fraction of capacity, and its intermittency must be addressed. To derive a conservative estimate for the cost of backup generation under suboptimal wind conditions, suppose that 130 GW of gas turbine capacity is installed.

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Wind power generated beyond the mean output can be sold, roughly compensating for fuel costs when backup generation is used. The amortized cost of the gas capacity is ~1 ¢/kWh. In addition, Jacobson and Masters dismiss transmission costs, suggesting that they "can be offset with turbine mass production." We are unconvinced. The best sites for wind farms are in the Great Plains, far from demand centers concentrated on the coasts, so transmission costs must be included if wind is to supply a significant fraction of national demand. Using modern HVDC (high-voltage direct current) technology, transmission costs are ~1.5 ¢/kWh for 2000-km lines (*3*). Therefore, combining the cost of backup and transmission adds 2 to 3 ¢/kWh to the cost of wind, partially explaining the discrepancy between simple cost estimates and observed behavior.

We believe that the challenges posed by remoteness and intermittency are surmountable, but it is an exaggeration to say that wind is now competitive with coal.

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1. See U.S. Department of Energy, "Green certificate marketers," *Green Power Network* (updated 18 Oct. 2001) (http://www.eren.doe.gov/greenpower/ mkt_gcert.html)
2. Energy Information Administration, "Annual energy review" (modified Oct. 2001) (http://www.eia.doe.gov/ emeu/aer/contents.html)
3. Calculation based on *HVDC Power Transmission Technology Assessment Report ORNL/Sub/95-SR893/1* (Oak Ridge National Laboratory, Oak Ridge, TN, April 1997).

Response

WE DISAGREE WITH DECAROLIS AND KEITH'S key points and believe that our conclusions still stand. First, DeCarolis and Keith speculate about the intermittency cost of wind (the cost of regulation ancillary service), but there is no need to speculate, because a study on this issue has been done. It showed that such costs are about 0.005 to 0.03 ¢/kWh, which is less than 1% of the price of wind energy, and the cost can be reduced further by using an hour-by-hour persistence forecast (*1*). In addition, the more turbines at a given wind farm and the more wind farms there are, the more intermittency of individual turbines cancel each other out (for example, lower supply from one farm can be made up by greater supply from another) (*2*).

As for the issue of transmission of wind-generated electricity, the National Renewable Energy Laboratory estimates that 175,000 MW of potential wind power are within 5 miles (8 km) of existing 230-kV or lower transmission lines, 284,000 MW within 10 miles (16 km), and 401,000 MW within 20 miles (32 km) (*3*). Sites close to transmission lines would be developed first. If North Dakota or other remote locations are fully developed, the cost of above-ground AC transmission lines range from \$120,000 to \$840,000 per mile (~\$75,000 to \$520,000 per km) (*4*). Assuming an average cost of \$310,000 per km (\$500,000 per mile), the cost of 10,000 km of new lines is \$3.1 billion, less than 1% of the cost of 225,000 new turbines. Over distances greater than 500 km, HVDC lines are less expensive and lose less energy than AC lines (*5*). The transmission cost of 1.5 ¢/kWh that DeCarolis and Keith mention is not supported by the actual cost of transmission lines, nor would it be applicable over the many decades that transmission lines would be used.

The authors also use wind cost statistics from past experience, which are not applicable to current turbine technology. Turbines in the past have had relatively high ratios of rated power (P) to diameter squared (D^2). The turbine used in our example (P = 1500 kW, D = 77 m) has a low ratio, giving it a greater capacity factor than a turbine of the same power but lower diameter (*6*). Plus, newer turbines are taller than older turbines, and wind speeds increase with increasing height. As such, one cannot use old statistics to argue against new technology.

Contrary to the authors' statement that no wind boom has been observed, wind energy today has the fastest growth rate of any new source of electricity in the world. Because the base amount of wind energy is so small, it will take awhile, even at fast growth rates, for wind to gain a large market share. DeCarolis and Keith also mention wind subsidies, but what about current and historic coal and natural gas subsidies, including exploration and mining tax credits, preferential loan interest rates for fossil-fuel power plants, long-term utility contract subsidies to coal, gas pipeline subsidies, and greater federal funding of coal- and natural gas-technology programs, not to mention portions of the cost of the U.S. Acid Deposition Program and U.S. Environmental Protection

Agency for cleanup and monitoring of pollution attributable to these industries? In addition, we should not ignore the costs from coal and natural gas's exacerbation of acid deposition, urban smog, human health and mortality, visibility degradation, and global warming.

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3. M. Shaheen, *Wind Energy Issue Brief* **9a** (October 1997) (http://www.nationalwind.org/pubs/wes/ibrief09a.htm).
4. J. Makens, *Upgrading Transmission Capacity for Wholesale Electric Power Trade* [modified 17 May 2001], table FE2 (http://www.eia.doe.gov/cneaf/pubs_html/feat_trans_capacity/table2.html).
5. Greenhouse Gas Technology Information Exchange (GREENTIE), "High Voltage Direct-Current Transmission" (modified March 2001) (http://www.greentie.org/class/ixd04.htm).
6. The capacity factor equation has been verified independently to within 2.8 to 3.5% of our calculation by Enron Wind, a wind power company. They determined the annual energy yield of their 1500-kW, 77-m turbine (the one used in our example) as a function of mean Rayleigh wind speed {Enron Wind, "1.5 [wind turbine] Technical Data," figure 2 (cited September 2001) (http://www.wind.enron.com/PRODUCTS/15/15data.html)}. The comparative numbers in units of kWh/year (divide these numbers by 8760*P* to obtain the capacity factor) are as follows:

Mean Rayleigh wind speed	7 m/s	7.5 m/s
Our calculation $E = 8760P(0.087V/P/D^2)$	4.68×10^6	5.26×10^6
Enron's data	4.55×10^6	5.08×10^6

[V is the mean annual Rayleigh-distribution wind speed (m/second), P is the rated power (kW) of the turbine, and D is the diameter of the turbine (m).]

CORRECTIONS AND CLARIFICATIONS

News of the Week: "Vesuvius: a threat subsiding?" by A. Hellemans (19 Oct., p. 495). Because of an editing error, the name of the institute at which Riccardo Lanari and his colleagues work was incorrect. It should have been given as the Institute of Electromagnetic Sensing of the Environment of the CNR (IREA-CNR).

News Focus: "Science awards pack a full house of winners" (19 Oct., p. 502). Eric Cornell, one of three co-winners of the 2001 Nobel Prize in physics, is not primarily employed by the University of Colorado, as was indicated in the section "Laurels for a new type of matter." While it is true that Cornell holds an adjoint professorship with this university, his primary employer is the National Institute of Standards and Technology, where he is a senior scientist.

Reports: "Room-temperature ferromagnetism in transparent transition metal-doped titanium dioxide" by Y. Matsumoto *et al.* (2 Feb. 2001, p. 854). The publication year was incorrect in References 2 and 3. The correct year for Ref. 2 is 1988; the correct year for Ref. 3 is 1999. In Ref. 6, the page number was erroneously given. The correct page number is 3860, not 25.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letter2science.org), or regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.