GETTING AMERICA BACK ON THE ENERGY EFFICIENCY TRACK

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ABSTRACT

U.S. energy use in 1986 was equal to that in 1973 even though GNP was 36% higher, implying a 26% decline in national energy intensity. Efficiency improvements in automobiles, appliances, buildings, and manufacturing processes were a major cause of this dramatic reduction. During 1986-90, however, energy use rose almost as fast as GNP. Growing energy use increased dependence on oil imports, the cost of energy services, and emissions of carbon dioxide and other pollutants. America can get back on the "energy efficiency track" by adopting a mixture of economic incentives, efficiency standards, research and development initiatives, and information programs. Relative to the Department of Energy's forecast for the year 2010, a concerted effort to improve energy efficiency could save consumers around $100 billion per year, lower oil imports by 2.7 million barrels per day, and reduce carbon dioxide emissions from burning of fossil fuels by 20%.

I. Introduction

Increasing the efficiency of energy use saves money and reduces environmental damage and energy security problems associated with fossil fuels or nuclear power. This opportunity springs from a new paradigm of energy planning which shows that traditional energy supply investments cost more than improving the efficiency of energy-using technologies, per unit of energy supplied or saved. Making cost-effective efficiency improvements also lowers emissions of carbon dioxide (CO2) and other pollutants associated with the production, transport, and combustion of fossil fuels. Although a high-efficiency, low-emissions energy system tends also to be the least-cost system, market barriers and lack of effective policies are constraining efficiency improvements at the present time.

In this article, we review efficiency trends over the past

18 years and present a high energy efficiency scenario that results in lower CO2 emissions and lower economic costs in the year 2010 than a corresponding business-as-usual forecast published by the U.S. Department of Energy. Rather than a list of technical fixes, our scenario is based on 14 policy initiatives that could make it a practical reality. The scenario employs efficiency technologies that are commercially available and policies that by and large have been demonstrated in the United States at the national level or state level, or in other countries.

Energy Services

The conceptual foundation for our perspective on the energy problem is summarized by the term "energy services". Energy in and of itself is only the means by which nations derive the various services (illumination, drivepower, cooling, heating, transport, and so on) that run economies and otherwise contribute to the standard of living. The amount of purchased energy used to provide a given energy service varies widely, depending on the efficiency of energy use. This point is illustrated in the following example.

Consider the need to provide artificial lighting in a commercial building. Table 1 compares the electricity use and cost of providing this energy service over a 2.5 year period in two different ways: (1) with conventional incandescent lamps (75 watts per lamp); or (2) with integral compact fluorescent lamps (18 watts per lamp). Electricity use is about four-times greater with incandescent lamps. Although the initial cost of each compact fluorescent lamp is significantly more than that of an incandescent lamp, fluorescent lamps offer a more economical way of providing light due to their longer life and lower operating cost. Of course, associated emissions of CO2 and other pollutants will be four-times greater if households use incandescent lamps rather than fluorescent lamps. Compact fluorescent lamps are just one example of the vast number of technologies that can reduce energy use without sacrificing the amount of useful energy services (1).

Energy and Climate Change

Future growth in energy use and emissions of CO2 is especially troubling given the possibility that, even if the world limits the growth of CO2 emissions to 1.5%/year, the earth may commit to a warming of 3.5° to 5°C by around 2050 (2). Even warming at the low end of this range could dramatically alter rainfall patterns, reduce crop and forest productivity, and damage coastal areas. Changes triggered by global warming could be irreversible. A scientific and political consensus is forming that reductions of greenhouse-gas emissions are urgently needed to minimize the risks associated with climatic change (3). The Intergovernmental Panel on Climate Change (IPCC) concluded that CO2 emissions, for example, must be reduced by over 60% to stabilize atmospheric concentrations at current levels (4). Energy use in the United States is critical given that, with only 5% of the world's population, the United States is responsible for 22% of global CO2 emissions.

As energy analysts, we have observed how nuclear power has been plagued by high costs and the fear of high-consequence accidents and ensuing economic and human losses. Similar fears are warranted with respect to climate change. During the years that it will take to better understand the risks associated with emissions of greenhouse gases, it would be foolish not to pursue energy efficiency--especially given that increasing efficiency is fully justified on the basis of its cost effectiveness. Slowing global warming comes as a bonus from "no-regrets" policies that promote the use of cost-effective efficiency resources.

With growing attention devoted to the climate-change issue, energy specialists are debating the costs of possible response options. This debate can be characterized by "top-down" energy analysis versus "bottom-up" analysis. The "top-down" approach uses econometric modeling, which leads to the conclusion that it will be very costly to reduce greenhouse-gas emissions and thus that policymakers should adopt a "wait-and-see" position (5). Such analyses rarely focus on specific technologies to reduce emissions; instead they focus primarily on the impacts of various energy pricing strategies. When energy efficiency improvements are considered, they are treated in an aggregate and implicit manner.

The "bottom-up" approach uses an economic-engineering approach to assess the costs and benefits of specific energy end-use and supply technologies, and ranks the options on the basis of cost effectiveness (6). This approach, which we subscribe to, identifies a large cost-effective potential to reduce emissions with means now at hand and applies a range of policies to obtain these energy savings, including pricing, standards, R&D, information, and financial incentives. These policies are intended to reduce or eliminate market imperfections that lead to inefficient use of energy. As used above, a "cost-effective" investment in efficiency means one which saves money over its lifetime (i.e., the net present value of benefits exceeds costs). Such investments, and the policies to implement them, are frequently called "no-regrets" in the sense that they reduce CO2 emissions but can be justified solely on the basis of economic self-interest.

Both the engineering and econometric approaches were used in a recent study on the policy implications of global warming sponsored by the National Academy of Sciences (7). This study indicates that full implementation of cost-effective energy efficiency measures could reduce U.S. CO2 emissions by up to 40%, with a net economic benefit of $80 billion per year (equivalent to about 15% our national energy bill as of 1990). The consensus among Mitigation Panel members was that half of this potential is achievable. The study goes on to recommend a variety of policy actions to capture a large fraction of this potential, including efficiency standards, financial incentives, education and information programs, and greatly expanded federal R&D on efficiency and conservation.

Prior to providing our recommendations on how to stimulate greater energy efficiency in all sectors of the United States, it is helpful to review trends over the past 18 years. During this period, the United States witnessed rapidly declining national energy intensity followed by a return to robust energy demand growth.

II. 1973-1986: The Energy-Efficiency Boom Years

The 74.3 Quads (1 Quad = 10^{15} Btus) of primary energy consumed in the United States in 1986 was almost identical to energy demand in 1973. Real gross national product (GNP) grew by 36% during this same period, so "E/GNP" (energy intensity) declined by 26%, or 2.4%/year (8). As a result, energy demand as of 1990 was lower than that projected for the "soft" energy path published by Lovins in 1976 (9). Had this reduction in aggregate energy intensity not occurred, the nation would have consumed 100 Quads in 1986 and would have spent at least $150 billion/yr more on fuels and electricity. If electricity use per unit of GNP had remained constant, the nation would have used 1650 billion kilowatt-hours (63%) more electricity in 1989 as compared to the actual value that year (10). Without increases in energy efficiency, air pollution, dependence on oil imports, and other problems associated with energy use would be far worse than they are now. Use of coal and other fossil fuels would have increased and CO2 emissions would be approximately twice what they are today if the United States had followed the path it was on prior to 1973. In short, energy efficiency improvements were the most important new resource for providing energy services during 1973-86 (11).

History shows that it is wrong to view energy demand as inexorably linked to GNP. However, the notion that energy use per unit of GNP is a precise measure of energy efficiency is also flawed. Activity levels (e.g kilometers traveled in a passenger car), structural factors (e.g. numbers of cars), and efficiency factors (e.g. kilometers per liter of fuel) together determine energy use. Efficiency improvements in all sectors explain about three-quarters of the large decline in E/GNP since 1973 (12). Structural changes and interfuel substitution caused the remainder of the decline.

Energy price increases during the 1970s and the early 1980s provided a major impetus for the impressive efficiency gains. Prices were driven up by two oil price shocks, decontrol of oil and natural gas prices, and escalation in power plant construction costs. Prices then sparked (or accelerated) structural shifts within the economy, technological improvements, and behavioral changes.

Public policy also played an important role in accelerating efficiency improvements during the 1973-86 period. Successful policies included the Corporate Average Fuel Economy (CAFE) standards for automobiles, state appliance efficiency standards, new utility regulations to stimulate cogeneration, and federal energy conservation research and development programs. Complementary policies that combine technology development and demonstration, consumer education, financial incentives, and minimum efficiency regulations work best (13).

In the **industrial sector**, primary energy consumption per real dollar of industrial output fell 32% between 1973 and 1985 (14). It is estimated that about 45% of the reduction in energy intensity was due to structural shifts (i.e., shifts from energy-intensive manufacturing industries to lighter industries) and about 55% of the reduction was due to falling energy intensity (i.e., less energy consumed per unit of output) (15).

In the **transportation sector**, efficiency improvements provided most of the energy savings. Due to a doubling of the average efficiency of new cars, total automobile fuel consumption fell by 10% between 1973 and 1986 even though total distance travelled (vehicle-miles of travel) increased by nearly 25% (16). In addition, the overall energy intensity (energy per passenger-mile) of commercial aircraft declined by about 46% during this time period (17).

In the **buildings sector**, primary energy use per household declined nearly 20% and primary energy use per unit of floor area in commercial buildings fell about 12% during 1973-85 (18). A variety of factors including reduced household size, migration from colder to warmer climates, improved thermal integrity of buildings, more efficient equipment, and changes in energy-related behavior contributed to these improvements. The cheapest and largest efficiency gains come from new buildings. In fact, from 1973 to 1986, the space heating needs per unit of floor area in typical new buildings fell by about 50% (19). But these efficiency gains slowly penetrate the building stock because of the long life of buildings.

III. Technological Improvements: Some Examples

It is useful to examine the extent of past and prospective efficiency improvements in some major energy end uses. These examples illustrate four general points: (i) the energy efficiency of goods produced in the late 1980s was typically twice that produced in 1973; (ii) due to time lags in turning over the equipment stock, new technologies produced in the late 1980s were considerably more efficient than the equipment or building stock in that year; (iii) today's "best" technology (from an energy-use standpoint) is significantly more efficient than today's average new technology; and (iv) there is considerable potential for further efficiency improvements during the next decade.

A methodology for more closely assessing the economic and energy impacts of past and prospective efficiency opportunities is to construct what is commonly known as a "supply curve of conserved energy". The stair-shaped conservation supply curve ranks various measures for increasing energy efficiency based on their cost effectiveness.

Automobile efficiency improvements made between 1975 and 1989 saved 2.45 million barrels of oil per day (Mbd), worth $32 billion per year excluding fuel taxes (20). A conservation supply curve for automobiles shows that even more savings remain to be captured (**Fig. 1**). In the figure, 17 measures which do not compromise performance or size (e.g. more efficient engines) are ranked in order of increasing cost per unit of gasoline saved. The average cost of conserved energy for all 17 measures is only $0.53/gallon--much less than the retail price of gasoline. Adoption of the available automobile efficiency improvements shown in Fig. 1 could lead to an aggregate energy savings of 2.6 Mbd by 2010 (21).

We now briefly review the past trends and prospective technological developments in four areas. The examples selected are major energy end uses in the transport, buildings, and industrial sectors.

Transportation: Automobiles and Light Trucks

The average EPA-rated fuel economy of new passenger cars increased from about 14 mpg in 1973 to 29 mpg in 1988, driven by the CAFE fuel economy standards (22). Fuel economy gains were accomplished largely through changes in design and technology rather than through production of cars with smaller interior volume or reduced acceleration performance (23). The two most important improvements have been reduced weight and increased engine efficiency. Vehicles have been lightened through design changes to reduce external dimensions while maintaining interior volume, and substitution of lighter materials such as high-strength steels and plastics. As a result, interior volume per unit weight increased by 16% from 1978 to 1987. The average engine output per unit of displacement was increased 36% during the same period through such measures as improved engine design, electronic controls and fuel injection.

In spite of the great progress made so far there remain major cost-effective opportunities to improve car and light-truck fuel economies. The types of efficiency measures shown in **Fig. 1**, applicable to passenger cars and light trucks, can be broadly classified as either load reduction or increased powertrain efficiency. One important way to reduce load is to reduce aerodynamic drag, as demonstrated by the General Motors Silhouette van and by the Ford Taurus (24). These vehicles have coefficients of drag (CD) of approximately 0.30. The lowest CD in current cars is 0.26 and the average is about 0.37. If the entire new car fleet were improved from 0.37 to 0.26, average fuel economy would increase by about 12%. Since cutting aerodynamic drag improves high-speed performance and has aesthetic appeal, even lower CDs are expected in future vehicles. In fact, some prototype cars such as the General Motors Impact have a CD of around 0.20.

Improving part-load efficiency offers one of the largest opportunities for fuel economy improvement in the next decade. At optimal load, automobile engines are roughly 30% efficient. The direct-injection diesel engine, not yet widely used in light-duty vehicles, has an optimal-load efficiency of 40% (25). However, part-load efficiencies are significantly lower. The average efficiency of one modern 106 horsepower spark-ignition engine in the urban driving cycle is 14%. Average driving involves relatively low power, about 5 horsepower in urban driving and 12 horsepower in highway driving. Yet vehicles typically have engines with maximum power of 90 to 150 horsepower, a power level rarely, if ever, used by the average driver.

There are many ways of increasing part-load efficiency. One approach involves technical engine modifications such as variable-valve timing, friction reduction, variable displacement, and use of a smaller engine with power enhancement, e.g. turbochargers or additional valves that improve the breathing of the engine when high power is required (26). Using electronic variable-valve timing to eliminate most or all throttling losses as well as increasing maximum power is a particularly promising strategy that would yield about 10% fuel economy benefits.

Another approach is to develop different engine systems that have higher part-load efficiencies, such as the two-stroke, diesel, or hybrid engine. Cars with modern two-stroke engines that provide 10% to 20% fuel economy benefits are expected to be introduced in the mid-1990s (27). Efficient direct-injection diesels, with 30% to 40% fuel economy improvements, were recently introduced in Europe (28). In a hybrid vehicle, the fueled engine operates only at optimum load and energy storage is used to balance loads. In principle, hybrid engines with storage could regenerate energy normally lost in braking and could eliminate most part-load losses, leading to around a 75% increase in fuel economy.

Additional fuel efficiency measures include computer-controlled aggressive transmission management (to keep engine speed low when little power is required) and stop-start (shutting off the engine automatically and restarting it as required) (29). The combined fuel economy benefit of aggressive transmission management and stop-start would be as much as 20%.

A new car introduced by Honda for the 1992 model year, the Civic VX, demonstrates that a combination of efficiency improvements can have a large impact. This car has a composite EPA fuel economy rating of 51 MPG, a 55% improvement in fuel economy compared to the 1991 Civic model of equivalent size and performance. The technologies used to achieve this level of fuel economy include a lean-burn engine, transmission and gearing changes, a shift indicator light, reduced fuel consumption during idle, and weight reduction (30).

Despite the impressive performance of the new Honda Civic, auto manufacturers in general have concentrated on increased engine power in recent years, thereby creating the impression that the potential for further fuel economy improvement is not as good as had been believed. Nevertheless, a full fleet of cars could be produced by 2001, with the size and performance characteristics typical of cars sold during the late 1980s, that achieve on average a fuel economy of 40-45 mpg (based on the EPA test procedure). In the longer term, much higher fuel economies could be achieved, as evidenced by considering the technical opportunities (31) and the high-fuel-economy prototypes (60 to

100 mpg) that have been built already (32).

Household Appliances: Refrigerators

The design of domestic refrigerators underwent a combination of improvements during the past 18 years, including shifting from fiberglass to polyurethane insulation, use of more efficient motors and compressors, and use of larger heat exchangers (33). The efficiency gains occurred without major technological innovation or radical product redesign. The top-rated models are only 5% to 10% more expensive than their counterparts of average efficiency, with operating savings paying back the extra first cost in three years or less (34).

The simplicity and low cost of the efficiency improvements no doubt contributed to their widespread acceptance by manufacturers and consumers. Other factors include minimum efficiency standards first adopted in California in the mid-1970s and at the national level in 1987, energy efficiency labels required by the Federal Trade Commission since 1980, and numerous utility promotional and incentive programs.

In the early 1970s, the average new U.S. refrigerator consumed about 1725 kilowatt-hours/year. By 1980, electricity use of typical new refrigerators fell to about 1280 kWh/yr, and by 1990 the typical new refrigerator consumed just 920 kWh/year. U.S. Department of Energy studies show that by implementing additional efficiency improvements--based on commercially available components--it is cost effective to reduce electricity use to about 650 kilowatt-hours/yr (35). Tougher minimum efficiency standards that take effect in 1993 will ensure that this level of performance is achieved.

An important innovation would be to perfect new insulation materials that out-perform polyurethane foam. Some of the candidates now in the R&D stage include evacuated panels, gas-filled panels, and silica aerogel. These materials improve efficiency and eliminate reliance on environmentally-damaging chlorofluorocarbons (CFCs), which are used as the blowing agent in today's foam insulation (36). Other promising advanced technologies include dual-refrigeration systems for the refrigerator and freezer boxes and capacity modulation through variable-speed controls.

A combination of innovations could reduce refrigerator electricity consumption by 50% to 70% relative to today's best technology (33). In Europe, Electrolux plans to introduce a refrigerator-freezer that uses 55% less electricity than the best model now available. Besides its outstanding efficiency, the Eletrolux model uses non-CFC-based insulation.

The Building Envelope: Windows

In addition to the appliances and equipment that go inside of buildings, significant advances have been made in the efficiencies of building envelopes -- walls, roofs, windows, etc. Approximately 5% of total U.S. energy use is required to offset the heat losses and gains through windows: this is equivalent to 1.9 million barrels of oil per day, which equals the flow through the Alaska pipeline or crude oil imports to the United States from the Arab OPEC nations in 1990. If the fluxes of heat and light through windows are optimized, windows can outperform any insulated wall because heat gains can exceed heat losses, even on the north-facing side of a building. In addition to saving energy, efficient windows block furnishing-damaging UV radiation, reduce outside noise, and have less condensation problems.

Traditional single-pane windows have an insulating value of about "R-1" (37). Their energy-efficiency can be improved many fold. Adding a second pane increases the insulating value to about R-2 and a third pane to about R-3. Additional savings are achievable when windows are manufactured with invisible low-emissivity (low-E) coatings that transmit desired visible light but emit less heat to the cold outdoors. First commercialized in 1982, low-E coatings are now used in more than 20% of all new U.S. residential windows. Some manufacturers are converting their entire production capacity to low-E glass. If sales of low-E windows follow current trends, consumers will realize a net savings around $4 billion per year (38).

Commercialization of even more efficient "Superwindows" has been achieved by combining three glazing layers, low-E coatings, and gas fillings having lower heat conductivities than air. The most efficient commercially-available windows have an insulating value of about R-8. In the future, still more well-insulating windows will likely be based on vacuum-panel technology or silica aerogels. These windows could achieve R-15 or greater from a thickness equal to conventional triple-glazed windows. Such windows have been produced in the laboratory and the focus now is on developing cost-effective manufacturing processes (39).

Advances in window technology can also lower energy consumption in hot climates. In situations where high air-conditioning loads exist, restricting solar and heat gains through windows can save significant amounts of energy, reduce a utility's peak demand, and enable down-sizing of cooling equipment. The commercialization of either "spectrally selective" windows that reflect near infrared radiation or "smart" windows that contain electrically activated optical window coatings would be especially useful for hot climates. Smart windows have the potential for a wide dynamic range of 10% to 80% visible light transmission.

Industry: Steel Production

The industrial sector is so heterogeneous that a single subsector is not a good example. Nevertheless, as a case study we will focus on the steel industry where major energy-intensity reductions have been achieved. The steel industry is a conservative choice for consideration of energy savings potential because it is closer to thermodynamic efficiency limits than are other industries.

Between 1973 and 1988, the U.S. steel industry reduced its primary energy intensity from 35 to 25 million Btu per short ton of steel mill products (40). For comparison, the Japanese steel industry operates close to the best-practice energy intensity established in a 1982 study by the International Iron & Steel

Institute: about 19 million Btu/ton for integrated mills (41). This achievement is based on pervasive refinements of classical iron and steel technologies, an approach which, given the opportunities for new processes, is not necessarily the best for the U.S. integrated industry.

Progress in the U.S. was achieved through two major developments: improvements in process technology and practices and a major shift in feedstock toward post-consumer scrap instead of iron ore. Much of this progress came from the closure of older mills associated with a decline in production from 151 million short tons in 1973 (the all-time high) to 100 million tons in 1988 (the highest level since 1981).

Major technological improvements have been made in every area of the steelmaking process, including: continued reductions in coke use per ton of blast furnace product, the replacement of almost all open-hearth furnaces with better steelmaking furnaces, and impressive improvements in the yield of products (ratio of mill products to cast, or raw, steel) from 71% in 1973 to 85% in 1988 (42). In part, this improvement in yield is due to installation of continuous casting, but it also stems from great improvement in rolling and treating facilities including the modernization of control systems.

The U.S. industry used scrap from downstream fabricators and final consumers for 42% of its metal input in 1988 (43). This high level of scrap use is very economical. Products made from post-consumer scrap require only about half the primary energy per ton as those made at integrated (ore-based) mills (44). Furthermore, improvements in electric arc furnaces for scrap melting reduced electricity intensities at the best furnaces from 570 kilowatt-hours/ton of molten steel in 1965 to 390 kilowatt-hours per ton in 1985.

Radical modifications in iron and steel production could result in relatively low energy intensities at much lower cost. At the "hot end", where ore is reduced to metal, basic oxygen steelmaking could provide the basis for development of a new approach (45). In this process, powdered ore, coal, and flux could be blown into molten iron to achieve direct steelmaking with reduction of the iron oxides and removal of impurities. Work on this process is underway in Germany, Sweden, Japan, and the United States. Such a technology would achieve an energy intensity roughly similar to best-practice classical technology at substantially lower cost. Much lower energy intensities are not likely in the foreseeable future because the best-practice classical technology already approaches the ultimate thermodynamic minimum of 6.5 million Btu/ton of iron for reduction of iron oxides.

In contrast with reduction, shaping and treating do not, in principle, require substantial energy inputs. The essential challenge is to directly form products at or near their final shape, thereby avoiding reheating and rolling processes. Such systems are under development in the United States, Germany, Japan, and elsewhere. Pouring molten steel onto a cooled, rotating cylinder, for example, has enabled direct casting of ribbon of sub-millimeter thickness. With such approaches it should eventually be possible to reduce the primary energy intensity of typical shaping and treating processes from about 10 million Btu/ton to, perhaps, 2 million Btu/ton of mill products, depending on the complexity of the products.

By these means, including a further increase in use of scrap metal, the U.S. steel industry could reduce its energy intensity by at least 40% from current levels.

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The preceding four examples show that while there has been considerable progress in improving energy efficiency during the past 15 years, energy-saving opportunities are as great as ever because technological advances are continuing. Researchers and manufacturers are developing new energy-efficient technologies for virtually every end use. The next generation of advanced technologies is likely to be highly innovative, featuring new materials and processes.

IV. Post-1986: Energy-Efficiency Slowdown

Despite enormous technological advances and opportunities, overall energy productivity in the United States is stalling. Primary energy use rose 2.3%/year on average during 1986-90, a period when GNP increased at the rate of 2.8%/yr on average. Rising energy use is attributed to the plunge in the world oil price in 1986 (itself largely a consequence of successful efforts to reduce oil use in OECD nations), a rebound by heavy manufacturing industries, behavioral and institutional barriers inhibiting further implementation of efficiency measures, and inadequate public policies for overcoming these barriers (42).

In some end uses, efficiency improvements are slowing or even reversing (12). For example, U.S. residential space heating intensity fell by 4.5% annually through 1983 but slowed to less than 1%/year after 1983. The energy intensity of cars and light trucks combined fell 6.2%/year up to 1983 but only 1.3%/year thereafter. As an example of efficiency reversals, the fuel economy of new cars and light trucks declined with the 1989 and 1990 model years (47). One reason for this is that the CAFE standards no longer force most manufacturers to make fuel-efficiency improvements. Another reason is the emphasis manufacturers are placing on increased power.

Rising energy use is adversely affecting the nation in a number of ways. In 1990 compared to 1986:

o The United States imported 1.8 million more barrels of oil per day ($12 billion/year at $18/barrel). Of this, 1.5 Mbd was from OPEC (a 51% increase). The United States is rapidly moving towards the day when over half its net petroleum use is imported.

o Consumers paid at least $36 billion more for energy than would have been the case had national energy intensity continued to decline at the same rate as during 1973-86 (48).

o Carbon emissions from fossil fuel combustion increased by nearly 120 million metric tons (9%). This accelerates global warming due to the greenhouse effect.

V. Prospects for the Future

Given current trends, it appears that U.S. energy use, costs, and CO2 emissions will continue to rise if major new energy efficiency initiatives are not adopted. The "reference case" in the 1991 Annual Energy Outlook issued by the Energy Information Administration predicts that, between 1990 and 2010, national energy use will increase by 27% (1.2% per year) (49). Carbon dioxide emissions from burning of fossil fuels are predicted to rise almost as fast. This forecast assumes that GNP grows by 55% (2.2%/yr) during the 20-year period. Likewise, the National Energy Strategy issued by the Bush Administration in 1991 projects in its "current policy case" that energy use will increase 39% (1.7%/yr) and GNP will increase 79% (2.9%/yr) during 1990-2010 (50).

Analysis of energy end-use trends confirms that energy use is not likely to continue to increase at the high rate experienced during 1986-90. Modest efficiency improvements should continue as the equipment stock turns over and approaches the efficiency levels inherent in new technologies (12). However, assuming increasing activity levels and limited interest in conservation, aggregate national energy intensity (E/GNP) is unlikely to return to the 2.4%/year rate of decline experienced during 1973-86. In addition to a lack of policies promoting greater energy efficiency, a number of behavioral and institutional barriers inhibit implementation of technically feasible and economically justified conservation measures.

VI. Barriers to the Efficient Use of Energy

For a variety of reasons, households, commercial businesses, manufacturers, and government agencies fail to fully exploit cost-effective energy-conserving opportunities. The result is a significant gap between current and optimum levels of energy efficiency. Although these barriers occur in the R&D, production, commercialization, acquisition, and use of energy-efficient systems, this section focuses on those related to acquisition and use because little information is available on the upstream barriers (51).

As evidence of these barriers, consumers in all sectors implicitly require very fast paybacks when making tradeoffs between greater initial costs and reduced operating costs. The resulting problem, often referred to as the "payback gap," is a significant difference between investment criteria for energy efficiency versus energy-production investments. For example, electric utilities accept 10 to 15-year payback times on their investments, whereas studies of efficiency choices reveal implicit payback times ranging from a few months to a few years (52). In industry a two-year payback requirement is typical. The payback gap leads to excessive energy use and less-than-optimal investment in energy efficiency from the perspective of minimizing the cost of energy services.

Some economists believe that the payback gap must be a surrogate for costs of acquiring energy efficiency which are not explicitly calculated, such as the costs of acquiring information and the costs associated with risk of failure. The literature previously cited shows instead that the payback gap is large even when such costs are accounted for. In short, market imperfections are real and substantial.

Compounding the payback gap, in many instances the life-cycle cost curve (initial costs plus operating costs) for major energy-consuming products can have a flat minimum region that spans a significant range of efficiencies (53). This happens if the value of energy saved is canceled out by the costs of investment required to achieve the savings. In this case, even economically rational consumers will only invest to the point where the curve becomes essentially flat. Further savings are not captured because there is no additional economic gain from doing so.

We now discuss five contributors to the payback gap.

Insufficient Information

For many consumers, energy use is largely invisible and automatic. For example, the major pieces of residential energy-using equipment, e.g. furnaces and water heaters, are out of sight and therefore out of mind. Also, consumers have no way of knowing from their utility bills how much energy is used by different pieces of equipment. In addition, energy end users are not adequately informed about the energy-use characteristics of the products they buy. Evidence of this is provided by a recent study of gas furnace purchases, which found that the energy-efficiency rating is a poorly understood characteristic of furnaces (54). The importance of the information gap is evidenced by studies showing that households will reduce their energy consumption by 5% to 20% when provided with detailed feedback on the energy consumed by their appliances, heating equipment, and air conditioners (55).

Energy audit programs have attempted to narrow the information gap, but have been much less effective than they could be, partly because information is often presented in a dry, statistical fashion (56). Also, energy audits were performed in only a small fraction of the households, commercial buildings, and factories in the United States during the past 18 years.

Limited Access to Capital

Energy-efficient systems are usually more expensive than their inefficient counterparts, and obtaining the additional money to pay the incremental capital costs is often a problem. Obviously, scarcity of money is a major barrier for low-income households and cash-constrained industries. For example, a study of 15 energy-intensive manufacturers found that capital constraints within firms often prevented adoption of what they otherwise viewed as attractive efficiency investment opportunities (57).

Investment Rules and Split Incentives

Energy consumers often employ investment rules that rank efficiency investments below other investments of equal or poorer merit. Even "sophisticated" commercial energy users may fail to value indirect economic savings from energy-efficiency efforts, e.g. increased precision and control, reduced materials wastage, or reduced labor costs. In the manufacturing sector, energy-efficiency investments are hindered by a preference for investments that improve products or increase output compared to investments that reduce operating costs. Many firms employ a two-tiered system of investment criteria in which non-product-related investments, such as energy conservation measures, must achieve a rate of return substantially higher than product-related investments (58).

Decision makers in the buildings sector (e.g. landlords, home builders, developers of commercial properties, and realtors) often seek to minimize first costs, putting little or no value on energy and other ongoing operating costs. Efficiency investments are unattractive when they are seen as contributing less to the resale value of a home or building than more visible amenities. Furthermore, most public institutions (e.g. public housing authorities) are penalized with reduced operating funds if they lower costs by investing in energy efficiency (59).

Many energy suppliers also face investment rules and split incentives--imposed by their regulators in the case of gas and electric utilities--that systematically direct their capital towards supply technologies rather than towards a rational supply/efficiency mix. Most utilities, for example, lose revenues and profits in the short run when they encourage their customers to use energy more efficiently.

Infrastructure and Workforce Limitations

The availability of new energy-conserving technologies is often limited to particular geographic regions of the country. For example, electronic lighting ballasts are more easily found in those areas where electric utilities promote them. The small markets for heat-pump water heaters and ground-coupled heat pumps illustrate the consequences of limited supply infrastructures (60).

Similarly, there is a lack of people skilled in engineering, operations, and maintenance to adequately nurture the development and deployment of new energy-saving technologies. Energy efficiency potential is not strong component of the college curricula that train automotive, industrial, and HVAC engineers. In addition, companies that manufacture, distribute, and service energy-efficient products underinvest in training programs to keep their employees abreast of the latest technological advances. These problems plagued the electric heat pump industry during the 1950s and 1960s.

The infant industry of energy-services companies--firms that finance and install energy-efficiency improvements and possibly even operate energy systems--is another weak link in the diffusion of energy-efficient technologies. With the exception of a few large companies, this industry is composed primarily of small firms that lack the resources and name-recognition to effectively market their services. Also, some energy service companies have performed poorly and/or gone out of business, hurting the image of the entire industry.

Distortions in Energy Prices

In addition to the payback-gap problem, energy prices do not reflect fully the environmental, security-related, and social costs (so-called externalities) associated with fuel production, conversion, transportation, and use. For example, the damage caused by acid rain and urban smog is not now reflected in the prices of fossil fuels and electricity in the United States (61). Even after the 1990 Clean Air Act amendments are implemented, energy use will result in substantial air pollution. Similarly, the national security and foreign balance-of-payments implications of oil imports are not incorporated in fuel oil and gasoline prices (62). Such costs can be high, as in the case of the tens of billions of dollars spent on military operations in the Middle East following Iraq's invasion of Kuwait.

The situation is further complicated for electricity because of the way that state public utility commissions set prices. Traditionally, electricity prices are set so that they reflect the average cost of production. But the costs to build and operate future power plants are greater than today's average cost of production, so consumers receive inappropriate price signals. A similar, although less dramatic, situation occurs for natural gas.

Having the "right" price is helpful but not sufficient to achieve optimal efficiency improvements in the future (63). As a result of these price distortions and the payback gap described above, public authorities have a responsibility for promoting energy-efficiency improvements that will reduce the cost of energy services and provide other benefits for society.

VII. **Getting Back on Track**

Continued growth in energy use is not preordained. The United States could set a goal of capping energy consumption and CO2 emissions. Ahieving this goal is technically and institutionally feasible, it will save money, and it does not require personal or national sacrifice. But it requires new policies for improving the energy efficiency of buildings, appliances, vehicles, and factories throughout the United States.

Fourteen major energy-efficiency initiatives, taken together, can help get America back on the "energy-efficiency track". These policy proposals address all major areas of opportunity through a mixture of economic incentives, efficiency standards, research, development and demonstration activities, and information programs.

Economic Incentives

Economic incentives can take the form of stronger price signals, rewards to consumers or utilities if they invest in cost-effective efficiency measures, or penalties for failing to pursue energy efficiency or to internalize social costs.

(i) **Raise the federal gasoline tax**

The market prices for all fuels do not reflect their real cost to the nation, i.e., considering externalities. This is especially true for gasoline in the United States, which is taxed about $0.30/gallon, far below the $1.50 to $3.00/gallon paid in most other industrialized nations (64). Substantially raising the gasoline tax could rekindle interest in fuel economy among car buyers and help to limit growth in vehicle usage. We suggest increasing the gasoline tax by at least $0.50/gallon, phased in over a number of years if necessary. One recent analysis estimated that a $1/gallon tax would reduce oil consumption by about 2 Mbd and cut U.S. CO2 emissions by 7% (65).

(ii) **Expand the gas-guzzler tax and establish rebates for high-MPG cars**

We believe that a revenue-neutral fee/rebate scheme--"feebates"--should be adopted to complement higher gasoline taxes and new fuel economy standards. Specifically, we suggest expanding the existing federal "gas-guzzler" tax on inefficient cars and light trucks. We also suggest simultaneously providing rebates to buyers of fuel-efficient new cars. This approach has the following advantages: (a) it aims directly at improving fuel economy (miles per gallon) rather than limiting an amenity (miles driven per car), (b) it avoids economic dislocation and political opposition by not shifting income away from light vehicle producers and purchasers as a whole, and (c) it could be revenue neutral (66).

Feebate systems have been proposed in California and Massachusetts. In 1991, the province of Ontario, Canada actually adopted a limited feebate system (67). The state and provincial schemes use the existing car sales tax or registration fee mechanisms to collect the fees or give credit for rebates. Similar fees or rebates could be applied to new vehicles based on pollutant emissions, and could also incorporate vehicle safety characteristics (68). Also, vehicle size could be factored into a feebate system (69).

(iii) **Reform federal and state utility regulation so that utilities can profit from their investments in energy efficiency**

Most utilities do not allow energy-saving options to compete on a level playing field along with energy-supply options when they are acquiring new resources for providing energy services. This is not surprising, given that most utilities are penalized when they operate successful energy-efficiency programs if such programs result in lost sales revenue in the short run (70). To remedy this problem, we suggest: (a) that energy-efficiency measures be allowed to compete fairly with energy supply options under the 1978 Public Utility Regulatory Policies Act (PURPA); (b) that state regulatory authorities provide all utilities with financial incentives for pursuing least-cost energy services by investing in energy efficiency measures (both in power supply and end use). A variety of incentive schemes have been devised and are being tested by more innovative utility commissions and utilities (71). One such system will allow Pacific Gas and Electric Company to retain 15% of the net economic benefits (total savings minus program costs) of its conservation programs (72). For investments made in 1990, net benefits are projected to be $200 million.

(iv) **Offer financing and incentives to buyers of efficient homes**

The federal mortgage lending agencies (e.g., Fannie Mae and Freddie Mac) are willing to provide larger mortgages to buyers of efficient homes with low utility bills, because their residents are able to afford a higher monthly loan payment. They also approve higher debt-to-income ratios (e.g. 32% instead of 28%) for purchasers of efficient homes. This program needs to be streamlined, better promoted, and expanded to include other kinds of home loans (73). Primary lenders (i.e. local banks) should participate in the program on a much larger scale.

We also recommend use of sliding-scale hook-up fees and rebates based on the electrical intensity of new buildings. Buildings that use more watts per square foot than a target value would pay a fee; those that are below the target value receive a rebate from their public utility (66). This "feebate" scheme can be applied to commercial as well as residential buildings. It is an extension of the variable rebate approach already used to encourage energy-efficient construction by many utilities (74).

(v) Revise procurement practices and provide funds and incentives for efficiency improvements in government facilities

Legislation from the 1970s requires federal agencies to select equipment and products on the basis of minimum life-cycle cost. However, federal agencies are passing up enormous opportunities for efficiency improvements (75). In order to cut energy waste by the federal government, a large and dedicated source of funds for energy efficiency projects is needed, as are incentives such as allowing individual facilities to retain a portion of the energy cost savings and providing cash bonuses to outstanding energy managers (76). Also, procurement practices should be reformed so that the federal government routinely buys energy-efficient buildings, motors, appliances, lighting products, etc. The Department of Energy recently issued new energy savings goals for federal agencies, but unfortunately no funds were committed to this effort (77).

State and local governments also should take steps to implement energy-efficiency measures in their facilities. In this regard, Texas has established a $100 million energy efficiency fund and a model energy efficiency program for state buildings (75).

Efficiency Standards

Minimum efficiency standards can affect the efficiency of all new products or buildings and thereby significantly reduce energy use in the future. Standards are justified if the economic savings (including monetization of externalities) exceed the costs for manufacturers and consumers as a whole. There are a number of areas where efficiency standards should be strengthened or where new standards are needed.

(i) Strengthen the fuel economy standards for cars and light trucks

The fuel economy standards adopted in 1975 were met in 1986; the efficiency of new cars and light trucks is no longer improving. We recommend that existing standards be increased to at least 40 mpg for cars and 30 mpg for light trucks by 2001. These levels would make vehicles about 40% more efficient than the average fuel economy of vehicles sold in 1990 but less efficient than that of the most efficient cars on the road. The standards could either require each manufacturer to achieve a specified average efficiency (i.e., the current approach), require equal percentage efficiency improvements from all manufacturers, or take into account vehicle size when computing average efficiency. New efficiency standards can be met with technologies that are available and cost-effective, without any reduction in vehicle size, performance, or safety (78).

(ii) **Strengthen and expand equipment efficiency standards**

National appliance efficiency standards were enacted in 1987 and 1988 after various states had adopted appliance standards. Efficiency requirements already issued are estimated to save consumers $44 billion (net) and cut peak electricity demand by 30,000 megawatts (79). In addition, the U.S. Department of Energy (DOE) is required to review the standards on a regular basis and to promulgate more stringent standards if such action is deemed technically and economically feasible. DOE should tighten the standards on air conditioners, furnaces, water heaters, refrigerators, lighting ballasts, and other products covered in the original law. Minimum efficiency standards should be extended to other products such as incandescent lamps, fluorescent lamps, motors, commercial heating and air conditioning equipment, transformers, showerheads and faucets, and lighting fixtures (80). If the federal government is unwilling to adopt standards on these products, individual states should take action (81).

(iii) **Strengthen building energy codes**

The energy-efficiency requirements in most state and local building codes are outdated and below cost-effective levels (82). The federal government should require states and municipalities to upgrade their codes so that they meet or exceed established reference levels, such as the standards that are mandatory for federally-owned buildings but now only voluntary for the private sector (83). DOE should assist states and municipalities in code revision and implementation (e.g., in training designers, builders, and inspectors). Also, all new homes financed by the federal government (e.g., public housing and homes receiving Federal Home Administration or Veterans Administration loans) should be required to meet cost-effective efficiency standards such as the voluntary Model Energy Code issued by the Council of American Building Officials or new standards under development by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) (84).

In the near term, retrofitting existing buildings offers the potential to save more energy than efficiency improvements in new buildings. Several cities have already implemented residential energy conservation ordinances requiring that homes meet or exceed specified levels of thermal integrity when they are sold. The city of San Francisco recently introduced the first retrofit ordinance for commercial buildings. DOE should promote wider adoption of energy conservation ordinances and provide technical assistance to interested cities or states.

(iv) **Cap CO2 emissions as was done for SO2 emissions**

New amendments to the Clean Air Act set limits on total SO2 emissions by individual utilities starting in 1995 and 2000. Utilities that emit less than their SO2 cap can sell corresponding excess emissions allowances to other utilities. Also, if a utility invests in greater energy efficiency and reduces emissions before the target years, it receives extra emissions allowances that can be used once the caps take effect (85). The emissions cap and tradable allowances approach should be extended to the control of CO2 emissions, at least for CO2 emissions from major utility and industrial sources (86). This strategy would provide a powerful incentive for energy efficiency and conservation efforts since they are the most cost-effective means of cutting CO2 emissions (87). Utilities in particular would be encouraged to increase the efficiency of power generation, transmission and distribution, as well as end use.

Research, Development and Demonstration

Development and introduction of a new generation of energy-efficient technologies is essential if the United States is to substantially improve its energy productivity and cut its greenhouse-gas emissions over the long run.

(i) **Increase general funding for energy-efficiency RD&D**

DOE funding for efficiency R&D was cut by two-thirds (in inflation-corrected dollars) between 1980 and 1989. Even though the energy conservation R&D budget was moderately increased in 1990 and 1991, it accounted for only 6% ($220 million) of the

DOE's total energy R&D effort in 1991. The deep funding cut during the 1980s occurred in spite of DOE advancing the development and commercialization of many conservation technologies during the 1970s--technologies that could eventually save the nation well over $100 billion (88). We recommend doubling DOE's conservation R&D program within a few years by redirecting funds from other programs in the agency. Also, DOE should reinstitute demonstration of new energy-conserving technologies, expand efforts to transfer new technologies and practices to the private sector, and shift the focus of its R&D effort on fossil-fuel-based power plants to technologies that promise significant efficiency gains.

(ii) **Establish research centers for energy-intensive industries**

Energy use is growing rapidly in the industrial sector even though it is technically and economically feasible to reduce industrial energy use by 25% or more (89). In addition to expanding DOE's energy efficiency RD&D programs, we suggest establishing joint government-industry research centers to focus on energy-intensive industrial processes such as materials separation, metal casting and forging, or paper making. The centers would conduct basic and applied research, striving for advances that provide energy savings along with other benefits to industry. Similar R&D centers related to electrical technologies and applications have been started by the Electric Power Research Institute.

(iii) Improve utility energy conservation programs

Because electric utilities account for almost 40% of the nation's primary energy consumption, they can--and, in some cases, are beginning to--play a major role in improving energy efficiency. It is estimated that U.S. electric utilities spent around $2 billion (1% of revenues) in 1990 on programs to improve end-use energy efficiency and reduce electric demand at the time of system peaks (90). Some utilities have demonstrated the ability to reduce electricity use and peak load by 0.4%/year to 1.4%/year (91). Various strategies used to reach customers range from information and education approaches to financial incentives and utility installation of efficiency measures. Innovative program ideas continue to emerge (92). For example, utilities in New England have acquired demand-side resources through competitive bidding between vendors of improved efficiency and new power plants.

To ensure that utility conservation programs actively and effectively address all major end uses, utilities (and institutions supporting utility efficiency efforts such as EPRI and DOE) should conduct more research. Such research includes assessments of emerging technologies for application in their service areas, market research to determine customer interest in (and barriers to) different types of conservation programs, and experiments with different program designs.

Information Programs and Data Collection

Most of the preceding proposals will have greater efficacy if consumers are better informed regarding energy-saving opportunities and if the availability and quality of energy-use data are improved.

(i) Require energy ratings and labels

Home energy rating and labeling programs have been successfully implemented in some parts of the country (93). We suggest that ratings and labels be required on all new single-family homes. For existing homes, governments and utilities should promote the use of energy ratings at the time of sale or refinancing. These actions will help consumers to identify an efficient home, encourage builders to exceed minimum code requirements, facilitate calculation of incentives, and make it easier for lenders to offer larger mortgages for buyers of more efficient homes.

Standardized energy ratings and labels are also needed on certain products including windows, light fixtures, personal computers, and other office equipment. An efficiency rating program for windows was recently established and test procedures are being developed (94).

(ii) Collect additional data on energy use

Compilations of energy-use data are fundamental to the understanding of energy efficiency trends. Case-study data are needed to reduce uncertainty for consumers evaluating prospective efficiency investments and to help utilities and governments analyze the feasibility of conservation programs. Significant progress has already been made in the buildings sector by efforts such as the Buildings Energy Use Compilation and Analysis (BECA) data bases, which are used to compile measured savings and cost-effectiveness of building design and retrofit strategies, analyze peak electric demand savings, compare measured versus predicted savings, and study the persistence of savings in the years following a retrofit (95).

Of particular importance, the federal government has stopped collecting comprehensive data on energy use and efficiency improvements annually from large industries (96). This limits awareness of energy use and energy efficiency trends. We suggest that the government reinstate annual reporting of energy use and intensity by major manufacturers and set new energy efficiency improvement targets for the industrial sector. The targets should be voluntary and should refer to major industrial subsectors as a whole (e.g., the steel industry). Also, more data on the extent of implementation of efficiency measures in all sectors should be collected.

VIII. Potential Impacts

In this section, we present the energy, economic, and carbon dioxide savings that could result by 2010 from adopting the recommended policies just described. Also, we compare the high-efficiency scenario with other projections of U.S. energy use in 2010. This analysis updates an earlier assessment of similar energy efficiency initiatives (97).

Adopting our fourteen recommendations would lead to a high-efficiency scenario that could save large amounts of energy during the next 20 years, as shown in **Table 2**. The savings are calculated relative to the 1991 base-case forecast prepared by the Energy Information Administration of the U.S. DOE (49). To avoid "double-counting" of savings, efficiency improvements already assumed in the DOE forecast are excluded from our high-efficiency scenario. To facilitate the analysis, some of our policy recommendations are grouped together, e.g., automobile fuel economy standards and feebates or the various proposals aimed at increasing the efficiency of electricity production. Also, no energy savings are directly attributed to some of the data collection and RD&D proposals.

Table 3 compares total energy use, energy cost, and carbon emissions in 1990 with the respective values in 2000 and 2010 from a frozen-energy-intensity scenario, the DOE forecast, and the high-efficiency scenario. The high-efficiency scenario could cut projected energy use in the year 2010 by 18.6 Quads relative to the DOE forecast. The average cost of conserved energy is about \$2.50/MBtu versus DOE's projected average energy price in 2010 of \$8.90/MBtu (1990 \$). Consumers could realize a net economic savings (including efficiency investments) of \$106 billion per year, based on the difference between the DOE forecast and the high-efficiency scenario. Carbon emissions in 2010 could held to about 1450 million metric tons, about 22% below the emissions level associated with DOE's forecast and about 38% below CO2 emissions if energy intensity and fuel shares remain constant.

In the high-efficiency scenario, there is a slight increase in total energy use between 1990 and 2010 (see **Fig. 2**). Assuming GNP increases by 2.2%/yr on average, national energy intensity (E/GNP) would fall by 33% during 1990-2010, representing an average rate of decline of over 1.9%/yr. This is equal to the average rate of decline of E/GNP that prevailed during 1973-90, but is less than the rate of decline during the 1973-86 time period.

In the United States, there is a long-standing trend towards substitution of electricity for other energy carriers and for the introduction of new uses of electricity. In the high-efficiency scenario, electricity captures an increasing share of total energy supply. However, the efficiency of electricity use increases and total electricity demand grows by only 0.9%/yr during 1990-2010. The projected electricity savings in 2010, nearly 780 TWh of savings relative to the EIA forecast, is equivalent to the electricity supplied by approximately 150 large (1000-MW) baseload power plants.

Approximately 3.0 million barrels per day of oil would be saved in 2010 from the policy proposals, more than our current rate of oil imports from the Middle East. The oil savings represent about 23% of projected oil imports in 2010 in the EIA forecast. Saving this amount of oil would take pressure off of world oil markets, reduce the risk of another world oil price shock, and enhance national and global security. In addition, the natural gas saved as a result of the efficiency initiatives would become available as a substitute for oil, possibly cutting oil imports even further.

The potential reduction in carbon emissions from the proposed set of energy-efficiency initiatives is consistent with the near-term goal of a 20% emissions reduction. This goal has been proposed by environmentalists and members of Congress concerned about the risk of global warming (98). Our savings estimates indicate that the energy efficiency initiatives can cut CO2 emissions substantially from otherwise projected levels, but only slightly reduce the absolute level of CO2 emissions between 1990 and 2010. However, increasing the production of renewable energy sources (e.g., solar power and biomass-derived fuels), afforestation, shifting from more carbon-intensive fuels to natural gas, and/or further conservation measures could enable the United States to cut its CO2 emissions by over 25% early in the next century (99). Pursuing a combination of emissions reduction strategies is especially important given that deep cuts in worldwide greenhouse gas emissions are necessary to halt global warming (3).

Studies performed in other countries confirm that CO2 emissions can be reduced at negative cost through aggressive pursuit of energy efficiency and renewable energy sources. For example, an integrated supply-demand analysis of Sweden's electricity and heat sectors has shown that a 35% reduction in carbon emissions from current levels can be achieved, while GNP increases, the cost of energy services declines, and the country carries out the parliamentary decision to phase out nuclear power by 2010 (100). This result is significant, given that Sweden produces more nuclear-generated electricity per capita than any country, and five-times as much as in the United States. For Sweden, the U.S., and other nations, achieving large reductions in CO2 emissions requires new technologies and policies that address both energy supply and end-use efficiency.

Our high efficiency scenario is markedly different from the National Energy Strategy issued by the Bush Administration (50). That strategy, which emphasizes production of fossil fuels and nuclear power, is projected to result in a 31% increase in primary energy requirements, a 26% increase in carbon dioxide emissions, and an 8% increase in oil imports during 1990-2010 according to DOE. The Administration's strategy contains almost none of the strong energy efficiency initiatives suggested above.

IX. Conclusion

With energy use rising, oil imports surging, and a variety of pollution problems worsening, it is time to recommit the United States to greater energy efficiency. We estimate that a comprehensive set of policy initiatives can substantially reduce energy demand growth and put the United States back on a path where national energy intensity is rapidly declining. Also, growth in energy-related CO2 emissions can be eliminated. These "no-regrets" reductions can be achieved while population, economic output, and living standards are increasing.

Obtaining the energy savings indicated here will not be easy. A broad and aggressive set of policies is needed, the policies must be adopted promptly, the policies must be implemented effectively, and the response to the policies must be substantial. The savings will not be achieved without action and leadership. On the positive side, the economic, national security, and environmental benefits from substantially increasing U.S. energy efficiency are massive. Consumers would save on the order of a trillion dollars during the next two decades, industries would become more competitive, oil imports would drop, many forms of pollution would diminish, and global climate change would slow. Given these benefits, increasing energy efficiency is a challenge and an opportunity the United States and other nations cannot afford to pass up.

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36. T.F. Potter, D.K. Benson, L.K. Smith, "Impacts of Advanced Refrigerator Insulation", **Proc. of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings** (American Council for an Energy-Efficient Economy, Washington, DC, August 1988), pp. 4.86-4.98.

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39. C.G. Granqvist, "Energy-Efficient Windows: Options with Present and Forthcoming Technology", in **Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications**, T.B. Johansson, B. Bodlund, R.H. Williams, Eds. (Lund University Press, Sweden, 1989), pp. 89-124.

40. Adapted from the American Iron & Steel Institute's annual reports to the U.S. Dept. of Energy on Energy Efficiency Improvements (Washington, DC, various years).

41. **Energy and the Steel Industry** (Committee on Technology, International Iron & Steel Institute, Brussels, 1982).

42. **Annual Statistical Report** (American Iron & Steel Institute, Washington, DC, 1988 and earlier years). The yield in Japan is much higher still at 94%, see T. Ando, "Production and Technology of Iron and Steel in Japan during 1987", (Iron and Steel Institute, 28, 231 (1988).

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50. **National Energy Strategy** (U.S. Department of Energy, Washington, DC, February 1991); **National Energy Strategy, Technical Annex 2 - Integrated Analysis Supporting the National Energy Strategy: Methodology, Assumptions, and Results** (DOE/S-0086P, U.S. Dept. of Energy, Washington, DC, 1991).

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100. B. Bodlund, E. Mills, T. Karlsson, T.B. Johansson, "The Challenge of Choices: Technology Options for the Swedish Electricity Sector", in **Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications**, T.B. Johansson, B. Bodlund, R.H. Williams, Eds. (Lund University Press, Sweden, 1989). Although the nuclear power plants are removed from service, supply-side CO2 emissions from the electricity sector are kept in check with the use of gasified biomass fuel.

Table 1. Comparison of incandescent lamps and integral compact fluorescent lamps for commercial lighting (a)

Parameter	75W Incandescent lamp	18W Compact fluorescent lamp
Light per lamp (lumens)	1190	1100
Efficacy (lumens/watt)	15.9	61.1
Lamp lifetime (hours)	750	7500
Number of lamps needed during a 2.5 year period	10	1
Unit lamp cost ($) (b)	0.75	15
Electricity use (kWh)	562	135
Electricity cost ($) (c)	42	10
Total cost of light ($)	50	25

Notes:

(a) We assume the lamp is located in a recessed ceiling fixture and that it operates 3000 hours per year.

(b) The lamp costs are based on retail prices and purchase in small quantity. Use of wholesale prices and/or bulk purchase would make the compact fluorescent lamp look even more attractive.

(c) Based on an electricity price of $0.075/kWh, no charge for lamp installation, and no discounting of costs during the period.

Table 2. Potential savings in 2010 from the energy-efficiency initiatives (a)

Policy Proposal	Energy savings (Q/y)	Net economic savings(b) (B 1990$/yr)	Cost of conserved energy ($/MBtu)	Carbon emissions savings(c) (MT/yr)	Cost of conserved carbon(d) ($/tonne)
1. Raise car and light truck fuel-economy standards, expand the gas-guzzler tax, and establish rebates for highly efficient cars.	4.0	32.1	4.20	83	-390
2. Raise the federal gasoline tax by 15 cents per liter (60 cents per gallon) within five years and spend part of the revenue on mass transit and energy-efficiency programs.	0.9	10.9	3.00	18	-605
3. Reform federal utility regulation to foster investment in end-use energy efficiency.	4.0	17.5	2.20	94	-190
4. Improve the efficiency of power supply through regulatory reform, financial incentives, and RD&D.	2.1	2.1	2.00	53	- 40
5. Strengthen federal appliance efficiency standards and adopt new standards on lamps, motors, and other products.	2.8	15.3	2.70	64	-240

Table 3. Comparison of U.S. energy demand, costs, and carbon emissions (a)

Scenario	Energy demand (Q/yr)	Energy cost (b) (B$/yr)	Carbon emissions (c) (MT/yr)
Actual demand in 1990	84.4	531	1503
Frozen-energy-intensity (2000)	105.9	742	1886
DOE/EIA forecast (2000)	95.6	670	1668
High-efficiency (2000) (d)	86.3	617	1460
Frozen-energy-intensity (2010)	130.8	1169	2329
DOE/EIA forecast (2010)	106.9	956	1867
High-efficiency (2010) (d)	88.2	850	1451
Percentage savings in 2010 from high-efficiency case (relative to DOE/EIA forecast)	17%	11%	22%

Notes:

(a) Structural, economic, and demographic growth rates assumed in the scenarios for 1990-2010 are: real GNP (2.2%/yr), housing stock (0.9%/yr), commercial buildings floor area (1.8%/yr), passenger vehicle-miles travelled (1.7%/yr), manufacturing economic output (2.7%/yr). These growth rates were assumed in the DOE/EIA forecast and are used in the high-efficiency scenario for consistency only.

(b) Based on the final cost of purchased energy in the respective years as projected in EIA's Annual Energy Outlook. In the high-efficiency scenario, the levelized cost of additional energy-efficiency measures relative to the DOE/EIA base case is included in the energy cost. All scenarios are based on the same energy prices, i.e., energy prices are not changed in response to changing demand.

(c) Carbon emissions from the combustion of fossil fuels.

(d) Based on savings estimates presented in Table 2.

Table 2 (cont.)

Policy Proposal	Energy savings (Q/y)	Net economic savings(b) (B 1990$/yr)	Cost of conserved energy ($/MBtu)	Carbon emissions savings(c) (MT/yr)	Cost of conserved carbon(d) ($/tonne)
6. Strengthen building standards, promote home energy ratings, and encourage retrofits.	3.0	16.0	2.70	64	-250
7. Reduce federal energy use through funding for efficiency projects, incentives, and life-cycle cost-based purchasing.	0.2	1.0	4.50	4	-290
8. Reduce industrial energy use through R&D programs, reporting requirements, and voluntary savings targets.	1.7	11.0	2.00	36	-305
9. Cap CO2 emissions by utilities and major industries. (e)	---	---	---	--	---
Total	18.6	106	2.80	416	-255

Table 2 (cont.)

Notes:

(a) The savings listed here are relative to the 1991 Annual Energy Outlook prepared by the Energy Information Administration (see Table 3).

(b) The net economic savings are defined as the total economic value of energy saved minus the cost of the investment required to achieve the savings. Investment costs are levelized using a 6% real discount rate.

(c) Avoided carbon emissions are calculated using the following emissions factors: coal - 28.2 MT/Quad, oil - 20.7 MT/Quad, natural gas - 14.5 MT/Quad. Based on fuel shares projected by DOE/EIA for the year 2000, electricity supply from fossil fuel is assumed to be 70% coal, 20% natural gas, and 10% oil.

(d) The cost of conserved carbon is the net economic impact divided by the avoided carbon emissions. A negative cost means that there is a net economic benefit.

(e) It is assumed that carbon emissions from burning of fossil fuels are capped at their 1990 levels for utilities and major industries, and that the carbon emissions reductions from the other proposals are sufficient to meet the overall cap.

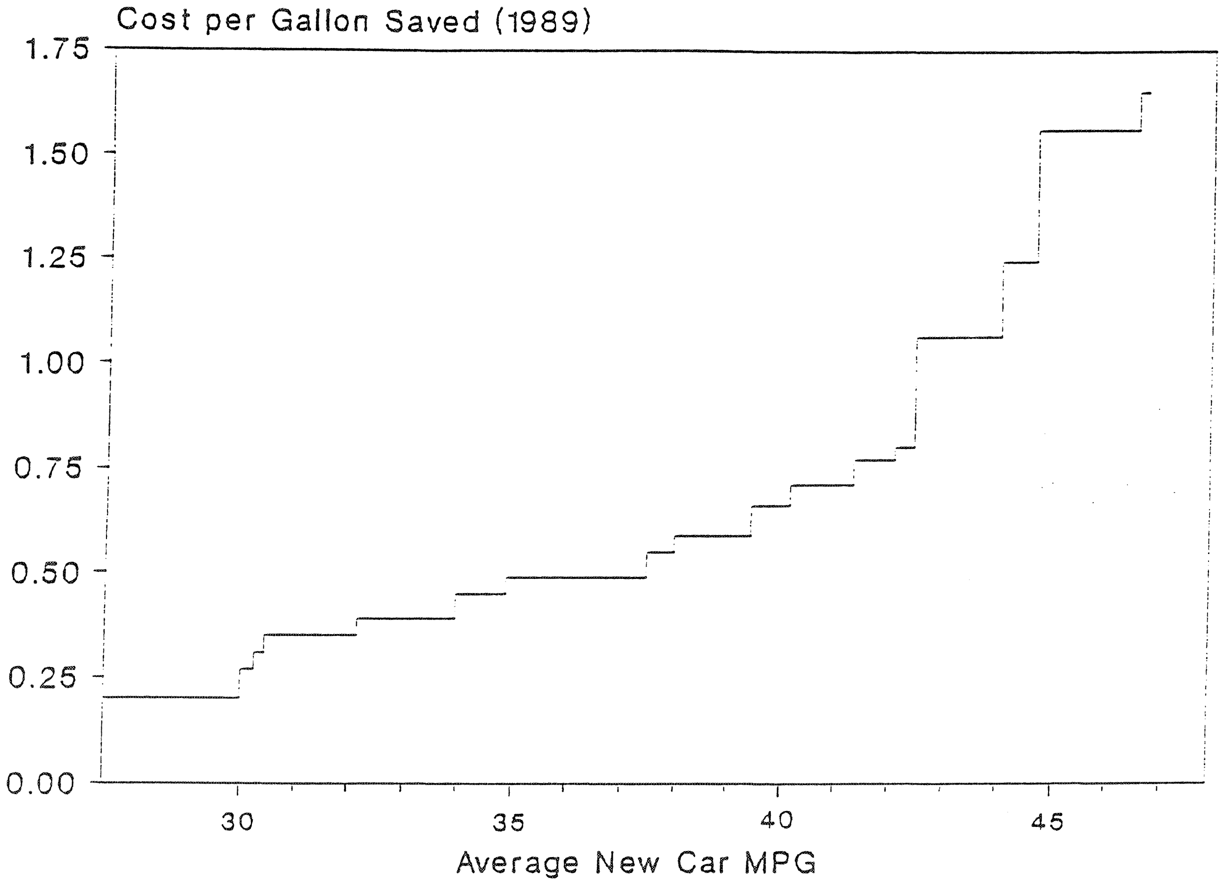

Fig. 1. Conservation Supply Curve for Automobile Fuel Efficiency. Each step in the curve represents a specific efficiency measure. The vertical dimension shows the investment required per unit of energy saved, assuming each measure has a lifetime of 10 years and is amortized using a 7% real discount rate. The horizontal dimension is the improvement in average MPG, assuming each measure is implemented to the maximum extent feasible in the new car fleet in the year 2000. Average interior volume and acceleration capability are held at their 1987 levels.

Source: M. Ledbetter and M. Ross, Supply Curves of Conserved Energy for Automobiles (American Council for an Energy-Efficient Economy, Washington, DC, 1990).

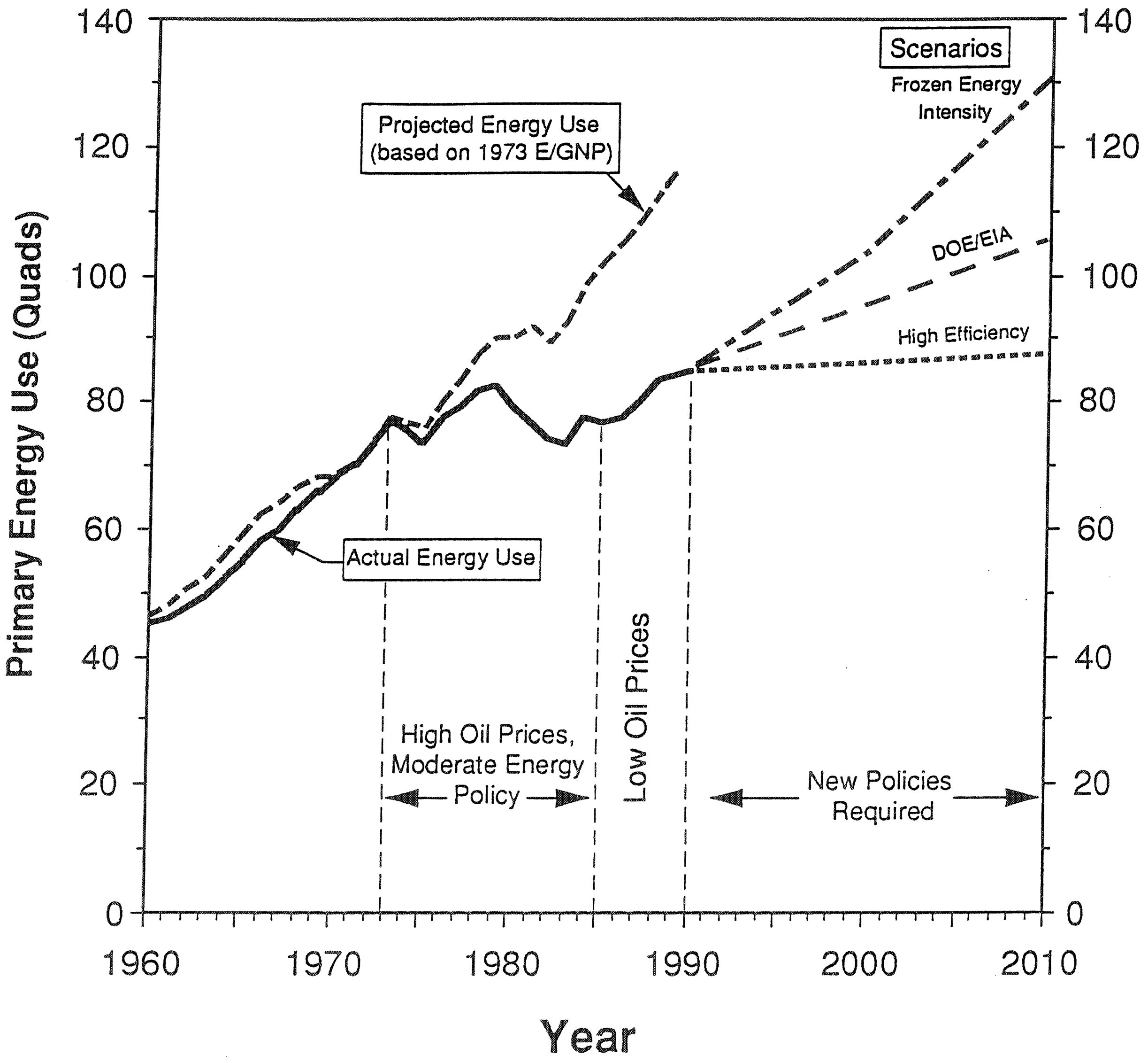

Figure 2. Aggregate National Energy Use. Prior to 1990, projected energy use assumes the 1973 aggregate energy intensity (E/GNP) remained constant. Starting in 1990, the scenarios compare constant energy intensity, the 1991 DOE/EIA reference case forecast, and "high efficiency" based on the 14 policy proposals presented in this article.