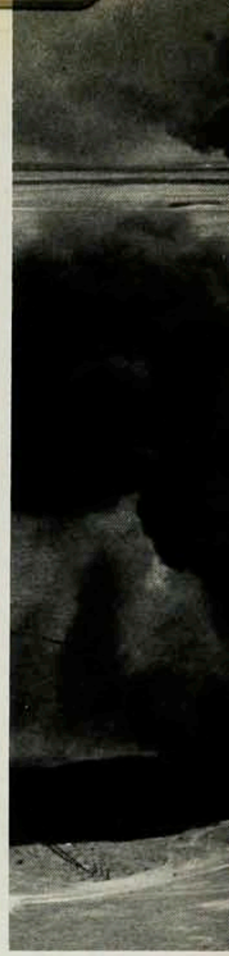

US ENERGY TRANSITION: ON GETTING FROM HERE TO THERE

President Bush's recently released National Energy Strategy suggests that the US can meet its future energy needs without pain or tears. Other studies argue that the country can only avoid dysfunction by creating an energy program that is less dependent on foreign supplies and meets three broad, overarching national goals: economic vitality, environmental quality and strategic security.

John H. Gibbons and Peter D. Blair

Uncommon events like the Exxon Valdez oil spill, the Three Mile Island nuclear power plant meltdown and the Persian Gulf war as well as such unremitting problems as global climate change and the balance-of-payments deficit point up the urgency of dealing with the nation's energy issues. Congress is now deliberating President Bush's National Energy Strategy. The topic is hardly a new one. In fact, in the words of that immortal American philosopher Yogi Berra, "It's *déjà vu* all over again."

The Bush strategy was issued on 20 February, after a year and a half of grassroots hearings across the country and contentious deliberations within the White House. It turns out that this is the ninth time a President has sought a thoroughgoing national energy program. The first time was when Franklin Roosevelt directed his staff, at the brink of World War II, to make sure the US was not left vulnerable for want of ample supplies of energy.

One conclusion that emerges from the history of these exercises is the realization that there are no energy "fixes" that are easy, quick or cheap. The last 20 years provide repeated examples of how susceptible the US has become to energy cutoffs and crises: electricity blackouts, nuclear plant accidents, oil embargos, price manipulations by a cartel, long gas lines and the chronic problems of increasing dependence on the volatile Middle East. If we didn't know it already, the Persian Gulf war reminded us how dependent most of the world is on oil from abroad.

As the latest Middle East crisis recedes, we may be beguiled again into a false sense of complacency about energy. Consider what happened in the past decade: Having been seduced by fairly steady supplies, easy gains in efficiency and small price increases for both gasoline and electricity below the rate of inflation, the country largely abandoned the efforts of the 1970s to push R&D in energy conservation and alternative sources. Such on-again, off-again policies haven't worked. Major changes in energy systems—and major changes are what must occur—require unwavering commitment over decades by political authorities, industrial captains, business chiefs and the rest of us. To be sure, energy is a flexible component of a modern economy, but it takes a long time to achieve a major turnover of the capital stock of energy and the capital equipment that produces and conveys energy. Short-term strategies for either spurring production or curbing consumption are usually inefficient and often traumatic. A sensible, comprehensive energy policy certainly must be responsive to sudden changes of events, but it must also be grounded in a long-term strategy.

Along with the President's new strategy, Congress is considering a wide range of other energy-related legislative proposals. It is important to weigh these options in the context of three of the country's overarching imperatives: economic vitality, environmental quality and strategic security. This is not easy to do. The means of achieving these goals often are at odds. For instance, increasing our reliance on coal could reduce our dependence on imported oil, and yet it could also aggravate air

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Symbolizing oil waste, this scene shows a few of the more than 600 fires set in Kuwait by retreating Iraqi troops in the last days of the Persian Gulf war. Though 160 oil wells and pipelines have been capped or controlled since February, about 500 fires are still contributing to an inferno that consumes about 3 million barrels of petroleum per day, equal to some 5% of the world's daily use of oil. The Gulf war heightened American concerns about the nation's vulnerability to stoppages and shortages of oil from the Middle East reminiscent of those in the 1970s. In 1990 the US bill for oil imports amounted to \$65 billion, nearly half of the total balance-of-payments deficit of \$101 billion.

TSGT PERRY HEIMER/US AIR FORCE PHOTO

pollution problems and exacerbate global climate change. Still, some energy options, particularly those that improve efficient production and use, can contribute to attaining all three goals.

In the almost two decades since the first Arab oil embargo in 1973, perceptions of the role of energy in the US and world economies have changed considerably. Throughout the 1970s, concern about the price and availability of oil spurred development of a wide range of new technologies for improving energy supply and consumption. The dramatic increases in energy efficiency in the US economy were second only to Japan's during that period. Those efficiency improvements, coupled with the decontrol of oil and natural gas prices during the late 1970s, contributed to increases and more diversity in energy supply and subsequently to a drop in energy prices during the mid-1980s.

Beyond price and availability of energy

Despite those gains, US energy use per dollar of GNP is still twice that of some industrialized nations. Today's inquiries into energy policy do not focus so much on price and availability as on such issues as regional and global environmental conditions, balance of payments, international industrial competitiveness and national security.

The US currently consumes about 81 quads of energy annually. (One quad equals 10^{15} Btu.) Most analysts forecast that by the year 2010 we will consume more than 100 quads. The Department of Energy, for instance, projects[1] a "base case" of 108 quads in 2010. Without fundamental changes in energy policy and with moderate economic growth, the sources of energy we use to fuel the economy in 2010 are expected to be similar to what they are today: about 40% oil, 20% natural gas, 25% coal and perhaps 15% renewable sources and nuclear power. Nonetheless, some important features in the US energy supply-and-demand balance are changing, and these changes, in turn, are affecting the realm within which policy decisions are made, especially decisions about technologies. Increasingly, far-reaching concerns such as the threat of global climate deterioration are influencing decisions about energy policy.

We need to understand the major changes in the patterns of US energy supply and demand since the 1970s. Four of the most significant changes are:

▷ the steeply declining energy intensity of the economy between the early 1970s and mid-1980s

▷ the falloff of domestic oil discovery and production and, with this, the sharply increasing reliance on foreign sources of oil

▷ the changing patterns of electricity use in the economy and shifts in the structure of the electric utility industry

▷ the increasingly complicated environmental implications of energy technologies.

For many years most observers believed that energy use and GNP were inextricably linked, always moving up in lockstep. We've learned since the energy shocks of the 1970s, however, that economic growth is not necessarily contingent on using more energy. In fact, slow economic growth tends to cause disruptions that impede actions to improve energy efficiency. Those actions include spending for less energy-intensive products, which would include retrofitting homes and commercial buildings with better insulation and efficient appliances, and funding research and development. Ingenuity can substitute for supply when the price is right. When the price of energy increased in the 1970s, it stimulated impressive gains in energy efficiency. Producers adopted more efficient ways of providing energy services; manufacturers introduced more energy-efficient automobiles, heaters and appliances; consumers shifted their market basket of purchases to more efficient products. The energy intensity of the economy—that is, the energy consumed per unit of GNP produced—fell 2.5% per year between 1972 and 1985, with most of this drop caused by improved efficiency. (See figure 1.) A striking example of the period was the doubling of efficiency for new car fleets from 14 mpg in 1973 to 28 mpg today, with little or no loss of size, comfort and safety.

Another trend over the past 20 years was the slowed growth in electricity usage. This is attributed primarily to improved efficiency, though demand was offset in part by the increasing substitution of electricity for other fuels in all sectors of the economy. Nonetheless, the net result was a drop in the ratio between electricity consumption and GNP by about one-half (from 2:1 to 1:1) since 1970.

Today, in addition to other energy sources, the US consumes about 17 million barrels of oil per day, which is about 25% of total world consumption. The current US consumption rate is about 14% more than it was in 1983. Over the same period the level of domestic oil production has declined considerably, due largely to the depletion of low-cost resources and the absence of new discoveries. The net result is that imports rose from about a third of total US consumption in 1983 to nearly 45% in 1990. Moreover, the fraction of total imports coming from Persian Gulf nations has increased at the same time from about 4% of total US consumption (10% of total oil imports) to more than 10% of current consumption (26% of current imports).

Dependence on Middle East oil

In some respects our oil use, domestic supply and import dependence are still similar to those of the 1970s, especially the transportation sector's virtually complete reliance on oil. In other ways our dependence on oil has improved considerably, however, especially the more efficient use of oil in many industries and the substitution of other fuels for oil, particularly by the electric utilities. The US government enlarged the strategic petroleum reserve and ended oil price controls and restrictions on the use of natural gas. In addition, an active spot and futures markets for oil supply has developed in recent years. Major oil-consuming countries have agreed to share world supplies of petroleum in times of crisis. All of these changes, and others as well, contain implications for the possible future of our oil use. In spite of these developments, the US economy is now and will continue to be increasingly dependent on foreign oil, especially on supplies coming from the volatile Middle East.

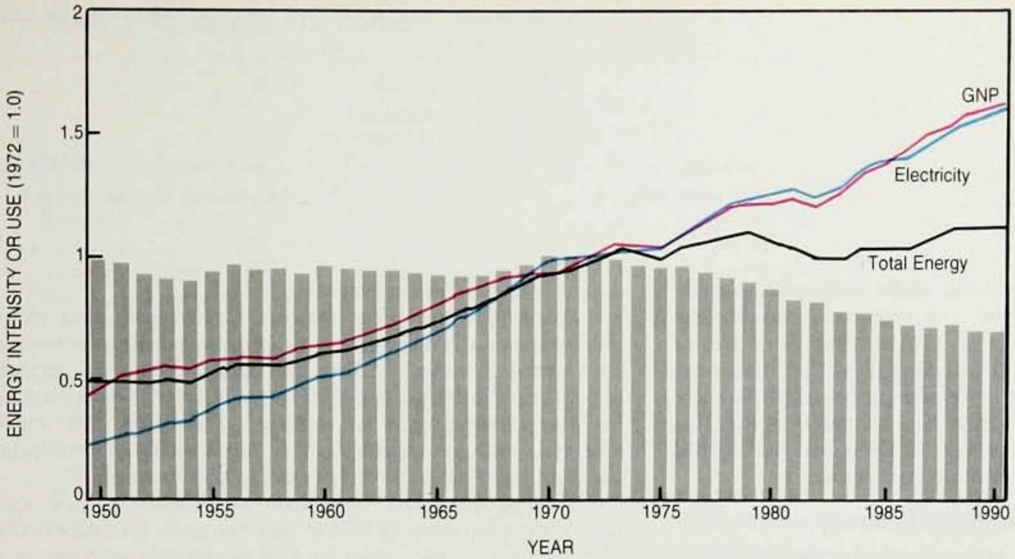
The US electric utility industry has weathered dramatic changes in the last two decades. Since 1986, the demand for electricity has picked up substantially, not only in the US but elsewhere, particularly in Japan. As a result, the industry faces a wide range of changes that are likely to shape its future technological choices, operating characteristics and regulatory structures. Among the possible changes is the emergence of a truly competitive power-producing industry, which could generate some major mergers and acquisitions as well as modifications of the Public Utility Holding Company Act. Some changes are already evident. One is the trend toward least-cost planning and toward demand-side investment and management; others are the emergence of natural gas as an increasingly important fuel for electric power generation and the almost certain consequences of the Clean Air Act of 1990 for electric utilities.

While such changes could significantly alter many features of the electric utility industry in the US, none of the changes supposes radical shifts in the fuel mix for creating electricity. Without significant action, electric power will continue to be generated by fossil fuels, notably coal, tempered somewhat by natural gas and nuclear power, well into the next century. (See figure 2.)

Much of the energy policy enacted in the last decade has actually been driven by environmental policy. Moreover, environmental concerns have motivated the accelerated development of some new energy technologies. For example, such clean coal technologies as advanced flue-gas scrubbers, fluidized-bed combustors and coal gasification are used increasingly in utilities and industry. The introduction of advanced engine technology, catalytic converters and alternative transportation fuels, particularly methanol and compressed natural gas, could have a similar impact on the transportation sector. What's more, a variety of technical developments have greatly improved energy efficiency in lighting, appliances and buildings. There is no question that more stringent environmental regulation of air, water, nuclear waste, surface mining, oil exploration and development and other matters will bear on the evolution of energy supply and demand technologies in the coming decades.

Technological innovation has always been a cornerstone of any strategy for dealing with current and longer-term energy policy issues. Today it holds promise for cleaner and more efficient energy use, safer and more effective recovery of energy supplies and smoother transition to a post-fossil-fuel era. Indeed, after two decades of experience with new energy supply and use technologies—some good, some bad—we as a nation have come to understand much better the pivotal position of new technologies in energy strategy.

Several technologies are of conspicuous interest in the 1990s. In what follows we discuss the prospects for the future of nuclear power, both fission and fusion, the evolving character of renewable energy technologies and our increasing experience with them, and the pace of research and development in quest of new energy-efficient technologies. We are also concerned about the specter of



Energy intensity (depicted by gray bars), or energy use divided by GNP, was relatively flat from 1952 to 1973. After 1973 energy use remained relatively constant while GNP continued to rise, resulting in a drop in energy intensity. Unlike the use of other forms of energy, such as oil, electricity usage grew in tandem with GNP. The graph illustrates that the nation's economic growth is not necessarily contingent on using more energy. **Figure 1**

global climate change, which hovers over virtually every technological choice for energy supply and demand.

In much of the industrialized world, most notably in France and Japan, nuclear power plays a large role in electric power generation. In the US today 20% of electricity is generated by 110 reactors—more than in any other nation. Even so, no construction of any new nuclear plant has begun since 1974. The full cost of nuclear power relative to other alternatives remains a significant concern. In addition, and related to cost, three major obstacles stand in the way of a new generation of nuclear power plants in the US:

▷ slow licensing procedures

▷ sluggish commercial development, along with a notable lack of acceptance of advanced reactor designs by industry, government and the public

▷ stalled decisions relating to nuclear waste disposal.

The order in which these issues are resolved could be very important. For example, assuming that the technology remains the same, a prolonged and unproductive debate over licensing reform is virtually certain. If, however, the nuclear waste issue were resolved and new reactor designs were available and shown to be responsive to public worries, licensing reform might be easier to achieve.[2]

The main issues of electricity supply narrow down to deregulation of production, access to transmission and minimization of cost. While nuclear power remains in limbo, some alternatives, including high-efficiency gas turbines, advanced coal burners and such renewables as wind power and solar thermal energy, are popular. It is likely that any new nuclear plants built in the US will be in the range of several hundred megawatts—smaller than any since the early days of the industry. Because of uncertainties in forecasting the growth of demand, the cost of capital and the length of construction, as well as regulatory rules and permitted prices, electric power utilities now generally avoid building any nuclear plants with capacities in the gigawatt range.

Utilities, regulators and investors are eager to limit their financial risk. As a result, they have shown increasing interest in modular units that are largely factory manufactured and can be delivered rapidly as needed, that incorporate passive safety features and that adhere to a standardized design. New reactor concepts responding to these criteria include the advanced light-water reactor, developed by Westinghouse and General Electric; the modular high-temperature gas-cooled reactor, designed by General Atomics; and the power reactor inherently safe module, known as PRISM, now under development at GE.

Advances in renewable energy systems

Several renewable energy technologies are already commercialized. These include hydropower, wind turbines, some biomass technologies, solar collectors and passive solar design features. These technologies continue to advance, especially in reliability, efficiency, cost, sophistication and durability. For instance, designs of wind turbine blades continue to evolve to optimize operation near stall speed.

So, while some renewable technologies, such as photovoltaics, certain solar thermal electric technologies, geothermal and wind, are available, such concepts are not generally competitive with more traditional technologies, especially for large-scale energy applications. Increased market penetration of many of the mature technologies is currently limited by the low cost of conventional fossil fuels and the availability of such highly attractive, familiar renewables as hydropower. Still, some of the newer renewables have experienced remarkable success and are already fully competitive in some regions of the country. Most of the commercial success of renewables has come in situations where the technologies are deployed in the most favorable locations. Examples include the geothermal sources at The Geysers in California, the wind turbines in the Altamont Pass near San Francisco and the solar thermal electric facilities in southern California. Many of these technologies have the potential for further improvement in cost and performance.[3] Additional renewables, such as some advanced biomass technologies, including biomass-based synthetic liquid and gaseous fuels, have few commercial applications to date. Even so, they possess great potential for improved cost and performance—hence for wide commercial use.

Compared with nuclear power, renewable technologies have attracted only modest investments in R&D from both public and private sources so far. (See figure 3.) In consequence, major innovations are not apt to come about soon for many of these technologies, compared with the likely incremental changes ahead for nuclear and fossil technologies. On the other hand, while comparative costs still favor fossil technologies, the costs are converging. The cost of solar energy is now within a factor of two of that of fossil fuels, down dramatically within the past decade. Indeed, some state rate-setting commissions are beginning to provide substantial incentives to companies that generate non-fossil energy, a decision that could accelerate interest in renewable technologies.

Efforts to improve energy efficiency

Over the last decade and a half, efforts to improve energy efficiency in end uses and in generating electricity from traditional fossil fuels have been among the most successful components of US energy policy. In many cases investments in energy efficiency brought about results that exceeded even the most optimistic forecasts, contributing substantially to the startling fact that there has been almost no increase in total energy consumption since 1974, despite a GNP growth rate of 40% in the same period. For the most part, the investments were in industry, transportation, commercial buildings and private residences—sections of the economy where fuel represented a significant operating cost and, significantly, where the payback on the investment could be realized quickly.

To be sure, many actions taken in the past were aimed at easy targets. While some involved simple changes in patterns of energy use, such as adjusting thermostats, most were investments in technology that involved essentially no changes in life-style. Among these were housing retrofits, such as adding more insulating material and installing more efficient lighting. Other efficiency improvements centered on new building designs and shell construction methods for both residential housing and commercial buildings, which led[4] to reductions in the amount of energy used per unit of floor space of new structures by half since 1974. Despite impressive efficiency gains in passenger cars since 1974, still greater gains in cars and light trucks are feasible over the next 10 to 15 years.

The Bush Administration's current strategy for developing new energy technologies, as set forth in its new energy plan,[5] and for advancing the relevant underpinnings in scientific research, assumes that there is adequate time and incentive to enable the private sector to fill the gaps of energy supply and to respond to conservation opportunities as these appear. This strategy may not be sufficiently sensitive to the concerns that stimulated special interest in supply and conservation technologies in the past. It is unreasonable, for instance, to expect commercial firms to take full account of environmental problems or foreign policy and national defense implications in making investment decisions about energy. This is one of the main reasons why the Federal government is so important in stimulating research, technology development and market incentives for energy. In this connection the government is particularly concerned that liquid fuel substitutes for oil be available and that oil be more efficiently used—two policies that are vital to virtually our entire transportation system.

Another nonmarket concern involves finding more environmentally acceptable ways to generate electricity. The current period of low and stable world oil prices, relative to the 1970s, is providing a window of opportunity for the development of supply substitutes and more efficient end-use technologies, to ensure commercial availability of these technologies in the future.[6]

Among the most important conditions for the sustained development of better technologies, and especially of conservation technologies and renewable sources, is a Federal presence in R&D that is committed to a long-term strategy. While many energy technologies are no longer in the basic research phase, their development still faces formidable hurdles, and the importance of R&D remains high. Policy options aimed at accelerating the commercial availability and market penetration of new technologies should focus on reducing cost, improving performance and resolving uncertainties in both cost and performance. A key to sustaining progress in R&D is to provide a stable funding environment so that long-term research ideas are encouraged or at least not penalized.

Oil as a 'pressure gauge' of politics

When policy analysts reflect on the Persian Gulf war and recount other events of the past 20 years in the Middle East, they attribute at least some of the rationale for our military presence in that part of the world to our dependence on its oil reserves or, in President Bush's own words, "US economic interests there." Yet energy security is only one dimension of our concern with energy supply and demand. As noted earlier, local, regional and global environmental pressures and international competitiveness issues are two of the newly added factors shaping future US energy supply and demand as much as concerns over energy security.

In 1977 the Office of Technology Assessment suggested that the level of US oil imports was a "pressure gauge" measuring how well American energy policies are succeeding. Today, while circumstances have evolved to lessen somewhat the significance of imports as a measure of energy security, the current level as a percentage of total oil consumption is at nearly 45%, and many analysts expect the percentage to run to more than 60% by 2010, despite major investments in domestic petroleum exploration and development.

It can be forcefully argued that imports should be allowed to increase as long as the net effect on our economy is positive. Other countries, such as Japan, are much more dependent on oil imports than we are. But the situation is not that simple, because in the US, unlike in Japan, the full cost of import dependence is not reflected in the price, which does not include support of the military, for instance. If we were to set policies that propelled us more steadily toward energy efficiency and development of non-fossil fuel, as Japan has done, and if we were to set gasoline prices at $3 to $5 per gallon, as Japan has done, then the argument for forgetting our vulnerability to oil imports might make sense.

Measures to lower US carbon emissions*

	Reductions in 2015 Moderate scenario	Reductions in 2015 Tough scenario
DEMAND-SIDE MEASURES		
Residential and commercial buildings		
New investments		
Shell efficiencies	3.6	6.0
Heating and cooling equipment	1.1	1.6–2.5
Water heaters and appliances	1.3	1.6–2.4
Lighting	2.1	3.0
Office equipment	1.6	2.1
Cogeneration	0.2	1.5–2.3
Operation and maintenance, retrofits		
Shell efficiencies	1.6	1.7
Lighting	1.1	1.3
All residential and commercial	8.9	18.6–21.6
Transportation		
New investments		
New auto efficiencies	0.8	3.5–3.8
New light-truck efficiencies	0.5	2.5–2.7
New heavy-truck efficiencies	0.4	2.4
Nonhighway efficiencies	0.5	1.2
Operation and maintenance, retrofits		
Improved public transit	0.2	3.5
Truck inspection and maintenance	0.3	0.4
Traffic flow improvements and 55 mph highway limit	1.2	1.4
Ride sharing and parking controls	0.4	1.0
All transportation	4.0	14.0–15.0
Industry		
New investments		
Efficient motors	1.2	3.7–4.0
Lighting	0.5	0.7–0.8
Manufacturing process change in the top four industries	3.0	8.2
Fuel switch to natural gas	0.0	2.4–2.7
Cogeneration	0.8	5.2–5.8
Operation and maintenance, retrofits		
Housekeeping	1.9	2.0
Lighting	0.1	0.2
All industrial	8.0	17.0–18.0
UTILITY SUPPLY-SIDE MEASURES		
Existing-plant measures		
Improved nuclear utilization	4.1	4.1
Fossil-fuel efficiency improvements	1.7	1.7
Upgraded hydroelectric plants	0.5	0.5
Natural gas cofiring	0.0	3.7
New-plant measures		
No new coal; higher fraction of new fossil sources	0.0	0.0–4.7
CO_2 emission rate standards	0.4	0.0–0.1
FORESTRY MEASURES		
Afforestation (Conservation Reserve Program, urban trees, additional trees)	0.2	3.2
Increased tree productivity	0.0	3.1
Increased use of biomass fuel	0.0	1.2
All forestry	0.2	7.5

* Expressed as percentage of 1987 total emissions (1% of 1987 emissions = 13 million metric tons of C = 0.75% of 2015 emissions).
Source: Office of Technology Assessment, 1991.

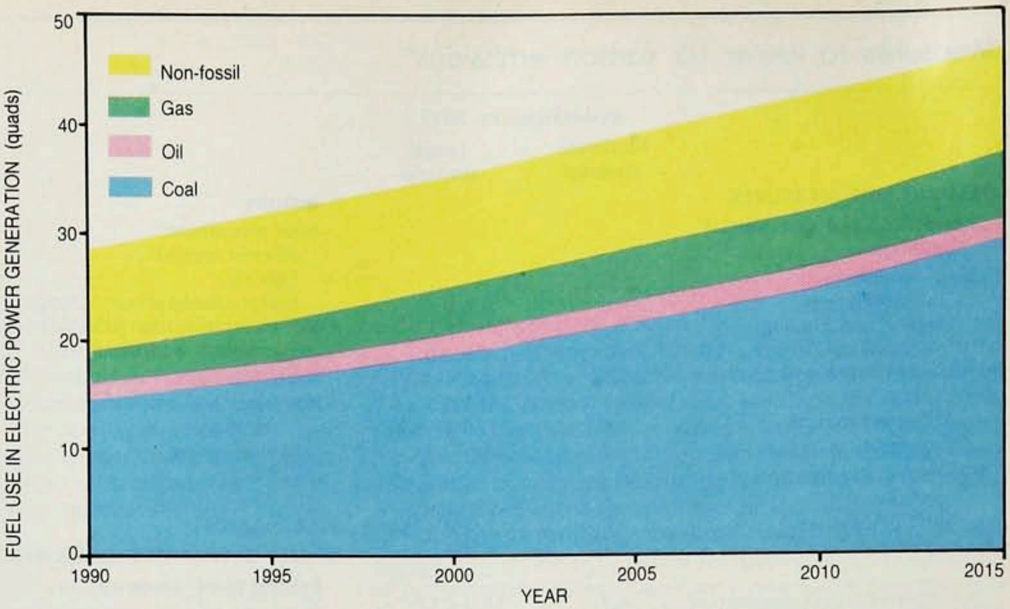
An essential component of that vulnerability is a seemingly intractable negative balance of payments. Oil imports amount to about half of our trade deficit and opportunities to reduce such imports offer an attractive means of improving our trade balance. It can thus be argued that some of our most attractive strategies for balancing our international payments are associated with investments in higher energy efficiency and alternative energy sources—the Japanese method, to be sure. As a nation we must stick to the strategy for achieving those goals through periods of both crisis and calm, as well as through periods of variable oil prices.

The discipline of physics enables practitioners to describe phenomena comprehensively and accurately, as well as to simplify things. Maxwell's equations are a case in point, providing a metaphor for an approach to energy policy. Society properly merits a policy that is described simply and framed in such a way that quantitative goals are explicit. Using previous studies and analyses by OTA, and paying heed to the lessons learned over the past two decades, we offer below three policy goals. We know that there can be other formulations, but the three we discuss could, in combination, guide us through a period of several decades to a vastly improved energy situation that is consonant with the national goals for our economy, our environment and our security.

In 1990 the nation's bill for oil imports amounted to $65 billion, well over half of our total balance-of-payments deficit of $101 billion. Unless aggressive actions are taken, our dependence on imported oil will grow substantially. Of course, if it is less expensive (as measured in *total* indirect and direct cost) to import oil than to offset that need domestically, then it makes sense to import. But there is strong reason to believe that the reverse is true, and that our national economic well-being would be improved by shifting investment to reduce imports under a long-term, least-cost strategy. For example, one goal we might choose in limiting oil import dependence would involve holding our imports to no more than 50% of total US oil use. The President's National Energy Strategy calls for a 40% limit but provides no convincing procedures for achieving that level. Our scenario would also include work to diversify sources of world oil production—and therefore sources of US imports—to regions of the world outside the Middle East where such imports can be aligned with other US policy interests.

Supply mechanisms for achieving such goals include sustaining current levels or at least slowing the decline of domestic oil production while developing and producing alternative transportation fuels, and spurring the development of petroleum resources in regions such as Asia, South America and the Soviet Union, where known

Demand for electricity continues to increase, and a wide range of changes in the electric utility industry are likely to shape its future technology choices and operating characteristics. None of the changes is likely to alter the fuel mix for generating electricity: Without significant action it will still be dominated by coal. Today, about 55% of US electricity comes from coal, and the Department of Energy projects that this will rise to 60% in 2010. **Figure 2**



reserves are yet to be extracted. Demand mechanisms include improving the efficiency of oil use in all sectors, particularly transportation, and shifting industrial, residential and commercial use into such other sources as natural gas and electricity. All these options imply not only investment and commercial development of new technologies, but also sustained research. We observed earlier that some of these technological options may be inimical to political or economic interests. Widespread commercialization of technologies for producing alcohol fuels from grain and biomass, for example, could affect food prices and alter land use patterns.

About two-thirds of the fall in US energy intensity over the last decade is attributable to improved efficiency in energy conversion and use in every sector of the economy. Such efficiency gains—that is, reductions in the energy consumed per unit of service provided (area heated or cooled, say, or miles traveled)—have generally come about without sacrifice of either comfort or dollars, but rather have resulted in net cost savings. Considerable future gains in energy efficiency are still possible in all sectors of the economy using existing technologies, and even greater cost savings and efficiency gains are possible with technologies now in research and development.

Considering what has happened over the past 15 years—and after analyzing additional opportunities that are both technically and economically attractive—we think a sustained improvement in efficiency of 20% per decade for the next two decades is a realistic goal. We believe this change is possible over and above the most likely continued drop in energy intensity due to structural changes resulting from factors other than energy use *per se*, including the readjustment of demographics and the continuing transformation from manufacturing to services. With more vigorous research on energy efficiency, coupled with greater investment and policy leadership, and with the help of more appropriate energy pricing, this goal can be met or exceeded—by means of options that are certainly no more costly than pursuing the present supply-side path.

This strategy is likely to provide great opportunities for innovative research and development—certainly home ground for physicists! An active R&D program in energy would bolster all three overarching national policy interests of economic vitality, environmental quality and national security.

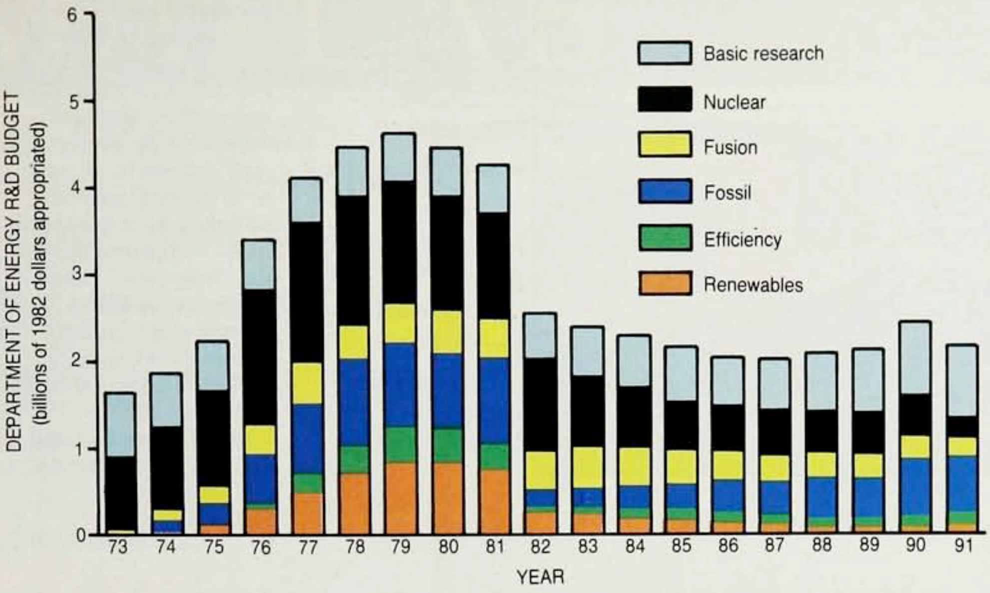
Beyond the age of fossil fuels

For decades most people have assumed that fossil fuels will supply human energy needs for several more centuries. But now the specter of air pollution and climate change casts an ominous shadow over the already troubled future for fossil fuels. The fossil era may wind down not in centuries but sometime in the next hundred years. This means that unless we ignore global climate change, which we would do at our peril, solar and nuclear power (both fission and fusion) must become the dominant energy sources everywhere on our globe—possibly within 50 years. That's a daunting prospect. Unfortunately, for different reasons, neither nuclear nor solar technologies are attractive options for massive deployment in their present state.

The only serious hedge to our long-standing bet on fossil fuels has been our effort to work on harnessing nuclear power. While attempts to develop a fusion power technology have so far been frustrating, fission power now accounts for 20% of US electricity, or about 8% of our total primary energy budget. Other non-fossil fuels, mostly generated by hydropower and biomass burning, add another 8%. So the non-fossil fraction of our present energy budget is in the range of 15% to 20%.

In this country the nuclear power enterprise, for several reasons, is in deep trouble—so deep that the task of rescuing it could well be more difficult than the original job of creating it. And our commitments to harnessing solar energy more effectively and broadly have been comparatively minuscule. However, developing attractive nuclear (fission and fusion) and solar options is patently possible. For example, efficiency gains in photovoltaic conversion have resulted in reductions of half an order of magnitude in installed costs over the past two decades—and further gains appear promising. Likewise, small-scale modular nuclear power reactors with passive safety features show great promise. Then, too, technologies using solar thermal arrays and aerojet turbines driven by burning biomass are nearing direct economic competitiveness. Despite the gains to date, such options require—and merit—long-term commitments of research, development and investment, which, in turn, means we must now move ahead on that odyssey.

A prudent goal for current US policy is an average reduction in carbon intensity of energy use of at least 10% per decade for at least the next two decades. Steps to achieve this goal could include improvements in end-use



Budgets since 1973 for R&D at the US Department of Energy reveal that in constant 1982 dollars, support for basic research has stayed virtually the same, while funding for nuclear fission and fusion and for renewable energy sources has decreased, in some cases drastically. DOE appropriations for fossil fuel R&D have varied considerably over the years, rising during the late 1970s and again in the 1990s with support of clean coal technologies. **Figure 3**

and energy conversion efficiency, changes in the fuel mix, such as replacing coal with natural gas or adopting a combination of the two, and increasing use of renewables and nuclear power. The number we offer for this goal is perhaps less important than the will to define a goal, to vigorously pursue that goal and to modify it based on the experience of pursuing it. Economically attractive efficiency improvements and increased use of methane would dominate the first decade or two, giving us time for nonfossil fuels to take hold in ground and air transport and for new sources of electric power to develop systematically and efficiently. Technologies emerging from such a commitment could give the US an advantageous competitive position in the world marketplace. To illustrate the implications of the policy goals we have outlined, in the following section we relate these goals more specifically to future scenarios of US oil production and use and to the reduction of greenhouse gas emissions.

Sustained energy for a robust society

In figure 4 we illustrate the vigorous and sustained efforts that will be required if we choose to limit oil import dependency over the next several decades—even to a relatively high level such as 50%. The largest and most attractive opportunities lie on the demand side. Fortunately, such options hold the promise of providing good new jobs and important new commercial activities to strengthen the nation's domestic economy. To the extent that we improve cost-effectiveness, supplies will last longer, our economic competitiveness is bound to improve, environmental problems will be eased, and the chances for international crises will be lessened.

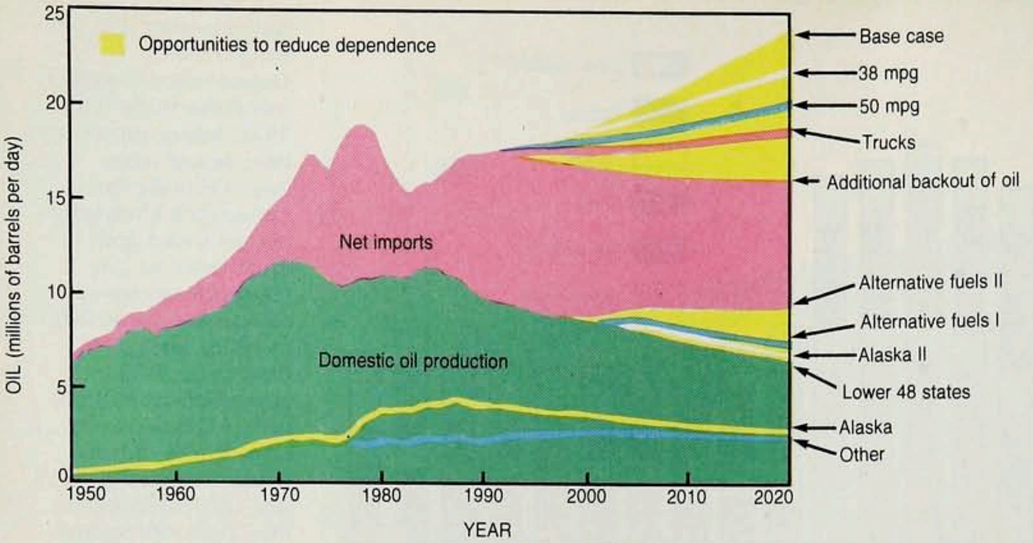
But improved efficiency, however dramatic, will not be enough. The traditional opportunities on the supply side, such as enhanced domestic production in the lower 48 states, off shore and in Alaska, are more modest than increased demand efficiency—though still important. And with time, there are various opportunities for shifting to alternative transportation fuels such as methanol, compressed natural gas, hydrogen and electricity. These fuels have extensive long-term implications, however. The oil replacement potential must be weighed against the energy, environmental and financial costs associated with producing and using these fuels.[7]

The pacing of all these efforts is an essential feature of energy policy. Like turning around a fully loaded supertanker, changing the present course of our national energy system will require time and vision if it is to be achieved without stress and strain on the economy. Patterns of energy supply or demand can change radically as technology changes and as capital stock turns over, but we have learned that short-term changes in policies and technological quick fixes can lead to economic hardships and inefficiencies.

A responsible energy policy will complement as much as possible a responsible environmental policy. There are some activities that might spur our economy and enhance national security but run counter to environmental goals. For example, by relying on coal the US could cut its dependence on imported oil but exacerbate the problems of air pollution and climate change. Such strategies should be seriously considered only if we've exhausted other options that more generally support all of our broad goals, such as a fuel cell for transportation that burns hydrogen derived from solar or other sources.

With a wealth of off-the-shelf technologies and some near-ready technologies, we see no reason why existing environmental goals need to be compromised to meet our demand for energy services. Energy and environmental concerns are closely linked and are usually considered to be on a collision (or perhaps orthogonal) course. Therefore neither energy nor environmental policies should be developed or changed in isolation. For example, more than half of US electricity generation today is fueled by coal, the major source of SO_2 and CO_2 emissions. Policies to improve the efficiency of electricity use directly translate into reducing such emissions, typically at a cost considerably less than that of new power plants.

The recent OTA report "Changing by Degrees: Steps to Reduce Greenhouse Gas Emissions" outlines the technical steps that would reduce carbon dioxide emissions in the US. In that analysis, we examined several alternative scenarios. In addition to a baseline scenario that assumes continuation of present patterns of energy production and use, OTA constructed a "moderate" scenario that involves measures such as increases in the operating capacity of nuclear power plants and various improvements in end-use efficiency typically requiring some capital investment but ultimately saving money through fuel savings—savings that in most cases would more than compensate for initial costs. (See the table on page 27.) While none of the measures included in this scenario are difficult to achieve



Scenarios for oil supply and demand to the year 2020 devised by OTA indicate several aggressive approaches, such as improving the average auto mileage to 38 mpg or to 50 mpg and the introduction of alternative fuels. Compared against the "base case," which simply extrapolates current usage, forceful actions could result in savings of about 50% in residential and commercial sectors and about 33% in industrial and utility sectors. **Figure 4**

technically, obtaining the cooperation of consumers to use them may not be so easy. An alternative "tough" scenario would lower energy demands further than the moderate case, but includes measures that cost more for the same level of convenience or comfort as well as measures that will be technically difficult to achieve. While all of the measures in the tough case are at least feasible technically, most are *not* based on the best available prototypes or practices. OTA made judgments about what would be feasible for widespread use. Implementing the technically feasible tough measures would also be politically, logistically and economically challenging. The net cost of complying with the tough scenario is inherently uncertain but would range from better than break-even to perhaps $150 billion per year (equal to possibly less than 2% of GNP in 2015), depending upon such factors as future energy prices and the rate of technological progress.

Commitment to energy transition

In addition to providing for contingencies such as interruptions in energy supply, the US needs to constrain its growing propensity for importing oil and emitting CO_2. We need to make an explicit commitment to a transition to the post-fossil-fuel age as well as to an era of constantly advancing energy efficiency. If we want to accomplish such goals at minimum cost, it will take several decades to stabilize our dependence on imported oil, and it could possibly require a century to get beyond fossil fuels. Our long-term economic, environmental and national security future hangs on these transitions, and the possibility of global warming could greatly foreshorten the time we once thought we had to count on fossil fuels. The relationships among the long-term goals of economy, environment and security provide some important guiding principles from which a systematic, integrated and comprehensive energy strategy could flow. There is an ancient Chinese saying worth repeating here: "If you do not change your direction, you are very likely to end up where you are heading."

The current debates about national energy policy have less to do with the goals themselves than with the strategies for reaching the goals and with the understanding of what would happen in the absence of any policy initiatives. Accordingly, President Bush, in commissioning his energy strategy, stated the objectives as "achieving balance among our increasing need for energy at reasonable prices, our commitment to a safer, healthier environment, our determination to maintain an economy second to none, and our goal to reduce dependence by ourselves and our friends and allies on potentially unreliable energy suppliers." These objectives parallel those of the myriad of legislative initiatives being analyzed in Congress and indeed of the ideas we have offered here.

The actions proposed to achieve these goals, however, are deeply tempered in the case of the National Energy Strategy by the President's stated "keystone of the strategy"—namely, to rely on market forces. This feature of Bush's strategy forms a kind of litmus test for energy policy initiatives that excludes a good many options, such as efficiency standards for cars and appliances and, for that matter, such economic incentives as higher taxes on some forms of energy. Regrettably, the ideological test seems to have pruned the final portfolio of the Bush legislative proposals to what many view as a narrow set of production-oriented options and, on the demand side, an almost complete reliance on the fruits of R&D. Thus the stated objective of the Administration's energy strategy, however nicely phrased, falls flat in terms of the balance and the credibility of the proposed plan to reach or even carefully define specific goals. The sad consequence, of course, is that in Congress the President's energy strategy, instead of being viewed as a "vision thing" for lawmakers to contemplate carefully, is now only one of more than 160 energy-related bills in the legislative hopper.

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The opinions expressed in this article are those of the authors and do not necessarily represent those of OTA or the Technology Assessment Board.

References

1. "Annual Energy Outlook," U. S. Department of Energy, Washington, D. C. (1990).
2. For a more detailed discussion of the nuclear dilemma see C. W. Forsberg, A. M. Weinberg, Annu. Rev. Energy **15**, 133 (1990).
3. S. Sklar, Annu. Rev. Energy **15**, 121 (1990).
4. R. Bevington, A. Rosenfeld, Sci. Am., September 1990, p. 76.
5. "National Energy Strategy: Powerful Ideas for America," U. S. Government Printing Office, Washington, D. C. (1991).
6. A comprehensive look at the technological R&D horizon appears in "Energy Technology R&D: What Could Make a Difference," report no. ORNL-6541, Oak Ridge National Laboratory, Oak Ridge, Tenn. (1989).
7. This subject is examined in more depth in "Replacing Gasoline: Alternatives for Light-Duty Vehicles," Office of Technology Assessment, Washington, D. C. (1990). ■