WORLD•WATCH

WORKING FOR A SUSTAINABLE FUTURE

The Energy We Overlook

by Robert U. Ayres

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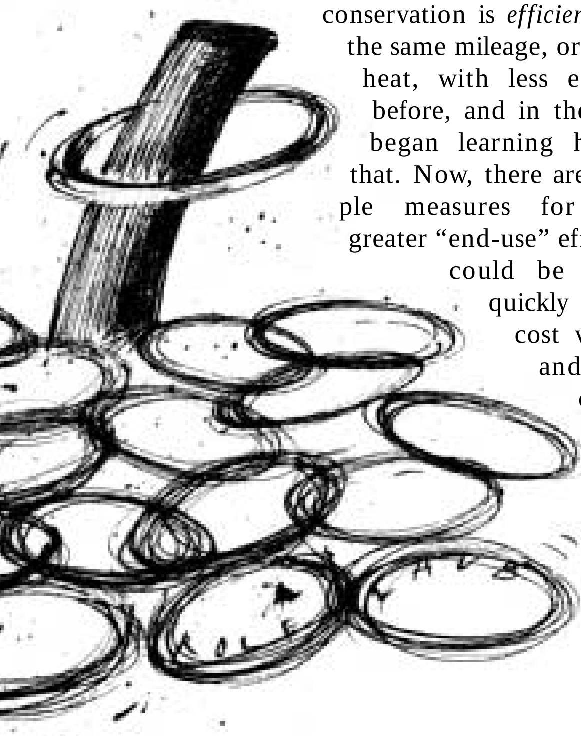
With the United States letting 19 of every 20 units of energy it generates go to waste, no wonder we can't get carbon emissions under control. If that figure surprises you, read on. If governments focused their energy R&D on the technologies that show real promise for the future, rather than on those of the past, they could substitute higher efficiency for increased energy production—while helping to wean us off fossil fuels altogether.

by Robert U. Ayres

Prologue: *The first article of this two-part series, in the September/October issue, exposes the flawed economic logic underlying the U.S. administration's rejection of the Kyoto accord on global warming. The second installment, below, reviews generic technological possibilities for serious innovation, both in energy supply and in conservation—and suggests ways in which government can act to accelerate (or to inhibit) changes that will supply adequate energy while moving toward a complete elimination of carbon dioxide emissions. The article concludes with a more "visionary" scheme—for engaging not only government, but every person who uses products or services resulting in carbon emissions.*

Carbon dioxide is not the only greenhouse gas (GHG). In fact, it accounts for only about half of the climate warming effect. But as a practical matter, the clearest path to reducing GHGs is to cut out carbon dioxide emissions from the burning of fossil fuels. There are three generic means of doing this: to get serious about conservation; to substitute other energy sources for fossil fuels; and to capture and sequester the CO_2 from fossil-fuel combustion. Let's take them in order of priority. By "priority," I mean the potential of each approach to produce gains large enough not just to meet Kyoto-scale goals, but essentially to "zero out" CO_2 emissions in the coming century.

Conservation. The energy industry routinely brushes this off as a non-starter, by suggesting that energy conservation means energy deprivation. This argument echoes the predictions of nuclear industry advocates of a generation ago, who told us that if we tried to rely on conservation and didn't embrace nuclear power, we would find ourselves "freezing in the dark" (a pro-nuclear bumper sticker from the early 1980s). We didn't, because a critical part of conservation is *efficiency*—getting the same mileage, or lighting, or heat, with less energy than before, and in the 1970s we began learning how to do that. Now, there are some simple measures for achieving greater "end-use" efficiency that could be introduced quickly and would cost very little—and in some cases would actually pay for themselves in a few months or years. There are also prospects for making more radical, long-term, improvements in energy efficiency, both in its production and in every stage of its use.



ILLUSTRATIONS BY ROLF LAUB

Substitution. The nuclear industry is already licking its lips about making a comeback in public esteem. It is advertising heavily that it offers a "clean air" alternative to coal and oil. But even if the problems that have caused the current public disenchantment with this industry could be solved overnight, nuclear power plants take up to ten years to design, site, and build. Moreover, they are not cheaper than fossil fuel-fired power plants. And the nuclear industry is relatively mature, so the prospects for sharp cost reductions are dim at best.

Other non-carbon power sources are more promising. They include hydro-electricity (especially from small "low-head" dams), wind power, solar power, geothermal power, ocean currents, and solar power satellites. At present, all except small hydroelectric facilities would be more costly than big central power stations, at least if the social and environmental costs of fossil fuel combustion continue to be ignored. Large-scale deployment of standardized mass-produced wind or solar powered units that could bring unit costs down dramatically could take two or three decades. There is an inevitable lag as market size and production costs move in synchrony. Geothermal power and ocean currents are wild cards that could be helpful in some, but not most, locations. Solar satellites are, for the moment, a very long shot.

According to conventional wisdom, none of these options can individually substitute for a large percentage of the existing fossil fuel-based energy supply. Taken together, however, these options can have a major impact. Moreover, conventional wisdom may be too myopic. The main reason wind and solar power are not usually taken seriously as potential substitutes for coal and oil in satisfying the power needs of most countries is that they provide only intermittent supply. The wind does not always blow and the sun does not always shine. But solutions to the problems of intermittency are feasible, and some are already under development.

Sequestration. Not to be confused with the sequestering of carbon in trees, this technological sequestration would involve intercepting emissions before they can dissipate into the atmosphere, and locking the carbon up. It appears that this approach may be quite cost-effective for certain large-scale users—especially coal fired steam-electric power plants, which currently account for about a third of the carbon dioxide produced in the United States. It also appears that the captured gas can be utilized quite productively, especially in repressurizing (extending the productive life of) aging oil and gas fields.

These three generic approaches are listed in inverse order of attractiveness to the existing fossil-fuel energy complex. The third approach is the one the established non-nuclear energy industries will prefer, and they will lobby hard to secure government funding and support for it, while undermining efforts to promote alternatives. Every U.S. politician from a district with an oil well, a coal mine, or a gas pipeline will be tempted to support this approach, but only after the political pressure to "do something" about climate warming has become irresistible. It hasn't yet.

What Offers the Largest Potential for Cutting Greenhouse Gas Emissions?

The answer, perhaps surprisingly, is conservation. To rely much more on conservation does not mean "freezing in the dark." Nor does it mean depending on voluntary individual choices to reduce domestic consumption, although that can't hurt. What it really means is to sharply increase the efficiency with which energy is used throughout the economy.

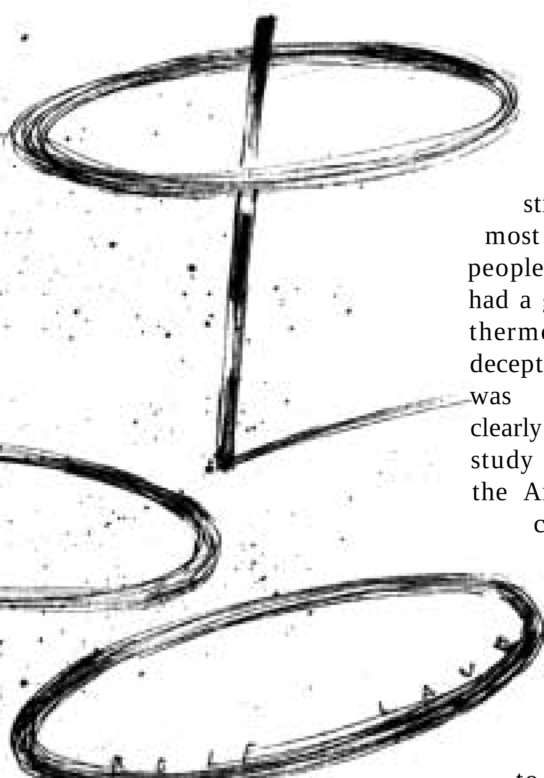
In the early 1970s, electricity demand in the United States had been rising for 20 years at about 8 percent per year. Some voices urged conservation then, as they do now. So the U.S. government promoted several "independent" (but noticeably orchestrated) studies of the potential for conservation savings. These studies all concluded that (1) conservation was a good idea but (2) the maximum potential savings were only around 15 to 20 percent, and (3) demand was going to keep on rising at the same rate as in the immediate past. In other words, this potential for conservation savings would be used up by two or three years of growth at 8 percent per year.

The implication of these studies was that many more new power plants and refineries would be needed before the end of the century. That view was reinforced by the propaganda of the nuclear industry in the 1980s, when it was fighting for survival in the wake of the reactor accident at Three Mile Island. Those projections turned out to be wrong. And a main reason was that the potential for conservation was grossly underestimated then—as it is now. Dick Cheney and George W. Bush, in making their energy policy proclamations of 2001, could well have lifted their projections from that decades-old nuclear industry propaganda.

One reason for underestimating conservation potential arose from a fundamental but very wide

spread misunderstanding of the science of thermodynamics. Most engineers and economists assumed that energy was already being used quite efficiently. It was the prevailing view, based largely on a study carried out by the Livermore National Laboratory for the Joint Committee on Atomic Energy (JCAE) of the U.S. Congress, which concluded that the U.S. economy in 1970 was achieving an astonishing overall efficiency of 47.5 percent. Efficiency was defined as the ratio of "useful" energy (output) to "total" energy (input). The finding was offered with a straight face, so to speak, despite the fact that not a single energy conversion system in operation at the time could come close to matching that performance.

The deception lay in the assumption that most of the heat energy consumed by industry, and by residences and commercial establishments for space-heating, cooking, hot water, etc., was being used as efficiently as possible—that is, at an efficiency of 70 percent or more. This underlying assumption was built into virtually all official studies and recommendations. If the country's economy as a whole were already 47.5 percent efficient, there couldn't be much additional potential for conservation. In effect, the JCAE conclusion, echoed by others, blinded policymakers and investors to the possibility that further efficiency gains were possible.



The implicit definition of efficiency used in that official study in 1973 (and still accepted by most of the industry people who haven't had a good course in thermodynamics) is deceptive. The error was pointed out clearly by a summer study sponsored by the American Physical Society in 1975. But that study received much less publicity—and is much harder to read—than the official report to the Congress's Joint Committee and its numerous clones and progeny.

What was the error? By definition, a measure of efficiency must be a fraction—a number less than one. The denominator of the ratio, on the bottom, must be the energy actually used, by the economy as a whole, or by some industry, or factory, or appliance. The smaller numerator, on the top, should represent the *minimum physically possible* amount of energy required to achieve the same outcome, whether in tons of steel produced or hamburgers cooked. Only by this kind of comparison can we see how much room there is for future improvement.

That is not always the kind of ratio used, however. The gas industry likes to advertise that gas furnaces are about 80 percent efficient—by which it means that 80 percent of the heat produced goes into the house and only 20 percent goes up the flue. No doubt, this is an improvement over the 50 percent or so that leaked out of the house from coal-burning furnaces in the past. But that comparison is quite misleading, because it is fundamentally wasteful to use very high temperature heat for home heating. The important clue is that 70 degrees F., the temperature you probably want to keep your house at, *is almost exactly the temperature of the waste heat from a conventional steam-electric power plant.*

One reason the potential for energy conservation is so grossly underestimated arises from a widespread misunderstanding of the science of thermodynamics. In most assessments of U.S. energy efficiency, the losses from waste heat are conveniently ignored.

Why is that a clue? Let us suppose, for purposes of argument, that electric power plants need not be big. (If electronics can be miniaturized, why not electricity generation?) Suppose the fuel used to heat your house were used instead to produce electricity. The electricity could run the lights and all the appliances in your house, and maybe your neighbor's house, and the waste heat would still take care of the space heating. In other words, the heat would be a free byproduct. (This sort of system—known as "district heating"—is quite common in Europe, by the way. It can pose practical difficulties due to the distance between the power plant and the housing. But that is irrelevant to the question of what the true energy conservation *potential* is for heating buildings.) Moreover, conventional electric power plants are not as efficient as theoretically possible. For instance, the overall efficiency can be raised considerably by putting a gas turbine in front of the steam turbine, and using the hot gases from the gas turbine to heat the steam. This so-called "combined cycle" can achieve efficiencies as high as 60 percent—because some of the heat energy overlooked by the conventional energy accounting is now being used. And still, the waste heat at the end of the cascade is enough to heat your house.

In short, the *minimum physically possible* amount of energy needed to heat the house could theoretically be provided by a scheme that makes far better use of the same fuel. In other words, the true efficiency of the gas furnace is far lower than advertised. The APS summer study estimated that space heating in 1970 by means of an oil- or gas-fired furnace, and distributed by hot water or steam radiators, was only 6 percent efficient, in contrast to the 70 percent or so assumed by the JCAE study.

By this sort of test, the U.S. economy in the mid-1970s was nowhere near 47.5 percent efficient. In 1975, I tried (with a colleague) to revise the JCAE estimate of the energy efficiency of the US economy, based on the principles explained by the APS summer study. Our first estimate, using 1968-73 data, came up with less than 2 percent. A later effort, using 1979 data and slightly more conservative assumptions, arrived at about 2.5 percent. The methodology of such calculations is arguable, especially in regard to deciding on what is the "minimum possible." But even with more traditional assumptions on that point, the real efficiency of the U.S. economy (and others around the world) is not more than a few percent at most. A very safe estimate would be less than 5 percent. What this means is that there is ample room to cut energy consumption, *without* cutting standards of living, for a long time to come.

> The real energy efficiency of the industrial economies is probably less than 5 percent. That leaves an enormous potential for conservation to meet increased demand without new drilling or digging.

Policies to Pump-Prime Efficiency

Some economists have advocated a carbon tax on fossil fuels, to reduce demand for such fuels and thereby cut CO_2 emissions. Model exercises have explored the possibility, and it turns out (as one might expect) that the outcome of this exercise depends upon what is done with the proceeds of the tax. The models tend to suggest that if the tax money is returned to consumers, or if it is spent by the government, employment and the growth rate will fall. On the other hand, if the tax funds are used to cut the existing social-security and value-added taxes on labor—thus reducing the effective cost of labor vis-a-vis energy—the macro-economic effects (on employment and growth) can be beneficial. Moreover, if a fraction of the proceeds is spent on energy research and development (R&D), there may be a double dividend—an economic spur to go along with the reduced carbon emissions.

In the 1970s, the U.S. government did help considerably by introducing the Corporate Average Fuel Economy (CAFE) standards for new automobiles and the Public Utility Regulation and Public Utility Regulatory Policies Act of 1978 (PURPA). The first of these laws simply mandated gradually better fuel economy for cars, leaving it up to the manufacturers to figure out how to achieve that result. The carmakers did so (kicking and screaming, to be sure) mostly by reducing vehicle size and weight and improving aerodynamics and tires. By 1988, U.S. automotive fuel economy was over twice as high as it had been in 1972, and roughly equal to the averages for Europe and Japan. The other law, PURPA, allowed utilities to make more profits for stockholders by producing power more efficiently. This was a sharp change from the earlier system in which a utility could increase its income only by building new capacity at a standard rate of return on investment fixed by regulators. (In those days, any savings from more efficient operation had to be passed on to consumers as lower prices. So why bother?)

The new law aimed to do something else as well: to force utilities to buy excess power from private producers at the utilities' marginal cost of production. Anyone with a small windmill or hydroelectric dam, or a cogeneration plant (making electricity from waste heat) could sell unneeded power back to the local utility at a known price. The utilities didn't like it, of course, because their control systems were not designed for decentralized production. They discouraged small suppliers as much as possible by imposing high "connection charges." Even so, many of them found themselves for the first time with excess capacity. A few utilities in regions that were growing rapidly and did *not* have excess capacity, notably in California, then found it worthwhile to help consumers save energy so as to delay the need for costly new generating capacity. (New plants were always more costly than older ones, due to rising land prices and increasingly strict environmental regulation.) This "demand-side management," as it was called by alternative-energy pioneer Amory Lovins, proved to be another effective tool for inducing conservation.

Lovins correctly predicted that thanks to such conservation, energy demand would not continue to increase at the historical rate. And indeed, between 1972 and 1988, conservation saved roughly a third of the energy that would have been needed had the industry and government experts been accurate in their forecasts.

Have we squeezed most of the potential from conservation by now? Far from it. In fact, we have barely scratched the surface. Take motor vehicles, the source of a third of the CO_2 emissions in the United States and other industrialized countries. The CAFE standards have not been tightened since the 1980s, and automotive fuel economy has ceased to improve. In fact, as most readers of this publication will be ruefully aware, the popularity of sports utility vehicles (SUVs)—classed as "trucks" to avoid strict regulation—has turned the trend in the wrong direction. Yet numerous studies confirm that fuel economy could be at least *tripled* by exploiting light but strong space-age composite materials (based on carbon fibers), using aerospace-related integrated design concepts that minimize the need for heavy steel frames, and using hybrid or fuel-cell propulsion units.

The Bush administration, under pressure from the auto industry, opposes any extension of CAFE standards. Yet, the US auto industry did not suffer when the first CAFE law went into effect. (The period of increasingly intensive import competition from Japan in the 1980s was rough, for a while, but Japanese competition had much less to do with fuel economy than reliability.) A new CAFE standard, forcing fleet average fuel economy for all new vehicles (including SUVs) to twice the current level over a period of 15 years or so would be nearly painless for consumers and a very valuable inducement to technological innovation for the industry. And there is no reason to worry about the so-called "rebound effect" (the idea that increased efficiency will only lead to increased consumption) in this case. True, consumers might save some money by paying for less fuel, but alternative uses of that money would certainly be less energy-intensive than driving SUVs to the shopping mall.

The impact of tougher CAFE standards on energy consumption could be magnified by another device, which Amory Lovins has called the "feebate." Each vehicle with a lower-than-standard fuel economy would be taxed in proportion to its excess use of fuel, while each vehicle with better than standard fuel economy would receive a proportional rebate. The money collected from the first group would pay for the rebates to the second group. This should satisfy the people who think that money collected by the government is always misspent.

The principles of the CAFE standards and the feebate scheme could just as well be applied to a number of other products, from refrigerators to home heating systems. In fact, by far the largest opportunities for increased end-use efficiency are to be found in the domain of residential and commercial buildings. Technologically, it is possible to reduce heating requirements for new buildings by as much as 90 percent, even in cold climates, by a combination of better insulation, better windows (triple-glazed with tight seals), and better design to utilize solar heat in the winter but exclude it in the summer. Extra costs for the insulation and high-performance windows are largely compensated for by the opportunity to meet all heating and cooling needs with a climate control system of lower capacity, thereby reducing capital costs. Solar photovoltaic (PV) panels on the roof can reduce the need for purchased power from the central utility. If the resulting structure costs a bit more—which it need not, in many locations—the difference would pay for itself in lower heating and cooling costs over its lifetime.

For older buildings, the potential is not nearly so great, at least on a per-building basis, but older buildings outnumber new ones. And retrofitting windows and roof panels can still cut heating needs substantially, while providing supplementary electric power at low marginal cost. Because a PV roof panel serves two functions (both power and heat), it spreads the cost base. In this application, PVs are already cost-effective in some locations and as manufacturing costs decline they will soon be more so.

> Between 1972 and 1988, conservation saved about a third of the energy that would have been needed if the energy industry and government experts had been accurate in their forecasts.

Why aren't these things being done on a large scale already? Part of the answer is sheer inertia. The building industry is very decentralized. It is also very conservative, as are most of its customers. Very few builders have the technological expertise to exploit the most energy-efficient techniques, and most don't even know about the possibilities—mainly because there is no competitive pressure for them to investigate these things. The pressure on home builders is essentially to maximize usable (and visible) floor space per dollar. Consumers do not often ask about future operating costs. And more importantly, mortgage financing institutions do not insist that they do so, even though there is an apparent incentive for lenders to assure themselves that borrowers are aware of—and can afford to pay—the full costs of ownership, not just the mortgage repayments.

Public awareness campaigns, like those initiated in the 1970s in response to the oil crisis, can help. But the real gains from conservation, especially in the decentralized residential and consumer sectors, will probably require a push from regulation. There are a number of ways to do this, but the one I favor would be to work through mortgage lenders and utilities. New houses could be sold as a complete *package* of services, including the house and its equipment, all the necessary utilities (accompanied by long-term contracts), and insurance. The base cost to the buyer would include payments not only for the mortgage, but also for all primary utilities, on a pre-specified sliding scale of increased rates for increased energy use.

How could this be achieved? What's needed is an organization to do the "packaging" of the service components. As matters stand today, builders build; banks lend; utilities supply electricity or water or gas. Combining these services in a single consumer-friendly package could be beneficial for all concerned, and a clever entrepreneur should be able to make a profit by doing so. In a competitive free market, deregulated utilities should be prepared to compete for such business with the commercial builders (not the individual consumers), and the insurance companies should insure the delivery of promised utility services, as well as the usual protections against structural problems, accidents, and hazards.

While sport utility vehicles have ***reduced*** average fuel economy in the United States, numerous studies indicate that fuel economy could be at least ***tripled*** by exploiting new materials, designs, and propulsion technologies.

Notwithstanding the conservatism of the residential housing sector, studies by the Lawrence Berkeley Laboratory and others indicate that with appropriate government policies in place, the residential and commercial use of energy can be cut by 50 percent or even more by mid-century, while the carbon emissions can be cut by 75 percent. Insulation, alone, will sharply reduce heat requirements. Most of the reduced amounts then required will be provided by solar collectors, small on-site generating units (fuel cells) with PVs, supplemented by electric heat pumps (as air-conditioning is now). The rest will come from natural gas or hydrogen. And the purchased electric power component can be made significantly less carbon-intensive by utilizing more low-head hydroelectricity, wind power, solar power, and industrial co-generation.

In those industries that have been traditional "big" users of energy (transportation, electric power generation, petroleum refining, metals, cement, glass, pulp and paper, and chemicals), fuels constitute such a large share of their overall costs that most of the obvious ways of cutting fuel use have been tried. In these industries, only more radical changes in technology will make much difference. In the electric power sector, the combined-cycle use of gas turbines and steam turbines has the potential to significantly increase thermal efficiency from its present plateau of 33 percent (including distribution losses) to 50 or even 60 percent. Newly constructed facilities already employ this technology. However, existing plants cannot be retrofitted for higher efficiency, so progress will occur slowly as total capacity increases and older plants are phased out and replaced. Unfortunately, the Bush administration seems intent on allowing old plants with obsolete pollution control systems to operate even longer, rather than encouraging their replacement.

In those "old economy" manufacturing and service industries in which energy is only a minor cost compared to those of labor and capital, the main incentives have been to save on labor, even if it means more mechanization and more use of energy. As a result, these sectors offer surprisingly numerous opportunities for what Amory Lovins has called "free lunches"—savings that cost nothing or that pay for themselves very quickly. Economists have been very skeptical about this, on the grounds that if there were major opportunities to save energy and money, the profit incentive would operate to make sure that such opportunities are not persistently overlooked. The fact remains that many such opportunities still exist, however—most likely because managers are much less concerned with finding small savings than they are with finding new markets and "growth."

Non-Carbon Alternatives

Of all the non-carbon alternatives[1]—water power, wind power, solar heat, photovoltaic electricity, tidal power, and geothermal power—the least expensive by far is low-head waterpower from small dams. In areas that have flowing streams and consistent rainfall, all that is needed to encourage more of these small generating units is to ensure that excess power can be fed back into the network efficiently. This is also a necessary—though not sufficient—condition for large-scale adoption of wind power and solar photovoltaic power.

Wind is the next cheapest. Western Europe is adopting wind power rapidly, albeit with some help from subsidies. But the subsidies have already created a significant market for the units, and this has brought a number of competitors into the field. Individual units are getting larger, now up to 1 megawatt, and costs are dropping sharply. A further 50 percent reduction is expected before 2010.

There is plenty of wind potential. Europe could generate two or even three times its current demand for electric power from wind. A similar potential exists in North America. However, so far the potential for stand-alone wind units has been relatively limited because of intermittence of both supply and

1 Excepting the nuclear option, which is of highly questionable viability because of its unsolved problems of radioactive materials proliferation and disposal.

demand. The grid has its *raison d'etre*. Until recently, it was technically quite difficult to integrate many small independent suppliers (that were also occasional net users) into the same grid that served the utilities' own large base-load plants. Most utilities have tried to discourage small retail power producers, either by means of high connection charges or legal restrictions. However, modern computer capabilities have largely eliminated the coordination problem, and it should not be a major barrier in the future.

For a long time, it has been assumed that local storage of energy—the thing that would really allow wind and solar power to take off—is not a serious option. But this is changing. The National Power PLC of Britain is developing a new type of regenerative fuel cell that is suitable for large-scale applications. As presently configured, it consists of tanks of sodium bromide and sodium polysulfide (there are many possible electrochemical couples). These concentrated salt solutions react electrochemically across a membrane, producing a cell voltage of 1.5 V. The cells can be combined in series (like any battery) to get higher voltages, and in parallel to get more power. The amount of energy stored is limited only by the size of the tanks. The storage capacity can be adjusted to a few minutes (to smooth out peaks) or to many hours. The technology has been tested in the laboratory and at pilot scale. A plant now being built in the United Kingdom is rated at 120 mWh of energy-storage capacity and up to 15 mW power rating.

It is true that at present, none of the alternatives mentioned (except hydropower) can compete economically with a large-scale conventional coal-fired power plant—assuming, as noted earlier, that the social and ecological costs of the coal-fired plant are ignored. However this does not mean that there are no cost-effective applications for renewables. On the contrary, there are already quite a few, with more to come. Mass production brings costs down dramatically—look at the history of the Ford Model T, or of the computer. Wind turbines and PV panels are still semi-customized products, made in rather small numbers. But in both of these industries, private investment is rising and capacity is growing at about 30 percent per year.

Getting CO_2 Out of Circulation

Techniques for capturing and sequestering carbon dioxide from thermal power plants have been gaining in credibility (and funding) in recent years. The costs can apparently be kept quite low, provided there is a convenient way to store or otherwise dispose of the carbon dioxide. One possibility is deep sea disposal—dissolving the gas in sea-water at high pressure. However, the effect on ocean dynamics has not been modeled yet. Another possibility is to pump the carbon dioxide back into the ground, especially into old oil and gas fields. The heavier gas would tend to displace dissolved methane and thus increase the output of natural gas, at least slightly. Presumably, very little—if any—of the carbon dioxide would ever reappear at the surface. Both of these schemes would involve long-distance transportation on a rather large scale, mostly likely by pipeline or ship. The costs would be quite large for power plants far from an oil or gas field, or from deep water. A third possibility is to find a way of utilizing pure (or nearly pure) carbon dioxide in some useful and long-lived product, almost certainly a construction material of some sort. This idea seems far-fetched, but researchers at Los Alamos National Laboratory, among others, are working on it.

Toward a Hydrogen Economy

Throughout the stationary (non-transportation) world, energy delivered to the final point of use is increasingly in the form of electricity. This trend is expected to continue. However, storage difficulties do seem to restrict the long-term potential for use in vehicles. At present, there is no realistic substitute for liquid hydrocarbons as fuels for mobile power sources. Nevertheless, there is increasing interest in another possibility—hydrogen. For many years, hydrogen was thought to be too dangerous to use in vehicles, perhaps in part because of the famous Hindenburg fire back in 1937. However cooler heads and recent research suggest that safe methods of storage, even in small quantities, are possible. Indeed, there may be an analogy with past experience with steam engines. Accidents were common (and often fatal) in the early days when the boiler was essentially a large teakettle, and when a leak could result in an explosion. The invention that made explosions impossible was the so-called monotube boiler—essentially a long tube inside a tank. There is no reason the same idea couldn't be applied to compressed hydrogen storage, perhaps on a microscopic scale (nanotubes).

> Extra costs for insulation and high-performance windows are largely offset by the reduced capacity – meaning reduced capital costs – of the climate control systems.

Fuel cells have emerged, since the 1980s, as the great hope for a new generation of vehicular power plants. The big breakthrough was the development of a plastic membrane that allows protons (ionized hydrogen atoms) to pass through while blocking the passage of electrons.[2] This makes it possible to accumulate negatively charged electrons on one side of the membrane and positively charged protons on the other, creating a voltage difference. The availability of this material has enabled the development of the so-called proton-exchange-membrane (PEM) fuel cells, which are the basis of the most active current research programs, especially by Ballard Power Systems Inc. However, these cells also depend upon the availability of hydrogen as a fuel, and platinum as a catalyst. To be sure, the amount of platinum required has been cut dramatically since the first prototypes, but it cannot be eliminated altogether. (Unfortunately, the less platinum is used per cell, the more uneconomic it is to recycle.) But platinum is an extremely scarce metal, and it is doubtful whether there is enough to support a whole new energy economy.

> With appropriate government policies in place, the residential and commercial use of energy can be cut by 50 percent or more by mid-century, while the carbon emissions can be cut by 75 percent.

There are, however, a number of other types of fuel cells. Some are suitable for use in buildings, where both heat and power are needed. The most advanced is the phosphoric acid cell. Another possibility suitable for buildings is the high-temperature molten carbonate fuel cell. This can be paired with small gas turbines, using the waste heat. Composite efficiencies of 60 percent are possible. Several other types of cells are also attracting interest. And recent research has overcome some of the barriers that formerly seemed to block progress.[3]

Owning Your Share of CO_2

The usual policy prescriptions for cutting greenhouses gases include eliminating direct or indirect subsidies to fossil fuels, setting efficiency standards (such as CAFE), directly regulating emissions, and taxing emissions. Carbon taxes to reduce consumption are being seriously considered in the European Union.

I would like to propose something more radical: a system whereby every legal resident over some minimum age receives a fixed carbon entitlement, based on the annual quota for the country as determined by international negotiation along Kyoto lines. This entitlement is equal for all legal residents over the minimum age, and it is recorded in a bank account. Parents of eligible children have control of their children's entitlements. The entitlements are tradeable, and have a market value. They can be bought and sold for money.

Here is how the scheme would work. Every time an individual makes a direct purchase of a carbonaceous fuel—say gasoline for the car—his or her carbon entitlement account is debited by the appropriate amount of carbon, as well as by the money price. The system works exactly the same way as a debit (money) card works today, except that there is a parallel unit of account in kilograms of carbon. Surplus individual entitlement units can be sold. The sale would be done through the bank where the account is held, at the prevailing market price, and the money value of the entitlement units sold would be deposited in the customer's money account at the same bank.

In this system, there are no automatic entitlements for businesses or other organizations. Unlike the widely discussed idea of CO_2 permit trading, it does not "grandfather" allocations to existing corporations; it requires those corporations to pay their way like everyone else. If a shop or a manufacturing firm needs to buy fuel it must use entitlements purchased in the market. This cost will, of course, add to the price of the goods or services being produced. The added cost is passed back to consumers, just as a carbon tax or a value-added tax is passed back. Thus, individuals pay indirectly for their carbon use, through higher prices for goods and services. Needless to say, energy-intensive services rise in price more than energy-conserving goods and services.

On average, people would receive a net income from the sale of surplus entitlements to finance the extra costs they have to pay. But low-income people with low levels of material consumption would gain from the scheme. Elderly stay-at-homes and bicycle-riding students would receive extra money from the sale of unused entitlements. They would receive more from the sale of surplus entitlements than they would have to pay in extra costs, amounting to a real income supplement. But for high-income people with high levels of material consumption—people with big display houses who drive SUVs towing large power boats, for instance—there would be an additional cost to buy the extra carbon units they consume.

The advantages of this scheme over a simple, uniform carbon tax are several. First, the level of the "tax" (i.e., the price of entitlements) would not be determined by politicians, but by the free market. Only the amount of carbon consumption (and emis-

2 The idea of a filter that allows protons to pass while blocking electrons is somewhat contrary to intuition, because protons are much heavier than electrons. But because of the nature of nuclear forces, they are more tightly bound and thus smaller.

3 For more detail, see Worldwatch Paper 157, *Hydrogen Futures: Toward a Sustainable Energy System*, by Seth Dunn, published earlier this year.

sions) to be allowed in that year would be fixed by government. Second, the scheme would explicitly recognize that rights to carbon consumption cannot be unlimited, and that as a limited resource they ought to be allocated equally to everyone. If politicians chose to award free consumption rights to certain favored users (say farmers) it would have to be done and defended openly. Third, and most important, the scheme would hit the wasters hardest and reward the conservers.

A Critical Consideration

A key point of this discussion is that economic growth in the long run depends upon continued technological innovation, not just marginal improvements in existing technologies. The potential for marginal improvements in any technology is always declining. For example, internal combustion engines improved dramatically in the half-century from 1876 to 1926. From 1926 to 1976, further gains were minor at best. Only radical changes can keep the forward momentum going. The fuel cell would be such a radical change.

But although giant companies dominate the economy, radical changes are rarely initiated by big firms. For example, the modern developments in fuel cell technology came from a small firm, Ballard Power Systems Inc. even though most of the basic research had previously been done by General Electric. Why didn't GE follow through? The short answer is that radical changes are disruptive, and big firms hate uncertainty. They are happy and profitable as long as things stay as they are. In a new ball game anything can happen. Today's profitable product can be an obsolete loser tomorrow. So, corporate giants are generally risk-averse. This does not prevent them from doing important basic research from time to time. Bell Laboratories invented the transistor, for example. But others, like the upstart Texas Instruments, exploited it. Hewlett-Packard and Xerox invented several important technologies underlying the PC. But Apple exploited them.

Small firms have different motivations. As long as things stay as they are, small firms remain small. In fact, they have trouble surviving against larger competitors. In order to survive and become more profitable they must get big, and that means taking market share away from some existing big firm, or—better yet—inventing a new market. Either way involves big risks. Most small firms that take big risks will fail. That is the way of the world. But when a risky venture succeeds, the payoff can be very big indeed. Most of today's big companies got that way by taking risks they would not take now.

The point I am making is that the Bush Administration is protecting the dinosaurs against the risk-takers. But then, it is the dinosaurs who can afford to make big campaign contributions.

One last but most important point: those who resist any challenge to the fossil fuel economy claim that government intervention invariably inhibits economic growth. My claim is almost exactly opposite, and it is based on the real technological history of the past century: many of the most important technologies of our age came into being only *because of* government intervention. This is not to deny that government-operated services tend to be inefficient. But consider a few examples related to energy: the railroads across the western plains were built by private enterprise but only because of large land grants (subsidies) from the government. The U.S. interstate highway system was a tax-supported federal project. Large civil jet aircraft depend on engines (and many other technologies) that were developed originally for military (government) purposes. The air traffic control system is still operated by the government. The big hydroelectric dams that provide both irrigation and electric power to several important areas were government-funded. Nuclear power was entirely based on reactor designs and fuels developed for nuclear weapons. In fact, the nuclear power industry still depends on a liability exemption mandated by congress. (You can't sue for damages in case of a nuclear accident.)

> For a long time, it has been assumed that local storage of energy – the thing that would really allow wind and solar power to take off – is not a serious option. But this is changing.

The Department of Energy supports extensive R&D programs in nuclear technology (including fusion power) and in several fossil-fuel related areas such as "clean coal." The government subsidizes Midwestern corn growers and grain processors to produce ethanol as a fuel. Why, then, is the U.S. administration so reluctant to support the really important new technologies like wind power, solar power and—above all, conservation—that could make the biggest difference?

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