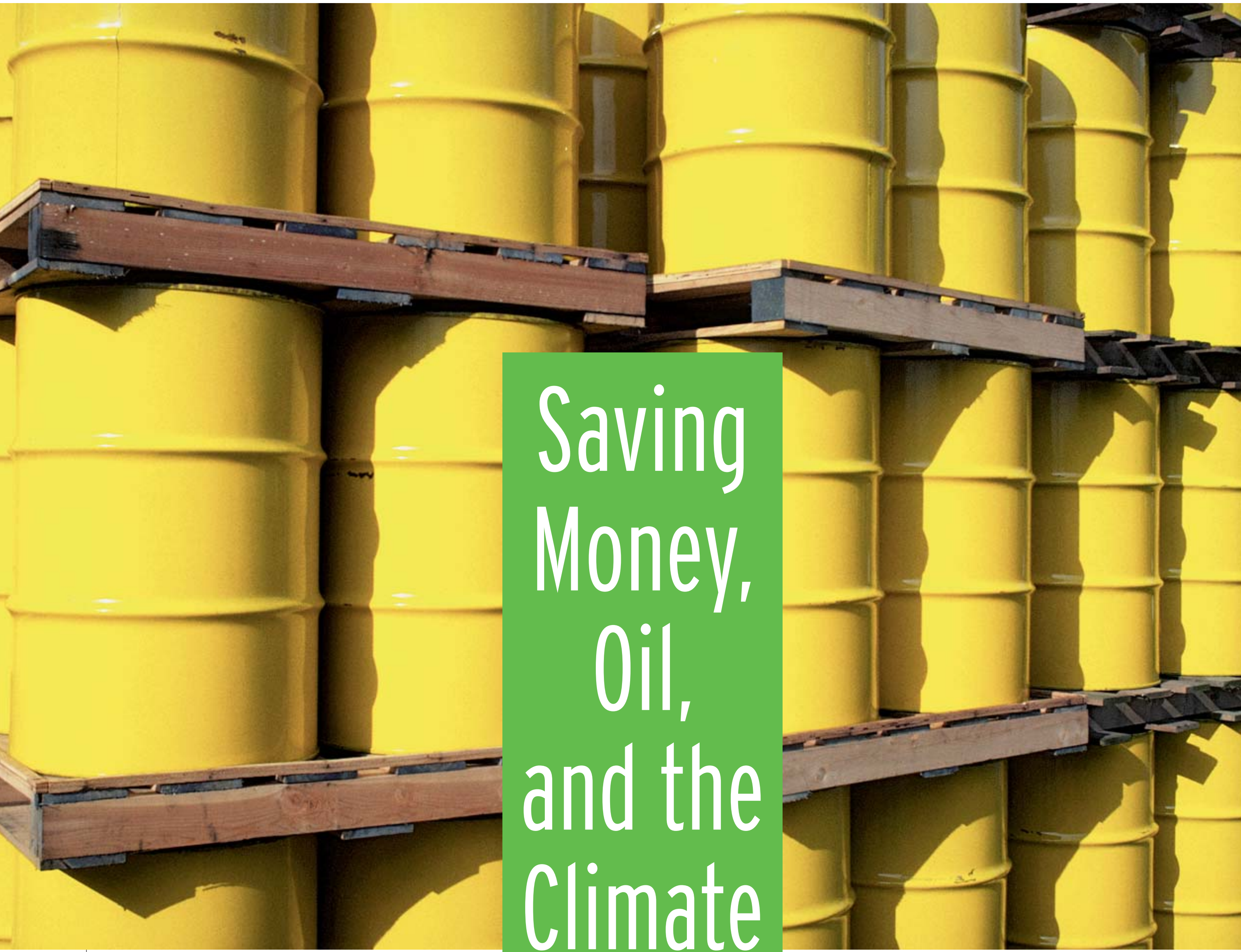

Saving Money, Oil, and the Climate

Using non-fossil energy sources to power our vehicles

by MICHAEL B. McELROY

THE UNITED STATES is in urgent need of a comprehensive, rational, and—above all—honest policy to guide its energy future, a policy that addresses two key, interrelated objectives: reducing dependence on vulnerable sources of imported oil and reducing emissions of the critical greenhouse gas, carbon dioxide (CO_2). Failure to address the first objective would imply that we are willing to accept possibly serious risks to our national security. Failure to tackle the second would confirm the increasingly prevalent international view of the United States as an irresponsible environmental citizen.

I shall argue that by changing the way we fuel our cars and light trucks—by switching from continued reliance on hundred-year-old, internal-combustion-engine technology to a combination of oil and electrically powered transportation—we could reduce our dependence on imported oil *and* lower our emissions of CO_2, and we could effect this transition at a net *savings* for the U.S. consumer. The key is to build on the success of the hybrid technology introduced by Japanese auto manufacturers (notably Toyota and Honda) in the 1990s.

The United States imported 12.4 million barrels of oil per day in 2006, a slight decrease from 12.5 million barrels per day in 2005 (reflecting reduced demand attributable to a warmer winter and a cooler summer in 2006). Imports in both years accounted for 60 percent of domestic consumption. At an average price of $66.05 per barrel, the bill for imported oil in 2006 totaled $299 billion—39 percent of the nation's trade deficit. With oil prices in early January 2008 climbing above $100 per barrel, the debt for the coming year could well exceed $450 billion (more than 3 percent of the nation's gross domestic product, potentially more than 50 percent of its international trade deficit, assuming values for 2006, the last full year for which these data were available at the time this article was written).

Combustion of oil in 2006 accounted for 44 percent of U.S.

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emissions of CO_2 (2.6 billion tons of CO_2, from a total of 5.9 billion tons), with 33 percent of the total (2.0 billion tons) attributed to transportation (cars, trucks, trains, ships, and aircraft). Gasoline-powered cars and light trucks were responsible for 40 percent of total oil consumption (18 percent of CO_2 emissions), with diesel-powered vehicles responsible for another 10 percent.

The fuel economy of American cars and light trucks averaged 12.4 miles per gallon in 1960. The oil crises of the 1970s triggered an increased demand for fuel-efficient vehicles, a pattern that continued through the 1980s, with fuel efficiency per vehicle rising from 12.2 miles per gallon in 1975 to 16.9 miles per gallon in 1991. But there has been little improvement since then, a trend reflecting the increased popularity of gas-guzzling pickup trucks and heavy-duty sport utility vehicles (SUVs). Our goal should be to raise the fuel efficiency of our cars and light trucks to an entirely new standard: 100 to 150 miles per gallon is not only feasible but could be accomplished in 20 years or less, limited by the time required for cost-effective turnover of the existing transportation fleet. Compare this with the target defined in the recently enacted United States Energy Independence and Security Act of 2007 (H.R. 6): 35 miles per gallon by 2020.

The Electric Option

Hybrid electric vehicles (HEVs) incorporate a conventional internal-combustion engine working in concert with an electric motor supplied with energy from a nickel-metal-hydride (NiMH) storage battery. The battery is charged "on board" the vehicle as required, using an electric generator run by the engine. The overall energy efficiency is increased by capturing a portion of the energy that would normally be dissipated as heat upon braking the car, employing it to run the generator. When the car halts in stop-and-go city driving, the engine turns off, conserving fuel. When it is time to restart, the electric motor provides the necessary power. The savings in fuel (and CO_2 emissions) that could be realized if the entire U.S. automotive fleet were converted to HEVs could amount to as much as 30 percent of current gasoline consumption, with the additional benefit of improved air quality.

Even greater savings could be realized if HEVs were replaced by so-called plug-in hybrids. With current HEVs, the energy used to propel the vehicles is provided exclusively by their onboard fuel (either gasoline or, potentially in the future, by increased use of more efficient diesel). With plug-in hybrids, a

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Running on Wind?

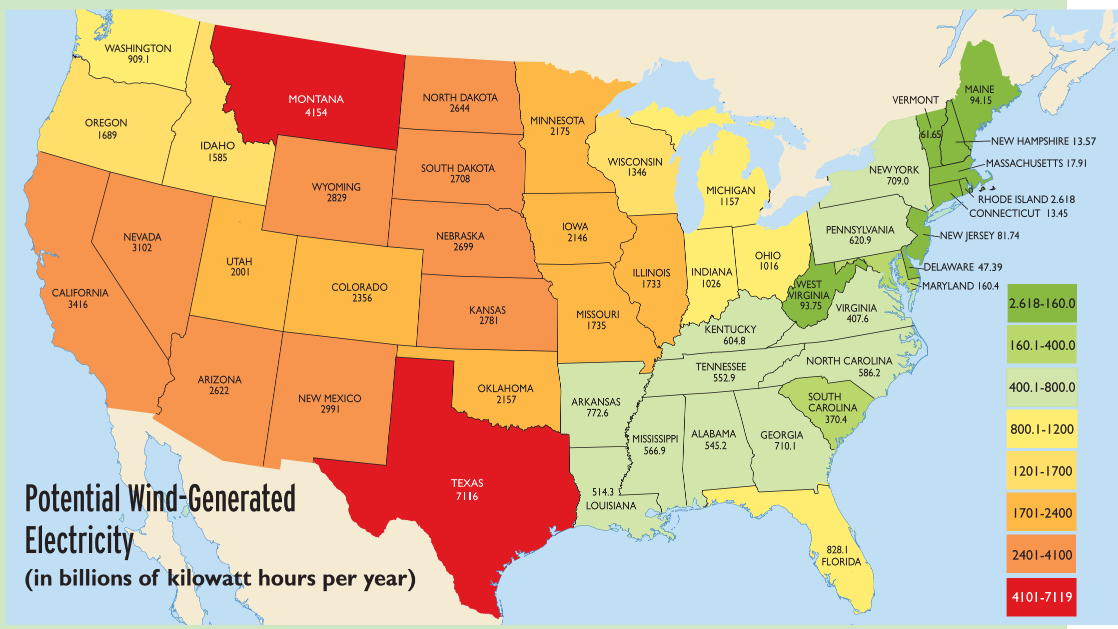
Michael B. McElroy's research group has launched an extensive program to define the potential of wind power as a source of electricity worldwide. The study capitalizes on a unique meteorology database developed by the Global Modeling and Assimilation Office at NASA's Goddard Space Flight Center. Validated by hundreds of regional and global air-quality studies, this data resource refines understanding of meteorologically dependent new energy sources, notably wind and solar, and can powerfully inform national and international strategies for their exploitation.

The database provides a record of wind activity every three hours averaged over a spatial grid with individual grid elements measuring 1-degree longitude by 1-degree latitude (equivalent to the area defined by a 100-kilometer by 100-kilometer square at mid latitudes, less at high latitudes, more at low latitudes) covering the entire globe. The McElroy group uses these data to calculate the electricity that could be generated by deploying specific wind turbines. Samples of preliminary results for the United States appear in the accompanying figures. They show, for example, that even for such populous, high-consumption states as California, Texas, and Florida, the potential for electricity generated by wind far exceeds total current consumption.

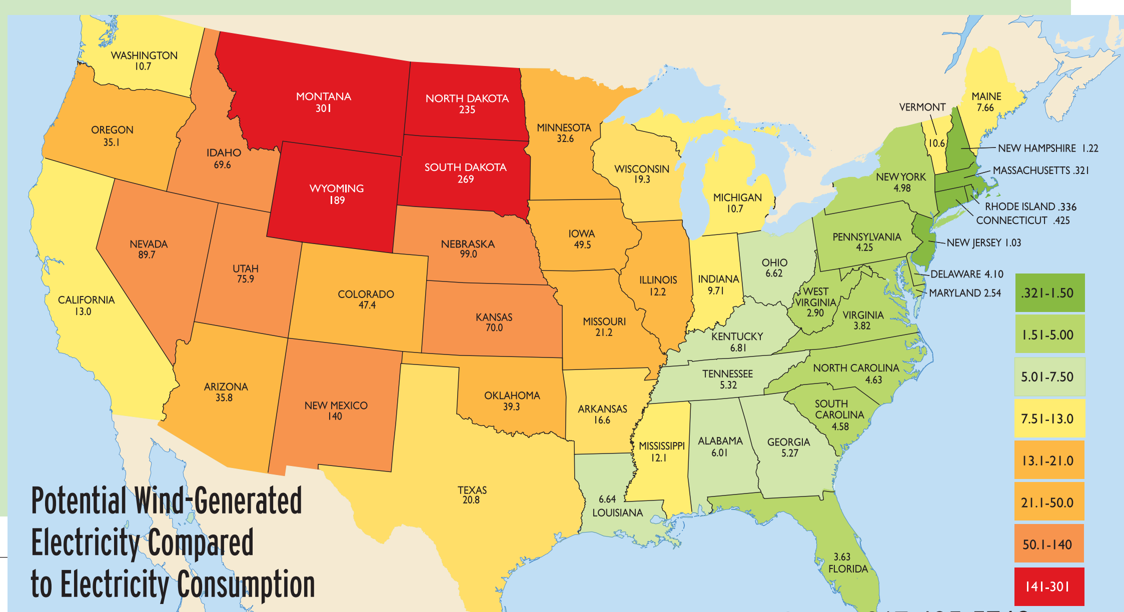
The results displayed assume deployment of 1.5-megawatt turbines throughout the entire country, excluding unsuitable regions such as urban and forested areas. The study identifies the variability of the wind source, which allows researchers to explore how it could be exploited in an integrated electrical system that must match variable supply to demand. It is worth noting in this context that the batteries on an expanded fleet of plug-in hybrid vehicles could provide an important opportunity for storage of electricity at times when the potential production might exceed the immediate demand. Future work will incorporate realistic economic constraints, such as: costs for installing turbines in specific regions and for extending the electrical grid to distribute the added power; electricity prices; and different turbine designs. The studies could also take into account the effects of future global climate change.

The data presented define the potential or *maximum* power that could be generated using wind. Although these results are restricted to onshore deployment in the United States, the study identifies the potential for wind power offshore as well, and for the globe as a whole. The potential U.S. supply could be increased by about 20 percent if turbines were installed offshore within viable distances from the coast and sea depths, notably in the Northeast and on the West Coast. To date, it has proven difficult to site wind farms in densely populated coastal regions such as Nantucket Sound. There is minimal opposition, however, to placing turbines in more sparsely populated regions of the continental interior, where landowners are now receiving annual rents of up to $3,000 for the installation of a single turbine on their property (siting that has minimal impact on other uses of the real estate).

The accompanying figures were prepared by graduate student Xi Lu, using 2001 as a representative model year.



Potential Wind-Generated Electricity
(in billions of kilowatt hours per year)



Potential Wind-Generated Electricity Compared to Electricity Consumption

major portion of the electrical energy consumed by the vehicles could be derived from the local electricity grid. Depending on the energy source used to generate that power, the savings in terms of CO_2 emissions could be even more significant.

The Electric Power Research Institute (EPRI) reported in 2001 a study of the potential environmental advantages of plug-in hybrids. That study examined four cases: a conventional vehicle (CV); a standard HEV without plug-in capability (HEV 0); a plug-in vehicle with sufficient battery capacity to provide for an all-electric range of 20 miles (HEV 20); and a plug-in option with an all-electric range of 60 miles (HEV 60). Performance characteristics were taken as comparable for all four vehicles: gasoline storage on-board sufficient to provide for a range between refueling of 350 miles; a minimum top speed of 90 miles per hour; and a time to accelerate from 0 to 60 miles per hour of less than 9.5 seconds. For the plug-in options, the study assumed that the electricity taken from the grid was generated by combined-cycle power plants (heat that would normally be wasted in conventional plants is instead captured to generate additional electricity) consuming natural gas as feedstock with an efficiency for conversion of chemical to electrical energy of 50 percent (contemporary conventional power plants operate at efficiencies of less than 40 percent).

Depending on the energy source used, the savings in terms of CO_2 emissions could be even more significant.

The study concluded that the reduction in emissions associated with the HEV 60 option could be as much as 60 percent compared to the conventional gasoline-powered automobile, and 30 percent compared to the HEV 0 vehicle. There would also be significant savings in emissions of CO_2 even if the electricity used to charge the batteries of the plug-in hybrid were generated using coal (the "dirtiest" fuel in terms of greenhouse gases). If the electricity taken from the grid to power the plug-in HEV were produced using non-fossil sources of energy (nuclear, solar, hydro, or wind, for example), the savings in emissions could be even greater.

It is instructive to compare the cost of driving using gasoline in a conventional internal-combustion engine with the cost of using power taken from the commercial electricity grid. Approximately 80 percent of the energy content of gasoline consumed in a motor vehicle is wasted: it is converted to heat. Storing energy in a battery and then employing it to drive a motor vehicle is much more efficient: the loss to heat amounts to only about 10 percent. Because the energy content of a gallon of gas is equivalent to about 33.6 kilowatt hours (kWh) of electricity, we would need about 7.5 kWh of electricity to obtain the same *driving* performance as derived from a gallon of gasoline. Electricity delivered to retail customers in Cambridge last December cost 19.7 cents per kWh. At this rate it would take $1.47 to drive the distance covered by a gallon of gas using electricity, a little less than half the then-prevailing price of $3 a gallon for gas. Given that electricity prices in Massachusetts are higher than the national average, savings on a national scale would have been even greater. Further, since one would normally expect to recharge the batteries of the plug-in HEV at night, when demand for electricity is at a minimum, customers could reasonably argue for a reduction in price to go with this off-peak demand.

The average length of a typical vehicle trip in the United States is about 10 miles, according to the 2001 National Household Travel Survey. Of such trips, 17 percent were for travel to and from work, 3.2 percent for work-related business, 46.2 percent for family/personal business, 8 percent for travel to and from school and church, 25 percent for recreation, with the balance, 0.6 percent, for unspecified purposes. To replace 90 percent of current gasoline consumption with power derived from electricity using plug-in hybrids with an electrical range of 60 miles (HEV 60) would require that less than 10 percent of travel by the average vehicle should involve distances of more than 60 miles following the last recharge of the vehicle's batteries. Given that the distance traveled per day by the typical car or light truck in the United States amounts on average to a little more than 30 miles (11,000 miles per year), it seems reasonable to expect that the objective of restricting gasoline-assisted travel to less than 10 percent could be satisfied by a fleet of HEV 60s (which typically would be charged on a daily basis, most likely overnight).

Photograph by Alan Schein Photography/Corbis

Replacing 90 percent of gasoline consumption by electricity would be equivalent to raising the fleet's average fuel efficiency from the present level of about 17 miles per gallon to close to 150 miles per gallon. Were we to accomplish this objective, total oil use would be reduced by 36 percent, cutting the demand for imported oil by as much as 60 percent (a savings of $270 billion per year at current prices for oil). With such a large reduction in demand, one would expect the price of oil to drop and the bill for imported oil to decrease even more, to the point where its contribution to the U.S. international trade deficit would be of minimal concern.

The bill for imported oil could decrease so much that its contribution to the U.S. trade deficit would be of minimal concern.

Replacing 90 percent of current U.S. gasoline consumption with electricity would require an increase of 23 percent in demand for electricity. If a significant fraction of this additional energy were supplied off-peak—at night, for example, when the supply of electricity is normally at a minimum—the increase in electric-generating capacity required to supply it would be relatively modest, potentially as little as 10 percent.

If the proposed transition to plug-in hybrids were implemented, and if the electricity used to charge the batteries of these vehicles were derived from non-fossil sources, the implied reduction in U.S. emissions of CO_2 could amount to as much as 16 percent (assuming a 36 percent reduction in overall consumption of oil).

The Climate Consequences

Given the proposed increase in electricity consumption (and production) from converting to hybrid vehicles, it is important to examine the climate-change effects of this shift in power demand. Combustion of coal accounted for 49 percent of electricity generated in the United States in 2006, followed by natural gas (20 percent), nuclear (19 percent), hydro (7 percent), and oil (1.6 percent), with the balance from renewables other than hydro (wind, biomass, and solar). Coal was responsible for 82 percent of CO_2 emissions from the electric-power sector, and natural gas produced 16 percent of emissions, with oil accounting for only 2 percent. If we are to seriously reduce emissions of CO_2 from the power sector, our objective should clearly be to reduce the relative importance of coal, and to increase the contribution from low-carbon sources such as nuclear, wind, and potentially solar (opportunities for increasing the contribution from hydro in the United States are minimal).

Wind power is the fastest-growing component of the world's renewable-energy portfolio. In its 2007 Alternative Policy Scenario, the International Energy Agency (an organization funded by 27 of the world's largest energy-consuming countries) projected the possibility of an 18-fold increase in wind-powered generation of electricity globally by 2030. The most impressive growth was forecast for Europe where, it was suggested, 30 percent of electricity could be contributed by renewable sources (mainly wind). Europe's commitment to sustainable energy is based in large measure on a conviction that the threat of future climate change is real and urgent. The Bush administration has not as yet seen fit to share this view; should future U.S. administrations do so, there is no doubt that wind power could make an important contribution to the future production of electricity in the United States.

The U.S. Department of Energy's Pacific Northwest Laboratory estimates the country's total annual wind-power potential at 10,777 billion kWh (a number our analysis suggests may be conservative), more than *twice* the amount of electricity consumed in the country in 2006 (4,000 billion kWh): resources available in North Dakota alone could accommodate more than 60 percent of total current U.S. demand (see "Running on Wind?" page 32). Wind power today accounts for only about 1 percent of the nation's supply of electricity, but that contribution is increasing rapidly. For the boom to endure, both federal and state government must demonstrate their long-term commitment to wind energy—and regulators must approve and fast-track authorization for expanding the transmission systems required to connect these potential new sources of power to the national electrical grid.

Chevrolet Volt plug-in hybrid, scheduled for production in 2010

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Nuclear power can also contribute to our energy future—depending on how the public perceives the safety factor. There is an urgent need for public education and discourse to identify both the risks and benefits of nuclear power, and for policies that will enhance the latter while reducing the potential of the former. It will be important, for example, to formulate viable plans for both interim storage and longer-term disposal of nuclear waste.

(An international committee convened under the auspices of the U.S. National Research Council in 2001 recommended that: "Decision makers, particularly those in national programs, should recognize the public's reluctance to accept irreversible actions and emphasize monitoring and retrievability.") From a purely technical point of view, both of these challenges appear manageable. With such a strategy in place, nuclear power (together with wind) can provide an economically competitive, environmentally constructive alternative to carbon-emitting fossil fuels.

Pursuing the Wrong Paths?

Effecting the transition from today's carbon-intensive energy system to a less carbon-intensive energy future will require a more focused approach than that defined in last December's energy bill. Among other initiatives, the act would encourage increased use of coal coupled with capture and burial of the resulting CO_2, in addition to greatly expanded production of ethanol.

Current multibillion-dollar federal subsidies encourage the conversion of abundantly available coal to an energy-rich but cleaner alternative, either gas or liquid: so-called clean-coal technology. The problem is that turning coal into liquid requires *more* coal to be consumed and *more* CO_2 to be produced than would be the case if the coal were consumed directly. In principle, this CO_2 could be captured and sequestered: buried in saline aquifers; in abandoned coal, gas, and oil fields; or even in deep-ocean sediments (see "Fueling Our Future," May-June 2006, page 40). But the quantities involved would be enormous: billions of tons per year, with costs estimated conservatively at a minimum of $30 per ton of CO_2, and with significant prospects for NUMBY ("Not under my back yard!") public opposition were such a strategy to be implemented on a large scale.

Converting biomass to ethanol offers a potential means to reduce our dependence on imported oil. Global production of ethanol is projected to rise to more than 15 billion gallons this year—more than half produced by processing corn in the United States (the new energy bill sets a goal of 9 billion gallons for U.S. production in 2008, increasing to 36 billion gallons by 2022, and projecting that by that time, 21 billion gallons would be derived from sources such as cellulose). Hailed initially as a panacea, ethanol has now become an important target for criticism. The Organization for Economic Cooperation and Development has described ethanol as "a cure that is worse than the disease." The controversy reflects concern that demand for ethanol has driven up the price of corn and potentially the price of other food crops that might be displaced by corn (see my article "The Ethanol Illusion," November-December 2006, page 33). Despite hopes that in the future ethanol could be produced from nonfood sources, such as switchgrass and wood chips—so-called cellulosic ethanol (*strongly* promoted in the new energy law)—does it make sense to spend significant resources to convert cellulose to ethanol when *more* energy could be delivered simply by burning the cellulose and converting 30 percent or more of its embedded energy to electricity? (Because the carbon contained in the cellulose is derived from the atmosphere by photosynthesis, this could be accomplished with no net additional emission of CO_2; producing ethanol from either corn or cellulose, on the other hand, is associated inevitably with significant emission of greenhouse gases.)

Promoting Practical Policies

To return to the twin challenges for energy policy posed at the outset: We could save money and markedly reduce our dependence on imported oil by promoting a transition in the transportation sector from today's reliance on gasoline-fueled internal-combustion engines to increased use of electricity delivered to plug-in hybrid vehicles. And we could reduce emissions of CO_2 released from generating electricity by promoting increased use of non-fossil alternatives such as wind and nuclear power.

A phased reduction in use of fossil fuels in the electricity sector could be promoted by a carbon tax (which would raise gasoline prices for drivers, too), or by requiring electricity producers to acquire permits for emission of CO_2. If permits were auctioned for as little as $20 per ton of CO_2, the revenue raised could be as much as $50 billion per year—comparable to the levy now imposed by state and federal taxes on gasoline. Allowing permits to be traded would encourage selection of the most efficient means to reduce emissions. Revenues raised by auctioning the permits could be used to compensate for tax revenue lost due to the reduction in gasoline sales, and potentially also to promote non-carbon energy alternatives.

Weaning Americans from an energy system based largely on carbon-emitting coal, oil, and gas will not be easy. Embedded interests (coal and oil companies and operators of gasoline stations, for example) will inevitably be threatened and will surely resist. It is a challenge, though, that we must meet. The present system is simply not sustainable.

Michael B. McElroy is Butler professor of environmental studies.

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