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Post-Rio: The Challenge at Home

Powering the Future

Efficient use and renewable supplies are key

by Robert H. Williams

Sustainable development requires that clean, secure, and safe energy be available for economic growth. As the 21st century approaches, the challenges implicit in "clean, secure, and safe" seem daunting for the United States.

- Urban air pollution is putting pressure on the internal combustion engine. California has mandated that 2 percent of new cars must be "zero-emission vehicles" by 1998; the percentage rises to 10 percent by 2003. Other states may follow California's lead.
- Domestic oil production has fallen to 9 million barrels per day (mmbd) from the 1970 peak of over 11 mmbd. The Department of Energy (DOE) projects that output will fall to 4 mmbd by 2030. It is generally expected that conventional oil production will decline after 2000 in all major regions outside the Middle East.
- If greenhouse warming is as serious as most scientists believe, the world may be required to reduce emissions of carbon dioxide (CO_2) substantially: by 60 percent or more to stabilize current atmospheric concentrations. Much of the burden would fall on the already industrialized countries, which today account for three-quarters of the emissions.

Despite such challenges, the prospects are good that energy can be provided consistent with sustainability goals. This will be illustrated by describing an energy future for the United States that emphasizes efficient use and renewable supplies of energy. The scenario was developed in an assessment of renewable energy carried out by an international team of experts as an input to the United Nations Conference on Environment and Development (UNCED).

Improvements in efficiency can reduce environmental and energy security risks substantially. While it has long been assumed that energy consumption must grow in lock-step with economic growth, U.S. energy consumption remained constant after the energy crisis of 1973 while the country's economic output increased by more than one-third. Although energy use since 1986 has once again followed economic output, the opportunities for decoupling energy and economic growth through investments in more efficient energy use are substantial. In the UNCED study scenario, during the period 1985 to 2050, energy use decreases by one-fourth (see figure) while economic output increases nearly five-fold.

Electricity (excluding losses during generation) has accounted for a growing share of energy use in the United States, increasing from 6 percent in 1960 to 12 percent in 1991. While driven primarily by desirable attributes—high quality, ease and flexibility of use—the trend would be reinforced if environmental concerns become a major determinant of energy carrier choice: It is generally easier to bring environmental problems under control with electricity than with alternative carriers. In the UNCED study scenario, electricity's share of U.S. energy rises to 20 percent by 2050. However, electricity demand grows at only one-fourth the rate of the last decade because of the emphasis given to more efficient use.

Coal, which is the source for 55 percent of U.S. electricity production, poses the greatest environmental challenges in the power sector: It is responsible for 85 percent of the sector's CO_2 emissions and for most of its air pollution. Air pollution problems are likely to be solved by the coal gasification technologies being developed for use with advanced power-generating cycles.

(Continued next page)

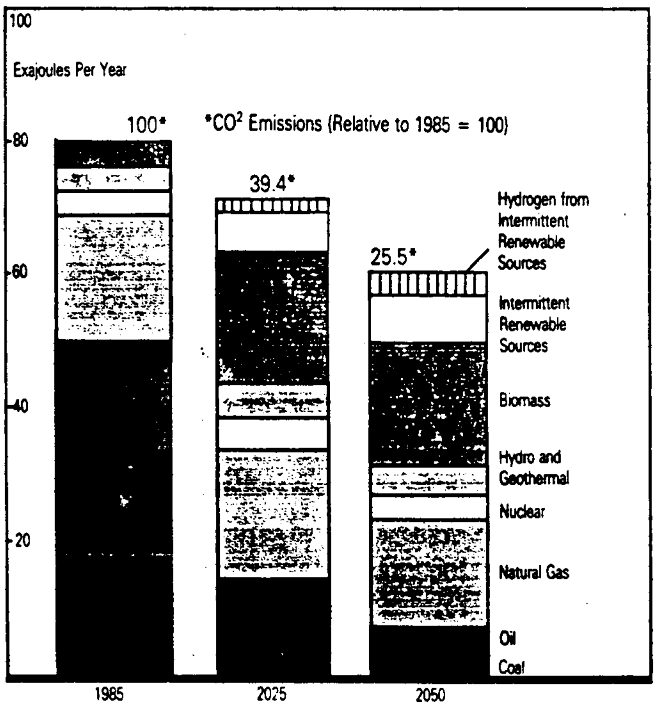
(Williams is a Senior Research Scientist at Princeton University's Center for Energy and Environmental Studies. The UNCED study scenario is detailed in the book Renewable Energy: Sources For Fuels and Electricity, *edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams, 1142 pp., Island Press, Washington, DC, 1992. It is available from the publisher.)*

In the near term, these advanced cycles will use gas turbines; sometime during the next 10 to 20 years, they will use molten-carbonate fuel cells as well. These systems will produce only a tiny fraction of the air pollution released from current steam-turbine plants equipped with scrubbers, and they will be more energy efficient. Compared to an average efficiency of 33 percent for existing coal plants, these gas turbine systems are expected to be 40 to 45 percent efficient, while fuel-cell technologies could achieve efficiencies of 55 to 60 percent. Nonetheless, the concomitant reductions in CO_2 emissions are not likely to be adequate if the atmospheric concentration must be stabilized.

Nuclear power produces no air pollution or greenhouse gases, and its use in generating electricity could reduce dependence on insecure oil supplies. Nuclear safety and radioactive waste disposal, the issues of greatest public concern at present, are, in principle at least, resolvable with technical fixes.

However, at high levels of nuclear power development worldwide, another issue—the nuclear weapons connection to nuclear power—would come into sharp focus: Millions of kilograms of plutonium would be produced annually in reactors; less than 10 kilograms are needed to make a nuclear weapon. New reactor designs that minimize plutonium production and unprecedented levels of international control over sensitive nuclear facilities would be needed to prevent diversions. To resurrect nuclear power, the industry must convince the public and investors that safe, diversion-resistant nuclear power can be provided at competitive costs.

Scenario for a Renewable Energy-Intensive Future in the United States



The chart shows U.S. primary energy requirements, in exajoules (EJ) per year, in a renewables-intensive global energy scenario developed as part of an assessment of future prospects for renewable energy worldwide (*Renewable Energy, 1992*). (One EJ equals 0.45 million barrels/day of oil.) This scenario reflects projections of the Response Strategies Working Group of the Intergovernmental Panel on Climate Change concerning demands for solid, liquid, and gaseous fuels and electricity. A mix of renewable and conventional energy supplies was constructed to match these projected demand levels, taking into account relative energy prices, endowments of conventional and renewable energy sources, and environmental constraints.

Source: *Renewable Energy: Sources for Fuels and Electricity*, T.B. Johansson, H. Kelly, A.K.N. Reddy, and R. H. Williams, eds. (Island Press, 1992)

Producing electricity from biomass (plant matter) is a promising renewable option. If the biomass is grown sustainably, there would be no net buildup of CO_2 in the atmosphere. The United States already has biomass power-generating capacity equivalent to the output of nine large nuclear power plants; the fuel is mainly low-cost biomass wastes. The steam-turbine technology used could not produce electricity at competitive costs with more abundant but more costly biomass feedstocks, such as biomass grown on dedicated plantations. However, electricity from more costly biomass sources could be competitive if produced with technology adapted from coal, involving gasification and gas turbine power cycles. Especially promising are turbines derived from aircraft engines that offer high efficiency and low cost at the modest scales needed for biomass power plants. Biomass is inherently easier to gasify than coal, and it contains negligible sulfur, which is costly to remove from coal. Several demonstration projects are being planned for this technology, which could be available for commercial applications in the late 1990s. Likewise, molten carbonate fuel-cell technologies being developed for coal could also be adapted to biomass.

Crops grown on excess agricultural lands represent a large potential source of biomass for energy. To prop up food prices and control erosion, the United States holds out of agricultural production some 80 million acres, an amount that is expected to increase substantially as a result of continuing improvements in crop productivities. Planting fast-growing trees or perennial grasses is a proven strategy for erosion control. Growing such energy crops on erodible and other excess croplands would conserve the agricultural base while providing new income for farmers.

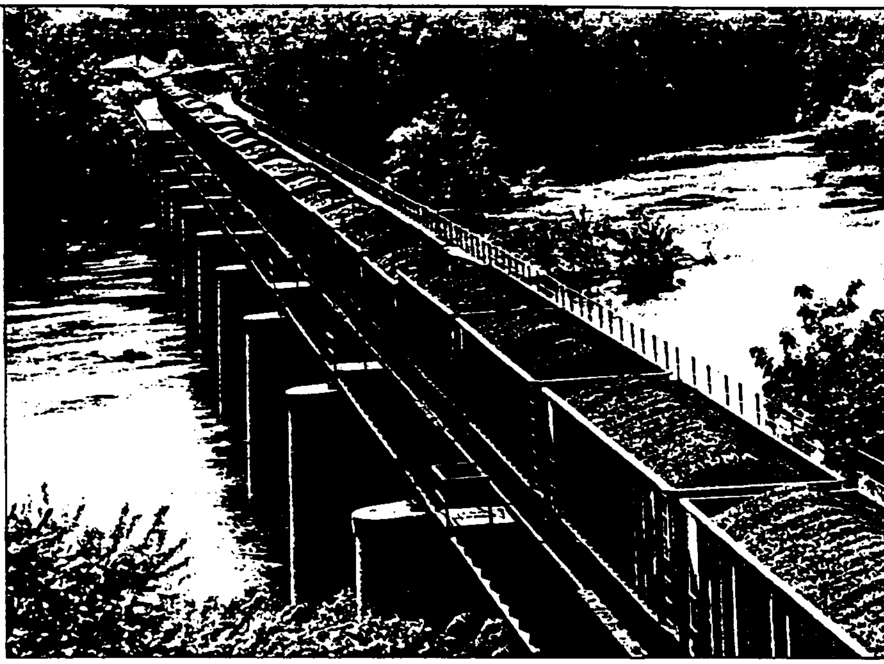
Most renewable energy technologies are characterized by modest scale and modular construction, making them good candidates for cutting costs through organizational learning—in other words, from getting better organized. Modern mass production techniques can be applied to most renewable energy technologies. Moreover, the short lead times from product design to operation make it possible to identify needed improvements by field testing and to incorporate these improvements in modified designs quickly, so that many generations of technology can be introduced in short periods.

The history of wind power in California illustrates the phenomenon. Wind power costs have fallen ten-fold since the first farms were established in the Altamont Pass in the early 1980s. Electricity produced with wind turbine technologies now coming onto the market is cheaper than electricity from new fossil-fuel power plants. Although some of the more recent cost reductions are due to technological improvement, most of the progress has been made through organizational learning. These reductions are expected to lead to rapid growth in the industry, which could potentially provide electricity on a large scale. In the 12 states of the Great Plains and Midwest that account for 90 percent of the U.S. wind energy potential, electricity generation from wind could be up to four times the amount of energy currently consumed in the entire United States.

Although photovoltaic (pv) power costs are about five times that of wind power, these costs are expected to fall sharply in this decade. The prospects are good that some pv technologies will enter electric utility markets before the turn of the century. The absence of scale economies and low operational and maintenance requirements for most pv technologies means that they can be deployed on rooftops and windows as well as in centralized power stations. Because power from pv units installed close to consumers is especially valuable to utilities, we will probably see such applications of pv first, before costs fall to the levels required for centralized configurations to meet competition.

A problem posed by these intermittent renewable sources is that electricity is also needed when the wind doesn't blow and the sun doesn't shine. While the problem seems especially formidable in light of the fact that progress for electrical storage technologies has been slow, it is not as serious as one might think. Both pv and solar thermal-electric technologies produce the most electricity when sunlight is the most intense; where there are air conditioning loads, this also tends to be the time of peak electrical demand.

In the case of wind power, the wind is usually blowing somewhere, so a system of widely distributed wind farms will provide electricity most of the time. A significant penetration of intermittent renewable sources can be accommodated on an electric power system if there are enough low-cost, fuel-burning plants with the flexibility to change their output quickly. Advanced gas turbine power cycles fueled with natural gas would provide such flexibility. Natural gas is the cleanest of the fossil fuels, and U.S. resources are probably 40 to 50 percent more plentiful than U.S. oil resources.



Association of American Railroads photo

In addition to "conventional" air pollutants, coal results in 85 percent of the power sector's emissions of carbon dioxide, a greenhouse gas.

Meeting sustainability goals for transportation will be more challenging than for electricity production. Yet even here the prospects are auspicious.

As described in a later article (see page 24), the quest for zero-emission vehicles has catalyzed a substantial effort to develop the battery-powered electric car. The potential for replacing internal combustion engine cars with this technology is limited, however, because several hours are required to recharge the battery and the range between charges is limited.

A promising alternative is the fuel cell electric car. As in a battery-powered car, the fuel cell provides electricity to power motors that drive the wheels. The proton-exchange-membrane (PEM) fuel cell, developed originally for space and military applications, is a compact power resource well suited for cars. In operation, hydrogen fuel combines with oxygen from the air to form water vapor, the only byproduct. Refueling takes only minutes for compressed hydrogen gas. A hydrogen fuel-cell car would be about three times as energy efficient as a gasoline-powered internal combustion engine car of comparable performance. Prototype PEM fuel-cell cars will be built in the mid-1990s, and commercial vehicles could become available less than a decade later.

Experience shows that hydrogen can be used safely, although it is often perceived as a particularly dangerous fuel. The perception is probably largely due to the Hindenburg disaster, one of the rare accidents involving an energy source that was caught on film. Certainly, the public must be convinced that hydrogen can be used safely before it is introduced on a wide scale.

Initially, hydrogen could be produced with existing technology from natural gas; subsequently, a shift to renewables could take place. The cheapest way of producing hydrogen from renewable sources is through the thermochemical gasification of biomass, a technology that could be commercialized by 2000. Hydrogen could also be produced electrolytically from water, using electricity derived from wind or pv sources. With expected reductions in the costs of these sources, fuel-cell cars operated on wind or pv hydrogen could well be competitive with battery-powered cars during the first decade of the next century. While this hydrogen would probably be twice as costly as that derived from biomass, the amount that could be produced is vast. For