City of the future

When windmills are used to generate power, they extract power from the wind. I assume this means that the wind has lost some energy. This suggests that if there were enough windmills, then the wind could cease to exist, which would create weather havoc around the world. At what point would there be too many windmills?

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[*Author replies*: Not being an expert on extracting energy from the wind, I brought your question to one of my colleagues at the Electric Power Research Institute, Chuck McGowin, who runs our wind program. Here is his answer:

The maximum theoretical fraction of the power in the wind that can be extracted (called the Betz limit) is about 59%, based on an energy balance between the air stream flowing in front of, and behind, the rotor. In practice, the collection efficiency is usually 30–45%. To significantly affect the local wind flow at ground level, it would be necessary to cover the entire area exposed to the wind from ground level to an elevation of, say, 200 m with spinning turbine rotors, which is, of course, impractical. In fact, wind turbines are purposely designed with rotors elevated above the ground, and the typical wind turbine site layout is designed to minimize the energy losses resulting from wake turbulence created by upwind turbines affecting the efficiency of downwind turbines. For that reason, the wind turbines are deliberately separated by at least 1.5 to 8 rotor diameters.

The energy extracted by wind turbines from the wind is thus a negligible fraction of the available energy.

These and other interesting wind energy topics are addressed by the Guided Tour at the Danish Wind Energy Association site at www.windpower.dk.

Paul Grant]

In your recent article "Energy for the City of the Future" (*The Industrial Physicist*, February/March 2002, pp. 22–25), the efficiency factor for hydrolysis is quoted as 80%. What about the energy needed to produce electricity for the hydrolysis and to transport liquid hydrogen through the network? What would the resultant efficiency rating look like after taking account of these factors? How does it compare with fossil fuel energy efficiency?

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[*Author replies*: A quantitative answer depends on various end-user choices, societal and policy pressures, and, of course, economics. Some advocates of the hydrogen economy believe that central generation, transmission, and distribution of electricity will no longer be required—that we should generate and distribute hydrogen and make whatever electricity is needed via fuel cells at the end point. On the other side, the "electricians" maintain that the stability, reliability, and universality of

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centrally generated electricity will always be needed. In fact, history tells us that the dual generation and delivery of potential (chemical) and kinetic (electric) energy together are essential, as witnessed by the cohabitation of the gas and electricity industries for the past 60 years.

The principal argument for hydrogen is to mitigate carbon emissions from coal, methane, and gasoline in the face of the enormous cost of adapting to global warming. However, hydrogen must be manufactured by either electrolysis or thermal "cracking" of water, both, preferably, using nuclear power. My preference is electrolysis because of its higher efficiency and use of a single modular reactor-generator design that easily can be switched between making hydrogen and grid-delivered electricity.

According to estimates I've seen from a hydrogen industry association, at an electricity cost of \$0.025/kW•h, liquid hydrogen produced by the electrolysis of water would run \$1.80/gal, compared with \$0.60/gal for diesel fuel out of the refinery. Keep in mind that the future cost of fossil fuel has nowhere to go but up as reserves fall, and way up if Kyoto-type protocols are imposed. Extrapolating all transport losses from a previous study we did for a liquid-nitrogen-cooled dc cable transporting 5 GWe with a cryogen flow of 8 L/s (the liquid-hydrogen power equivalent of 60 MW), gives a loss of 3 MW/1,000 km—about twice that suffered if the same amount of power were transported by a high-voltage dc transmission line.

Paul Grant]

Thanks for a clear article on energy policy for the future. However, if nuclear energy is so safe, why is the nuclear power system hiding behind the Price–Anderson Act, which essentially waives its liability to damages caused by accidents? Until this is eliminated, I know these plants are not really safe or economically competitive.

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[*Author replies*: The Price–Anderson Act covers many liabilities and issues in applied nuclear technology, of which the nuclear power industry is only one component. With due respect to Mr. Rubin's comments, Price–Anderson does not "waive" that industry's liability for nuclear plant accidents. In fact, it guarantees it. The act provides a self-funding insurance framework totaling more than $9 billion. The companies pool resources to cover liability incurred by any one of them. Each nuclear power company pays premiums to either the American Nuclear Insurers or the Mutual Atomic Energy Reinsurance Pool, must meet rigorous standards of safety in operation and design, and must undergo periodic review to qualify as a policy holder. I believe that such qualification is also required by the Nuclear Regulatory Commission for both initial and continued plant licensing and relicensing. Since the inception of Price–Anderson in 1957, as far as I know, no public funds have been expended to reimburse commercial nuclear plant liability claims, including those arising from the incident at Three Mile Island, all costs having been paid by the insurers and the utilities.

In the event of a serious accident, Price–Anderson affords the individual nuclear utility some protection from a concerted "tort attack" that might drive it into bankruptcy by spreading the liability throughout the entire industry. All claims must be presented to one of the nuclear insurers, a one-stop shop for claimants, if you will.

The Price–Anderson Act has been renewed three times since 1957 and, in March of this year, the Senate approved its next renewal by an overwhelming majority. The House is expected to follow suit this summer. In fact, since the events of September 11, 2001, Price–Anderson is now beginning to be considered by many legislators as a model for other industries—such as the airlines—that encounter rare events with considerable public consequences.

Although I am not a lawyer, my opinion is that there's nothing wrong with the section of the act related to nuclear power utilities.

Paul Grant]

Lunar solar power

[The article "Solar Power via the Moon" (*The Industrial Physicist*, April/May 2002, p. 12–15) received widespread attention in the media, including ABCNews.com, United Press International, National Geographic Online, *The Ottawa Citizen*, *Die Welt* (Germany), *Repubblica* and *Macchina del Tempo* (Italy), *Business A.M.* (Scotland), *The Straits Times* (Singapore), German Sat.1 TV, BBC-Scotland, ScienceDaily.com, Spaceflightnow.com, Slashdot.org, Green nature.com, Edie.net, Spacedaily.com, AviationNow.com, Astronomer.com, Cos miverse.com, and National Science Teachers Association online—*Ed*.]

"Solar Power via the Moon" (*The Industrial Physicist*, April/May 2002, pp. 12–15) describes another option of power from space systems that are envisaged to come into reality in this century. Central to these schemes is microwave power transmission from space to Earth. Criswell chooses the 2.45-GHz industrial, scientific, and medical (ISM) band as optimum and then assumes that wireless communications systems that operate at this frequency or its harmonics will vacate these bands and relocate to other frequencies. Before this happens, however, there must be a momentous shift in political power from wireless industries to a fledgling energy industry. The scenario of radio-frequency interference (RFI) between wireless and ISM will be played out between owners of more than 300 million microwave ovens in the world and the expanding wireless systems.

Although a prime technical problem is that of RFI, public acceptance of ambient microwaves will require a diminution of the electrophobia that has hindered the deployment of microwave technology, as in the current controversy over cell phones.

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[*Author replies*: Global prosperity requires a new source of clean and lower-cost commercial electric power. The annual net revenue from 20 TW of electrical power, sold at $0.01/kW•h, would be about $1,500 billion per year, which far exceeds the net revenues of the global wireless industry. Gross world product could increase by a factor of 10 or more with this electrical input.

The electromagnetic spectrum is a common benefit of the terrestrial biosphere. In principle, the spectrum is open to reallocation for the greatest good of humanity. In practice, each nation has control over the use of the electromagnetic fields above its boundaries. Poor nations are free to place a higher premium on access to clean, abundant, and low-cost power than on retention of existing spectrum allocations.

Some groups, especially in the rich nations, express fears of microwaves, magnetic fields of power lines, and emissions of cell phones. The controversy over cell phones and power lines is abating in the United States. Lawsuits over power lines have been unsuccessful. Solar power from space or the moon would be delivered to industrially zoned rectennas from which the general public is excluded. Stray power could be far below the Institute of Electrical and Electronic Engineers' standards for continuous exposure of the general population.

The Lunar Solar Power (LSP) System can be implemented at 2.45 GHz, 5.8 GHz, or other frequencies. Beams at 2.45 GHz suffer less attenuation in passing through the moisture of the atmosphere. Beams operated at other frequencies may require more costly combinations of more rectennas, long-distance power transmission, power storage, and power conditioning.

David Criswell]

In transporting any kind of power from the moon to Earth, efficiency is the problem. Propagation loss is proportional to the squared inverse of distance and to wavelength. At 12 cm, the propagation loss for the 384,000-km path from the moon to Earth will be ~ 212 dB, or 1.6×10^{21}. Thus, you would recover one part in 10^{21} on the surface of Earth. Some advantage would be gained by using geostationary satellites. They are about 10 times closer than the moon, but you gain only ~ 20 dB, or 100 times more. This amount of energy is worthless, a fact that ought to end all similar microwave power transmission dreams.

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[*Author replies*: Mr. Polivka provides a unique interpretation of the concept of wireless power transmission (WPT). His calculation assumes that all the power is radiated from one small aperture located at the distance of the moon from the Earth. The radiating power expands spherically over the moon–Earth distance and is of negligible intensity at Earth. Neither his model nor his calculation has any relation to WPT or to the LSP System described in the April/May issue of TIP.

WPT systems are not exotic. They are essentially specialized forms of radar. In the simplest radar system, the microwave source