AMERICA'S ENERGY CHOICES

INVESTING IN A STRONG ECONOMY AND A CLEAN ENVIRONMENT

ALLIANCE TO SAVE ENERGY

AMERICAN COUNCIL FOR AN ENERGY-EFFICIENT ECONOMY

NATURAL RESOURCES DEFENSE COUNCIL

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Many people and organizations worked together over the past year to produce this report. Four national organizations—the Alliance to Save Energy (ASE), the American Council for an Energy-Efficient Economy (ACEEE), the Natural Resources Defense Council (NRDC), and the Union of Concerned Scientists (UCS)—conceived and executed the project. The Tellus Institute of Boston was retained to perform scenario analysis.

Howard Geller of ACEEE, Daniel Lashof of NRDC, Alden Meyer of UCS, and Mary Beth Zimmerman of ASE made up the project's steering committee. Meyer served as project coordinator and wrote the executive summary. Geller was principal author of the methodology and overall results chapters, and provided substantial input to the policy chapter. Lashof was principal author of the background and policy chapters, and provided substantial input to the analysis chapters. Zimmerman was a contributing author for the background, methodology, and policy chapters. Stephen Bernow of the Tellus Institute helped write the methodology, analysis, and policy chapters.

The project was organized along sectoral lines. Analysts from the four sponsoring organizations, as well as independent researchers, developed the assumptions on technology costs and penetration rates for the various sectors. They then identified barriers to increased utilization of efficiency and renewable energy technologies, and proposed policies to overcome those barriers. David Goldstein (NRDC), Peter Miller (NRDC), and Robert Mowris were responsible for the buildings sector. Jennifer Jordan (ACEEE) and Daniel Lashof (NRDC) handled industry. John DeCicco (ACEEE), Deborah Gordon (UCS), John Holtzclaw, Marc Ledbetter (ACEEE), and Harvey Sachs collaborated on transportation. Michael Brower (UCS) handled renewables. Stephen Bernow and the staff of the Tellus Institute took responsibility for the utilities sector.

The Tellus Institute worked with the sector analysts to evaluate end-use consumption, fuel mix, primary energy requirements, pollutant emissions, costs and benefits, and integration of electric supply and demand for each sector. Stephen Bernow led the Tellus team, which included Richard Rosen, Bruce Biewald, Kevin Gurney, Elizabeth Titus, Jeffrey Hall, and Daljit Singh on the technical analysis, and Rosen, Rick Hornby, Harvey Salgo, and George Sterzinger on the utility sector policy analysis.

Warren Leon (UCS) supervised the editing and production process. T. M. Hawley did final editing on the report. Michael Brower (UCS), Stephen Frantz, and Janet Wager (UCS) assisted with copyediting. Herb Rich and Lynda Dreyfuss of UCS designed and produced the report.

Many people provided helpful written comments on the initial draft: Brady Bancroft, Jan Beyea, Robert Bishop, William Chandler, Andrew Clarke, J. H. Cushman, Angus Duncan, Craig D. Ebert, Jae Edmonds, James A. Fay, Nick Federick, Christopher Flavin, T. J. Glauthier, Rick Heede, Raymon Lark, Mark D. Levine, Jack Lillywhite, Amory Lovins, James MacKenzie, Alan Miller, Michael Replogle, Howard Ris, Marc Ross, Danilo J. Santini, Lee Schipper, Linda Stuntz and the staff in the Policy, Planning, and Analysis Office of the US Department of Energy, Michael Totten, Gunner Walnet, Stephen Wiel, and John Wilson. The technical analysis for the buildings sector benefited from consultation with R. Balasubramanya, Jim Block, Lee Eng Lock, Mary Ann Piette, and Jack Wolpert.

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Executive Summary

OVERVIEW

The vast and complex system by which energy is produced and used is increasingly at the heart of the environmental and economic challenges facing the United States. Our country is heavily dependent on highly polluting fossil fuels—particularly coal and oil. Moreover, it consumes these fuels in an exceedingly wasteful manner in comparison to our leading economic competitors, Europe and Japan. Thus, reducing fossil-fuel use is essential to America's long-term economic and environmental well-being. And yet, in the debate over national energy policy, economic and environmental issues are often portrayed as being at loggerheads. According to conventional wisdom, America cannot significantly change the way it produces and uses energy without sacrificing economic prosperity.

This report presents a strikingly different view of America's energy choices. America need not blindly follow past energy practices, but can steer a different course—one that will enhance public health and the environment, and save money at the same time. By combining strong economic and technical analysis with bold policy proposals, the report provides a sound basis for moving America away from its wasteful—and increasingly hazardous—use of fossil fuels toward the most efficient use of all energy resources, fossil and renewable. It further demonstrates that such a change in course will result in net economic savings amounting to trillions of dollars.

We initiated this project in order to examine the role that energy efficiency and renewable energy technologies can play in meeting the nation's economic and environmental challenges. We used a computerized energy modeling system designed by the Stockholm Environment Institute-Boston Center at the Tellus Institute, and tested four energy futures—a Reference case, which reflects current policies and trends; a Market case, which selects energy technologies based on the goal of minimizing the cost of energy services purchased by consumers; an Environmental case, which assigns monetary values to the environmental impacts of energy use; and a Climate Stabilization case, which seeks to meet predetermined targets for reduction of carbon dioxide (CO_2) emissions to the atmosphere. Analysts from the American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists, as well as several independent analysts, provided data and input to the study for over a hundred energy efficiency and renewable energy technologies. Each case assumes successively greater utilization of these technologies.

For each scenario, we estimate how much energy the US would need, how much of it would come from renewable sources, how emissions of key atmospheric pollutants would change, and the resulting net costs to energy consumers. In all cases, steady growth in GNP was assumed.

The results of the analysis were stunning. If current policies and energy-use trends continue until 2030, national energy consumption will rise 41 percent, renewable energy will continue to make only a modest contribution to our energy supply mix, petroleum consumption will increase by 16 percent, and carbon dioxide emissions will increase by 58 percent.

By contrast, the three other scenarios achieve dramatic reductions in energy use and air pollution emissions, a greater penetration of renewable technologies, and successively greater monetary savings. In our most aggressive case (the Climate Stabilization scenario):

- National energy requirements in 2030 would be cut nearly in half from the Reference case, with renewable energy sources providing more than half of our energy supply.

- Our nation's petroleum consumption would steadily decrease to just one-third of current levels by 2030.

- Carbon dioxide emissions would be cut by more than 25 percent from 1988 levels by 2005, and by more than 70 percent by 2030.

- Consumers would save $5 trillion in fuel and electricity costs over the next 40 years; subtracting the $2.7 trillion additional investment needed to achieve this, we estimate a net savings of some $2.3 trillion.

Our conclusion: whether one simply wants to minimize costs to consumers, or to mitigate global warming, vigorous adoption of energy-efficiency measures and accelerated use of renewable energy sources make sense.

Despite the logic of pursuing this course, it will not happen automatically. Current government policies and the marketplace are structured in a way that encourages the wasteful use of fossil fuels, not the efficient use of all available energy resources. Thus, in this report, we present an array of policies that can shift the nation from its current path toward any of the more beneficial energy futures we outlined.

In contrast to President Bush's National Energy Strategy (NES), which emphasizes reliance on fossil fuels and nuclear power and includes very limited energy-efficiency improvements, this report provides a sound basis for enhancing America's economic and environmental well-being.

BACKGROUND

During the last 20 years, the United States has experienced three major political and economic crises related to our energy practices, particularly our dependence on oil. That excessive dependence remains as burdensome as ever.

Our current wasteful use of energy also threatens the United States' ability to compete in world markets. Imported oil is the single largest component of our trade deficit. In many instances, US industry remains much less energy efficient than its competitors in Europe and Japan. Perhaps most important, US companies are at risk of losing out to foreign competitors in the battle over the expanding world market for energy-efficient appliances, vehicles, and processes, as well as renewable energy technologies.

Energy production and use also inflict heavy damage on the environment. To slow global warming, protect wilderness areas, and reduce acid rain and urban smog, we must change the ways in which we obtain and consume energy.

The last two decades showed that energy efficiency could be a pillar of US energy policy. Between 1973 and 1986, total US energy consumption remained level—and CO_2 emissions actually *dropped*—while our economy expanded by almost 40 percent. Both energy consumption and CO_2 emissions have since increased, however, because of a decline in the real price of oil and the contraction of federal energy-efficiency programs under the Reagan administration. In the same period, federal support for renewable energy technologies declined dramatically, despite evidence of their promise.

In 1989 we became optimistic that a new era in energy policy might be dawning. Energy Secretary James Watkins announced that he had been instructed by President Bush to develop a comprehensive national energy strategy. Secretary Watkins's efforts to carry out the president's wishes revealed a broad-based public consensus that energy efficiency should be at the core of the proposed NES. The summary by the Department of Energy (DOE) of its series of public hearings held across the country proclaimed that:

> *The loudest single message was to increase energy efficiency in every sector of energy use. Energy efficiency was seen as a way to reduce pollution, reduce dependence on imports, and reduce the cost of energy.*

The summary also revealed strong support for accelerated development of renewable energy sources.

Unfortunately, the final NES report, though strong on rhetoric, did not embrace these energy efficiency and renewable energy opportunities. Rather than calling for a decrease in our nation's dependence on oil, it anticipated a 13-percent increase in total oil consumption by 2010. Rather than attempting to decrease CO_2 emissions, it projected a 26-percent increase over the same period. And rather than presenting policies to foster the renewable energy industries that must dominate the 21st century if America is to be clean, prosperous, and secure, it proposed continued reliance on fossil fuels and nuclear power.

OBJECTIVES, SCENARIOS, AND MODELING ASSUMPTIONS

This study was originally conceived as an alternative to the administration's NES. The objectives were to examine a range of plausible energy futures, each conforming to broad programmatic themes, and to suggest policies that could move us toward each of these futures. Instead of attempting to predict what would happen as a result of specific policies, the study describes what *could* happen within assumed technological, resource, and market constraints. The result, we hope, will be to motivate further exploration and adoption of the policy, technology, and institutional initiatives that could lead us toward desirable outcomes.

We start with a **Reference** scenario, adapted from Department of Energy projections reflecting current policies, practices, and trends. Total energy use in 2030 is 17 percent less in our Reference case than in the NES reference case because of adjustments made in the industrial and transportation sectors to reflect more realistic trends. Our three alternative scenarios are all designed to deliver essentially the same level and quality of energy services as the Reference scenario, but to do so at lower cost and with less environmental damage by employing greater end-use energy efficiency, efficient new power supplies, infrastructure changes, and renewable energy investments. The alternative scenarios are:

- a **Market** scenario, making use of cost-effective energy-efficiency and renewable energy technologies, assuming moderate market penetration rates, with no accounting for environmental or security costs beyond those embodied in current trends and policies (e.g., the Clean Air Act)

- an **Environmental** scenario, employing additional energy-efficiency and renewable energy resources to the extent justified by the environmental and security costs of fossil fuels, and assuming more rapid market penetration rates

- a **Climate Stabilization** scenario, designed to achieve carbon dioxide emissions targets consistent with an effective international program to limit global warming (a 25-percent reduction in US CO_2 emissions by 2005 and at least a 50-percent reduction by 2030).

Our method in each scenario was to adopt efficiency and renewable resources starting with the least expensive options and proceeding to more expensive ones as needed. For example, a wide range of energy-efficiency measures were ranked according to their cost per unit of energy saved. We combined this information with detailed data on the existing stock of buildings, appliances, vehicles, and industrial equipment, along with projections of future changes in these stocks, to construct "conservation supply curves," representing the *technical potential* for efficiency improvements.

To estimate how much of this potential could be developed—the *economic potential*—we compared the incremental costs of energy savings to the incremental costs of new energy supply. We then estimated the rate at which those savings could be implemented—the *achievable potential*—by considering limitations imposed by such factors as rates of capital stock turnover, the existing infrastructure, and market inertia. The achievable potential varied in successive scenarios, reflecting increasingly aggressive development and adoption of new technologies.

A similar method was used to evaluate renewable resources. We compared the cost and performance of renewable energy technologies to competing fossil-fuel technologies, adopting those found to be cost competitive in order of ascending cost. Market penetration was gradual, reflecting constraints such as the rates of retirement of existing power plants. As would be expected, more costly renewable energy options were introduced sooner in the Environmental and Climate Stabilization scenarios than in the Market scenario, reflecting the inclusion of environmental and security costs in the price of fossil fuels.

This analysis yielded, for each scenario, projections of energy use by fuel type for each major energy sector—buildings, industry, transportation, and utilities. We also generated estimates of the emissions of seven atmospheric pollutants: sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), total suspended particulates (TSPs), and volatile organic compounds (VOCs).

Finally, we compared the costs and benefits of each of the alternative scenarios to the Reference case, considering the incremental investments in new equipment as costs and the net reduction in fuel use as savings (but disregarding the indirect benefits from reduced pollutant emissions). We used the current costs of those energy-efficiency technologies already available, and kept them constant over time, rather than reducing them to reflect potential production, distribution, and market efficiencies that might be realized as implementation expands. Costs and performance assumptions for more speculative efficiency technologies were estimated by our analysts. For those renewable energy technologies that are not yet fully mature, we relied on estimates of their future costs and performance based on analysis of current trends and likely technological advances. In several cases in the transportation and industry sectors, we were unable to develop cost and benefit estimates for individual technologies, so we used estimates of average returns for a range of potential efficiency improvements.

We calculated the annual capital and fuel costs over the life of each investment, using a 3-percent real discount rate to convert those costs to present value (in 1990 dollars). To test the sensitivity of our results to our choice of discount rates, we recalculated the net present value of the investments made in each scenario and the savings generated from these investments using a 7-percent discount rate.

SUMMARY OF RESULTS

The Market, Environmental, and Climate Stabilization scenarios all lead to substantial reductions in primary energy requirements and pollutant emissions from the Reference scenario; they also produce substantial cost savings for US consumers and business.

Summary Results

	1988	2000	2010	2030
GNP* (Billion 1990$)	5,292	7,090	8,941	12,792
Reference Case				
Primary Energy (Quads)	85.3	96.4	105.0	120.2
Primary Renewable Energy (Quads)	7.4	9.8	11.2	15.5
CO_2 (Billion tons)	5.3	6.0	6.8	8.3
Energy/GNP (kBtu/$)	16.1	13.6	11.7	9.4
CO_2/Energy (lb/MMBtu)	124.3	123.4	128.6	138.0
Market Case				
Primary Energy	85.3	88.5	83.4	82.2
Primary Renewable Energy	7.4	10.2	14.8	29.0
CO_2	5.3	5.4	4.7	3.8
Energy/GNP	16.1	12.5	9.3	6.4
CO_2/Energy	124.3	121.1	112.5	92.2
Environmental Case				
Primary Energy	85.3	82.2	72.7	70.2
Primary Renewable Energy	7.4	10.6	15.6	29.3
CO_2	5.3	4.9	3.7	2.7
Energy/GNP	16.1	11.6	8.1	5.5
CO_2/Energy	123.3	118.7	102.6	78.1
Climate Stabilization Case				
Primary Energy	85.3	78.4	68.9	61.9
Primary Renewable Energy	7.4	12.4	18.1	32.8
CO_2	5.3	4.4	3.2	1.5
Energy/GNP	16.1	11.1	7.7	4.8
CO_2/Energy	123.3	112.0	91.7	48.8

* GNP growth is taken from DOE's *1990 Annual Energy Outlook.*

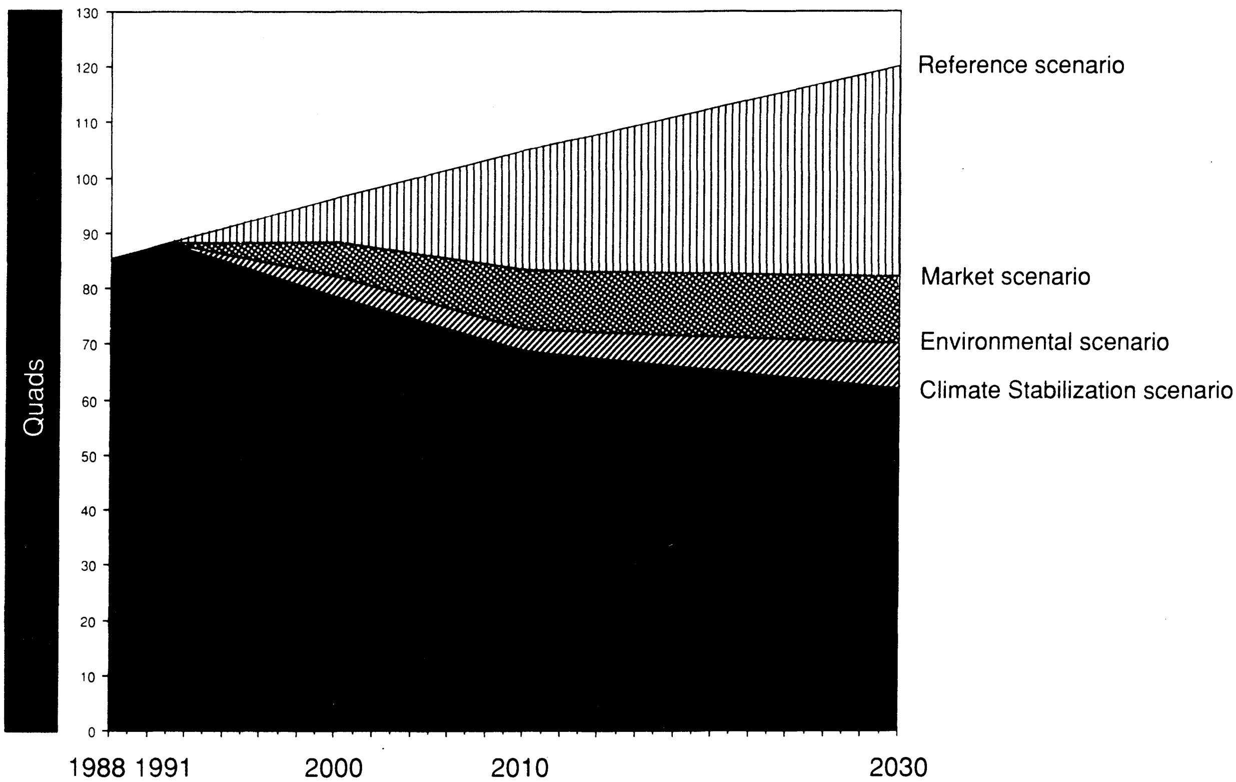
For all the scenarios, we compare energy intensity (the amount of primary energy used per dollar of gross national product) and carbon intensity (the amount of CO_2 emitted per unit of primary energy consumed). The Reference scenario embodies some energy-efficiency improvements, resulting in a 42-percent decrease in energy intensity over the 40-year period, or 1.3 percent per year. However, the fuel mix, especially a growing use of coal for electricity generation, results in an 11-percent increase in carbon intensity.

In the three other scenarios, the energy and carbon intensities *both* decrease over the 40-year period at a progressively greater rate from scenario to scenario, as a result of additional efficiency improvements and a shift to less carbon-intensive fuels.

The rates of energy-intensity reduction in our Market, Environmental, and Climate Stabilization scenarios are not unprecedented. US energy intensity fell by an average of 2.4 percent per year between 1973 and 1986; the three scenarios anticipate decreases ranging from 2.1 percent to 2.8 percent per year.

The rates of transition from fossil to renewable fuels envisioned in our scenarios also have historical precedent. Over the 40-year period, we project renewables increasing from 9 percent of current energy supply to 36 percent in the Market scenario, 42 percent in the Environmental scenario, and 53 percent in the Climate Stabilization scenario. The shift from coal to petroleum and natural gas was comparably rapid in the middle of this century, with coal use declining

Primary Energy Requirements



from 70 percent of our energy supply in 1920 to less than 20 percent in 1970. Our average growth rate of 3.7 percent per year in renewable energy supply between 1988 and 2030 in the Climate Stabilization scenario is less than the rates of growth in oil and natural gas consumption in the decades prior to the 1973 oil price shock.

Our analysis shows that it is the *combination* of steadily declining energy intensity and steadily increasing renewable energy supplies that yields the greatest environmental, security, and monetary benefits for the nation.

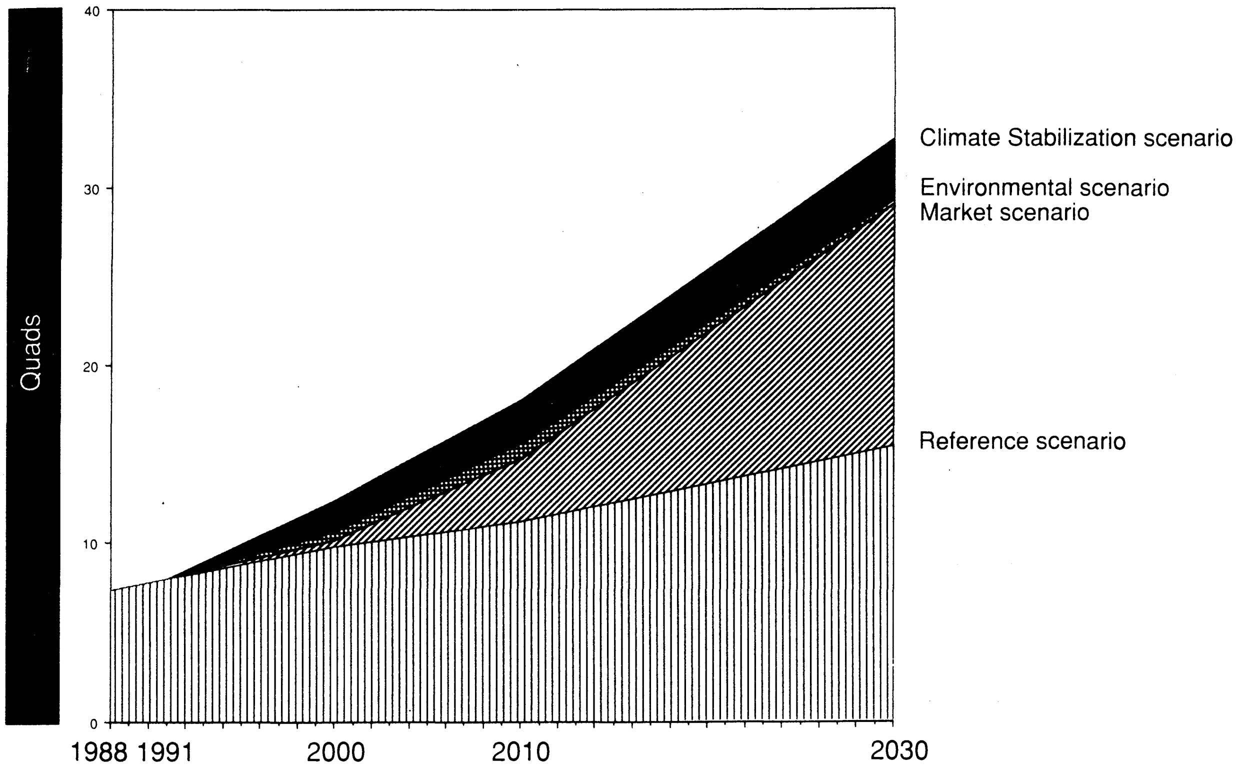
Primary Energy Requirements

Our Reference scenario projects that the primary energy requirements of the United States will increase by about 41 percent during the next 40 years, from the 85 quadrillion Btus, or quads, that the country required in 1988, to 120 quads in 2030. Oil consumption increases 16 percent over current levels. Although the *amount* of energy supplied by renewable sources in the Reference scenario will double during the same period, the *share* of US energy demand supplied by renewables increases only slightly, from 9 percent to about 13 percent.

In the Market scenario, the United States' primary energy requirements fall sharply to 82 quads in 2030. This is 32 percent less than the Reference scenario projections. Oil consumption decreases some 40 percent.

In the Environmental scenario, primary energy requirements decrease to just 70 quads in 2030, about 42 percent less than the Reference scenario projections for that year. Oil consumption is reduced by 54 percent.

Primary Renewable Energy Supply



Finally, in the Climate Stabilization scenario, the United States requires only 62 quads of primary energy in 2030—about half the Reference scenario levels and more than one-fourth lower than actual demand in 1988. Oil consumption is cut by two-thirds from today's levels. Renewable resources more than quadruple over the 40-year period, providing more than half of all energy requirements by 2030.

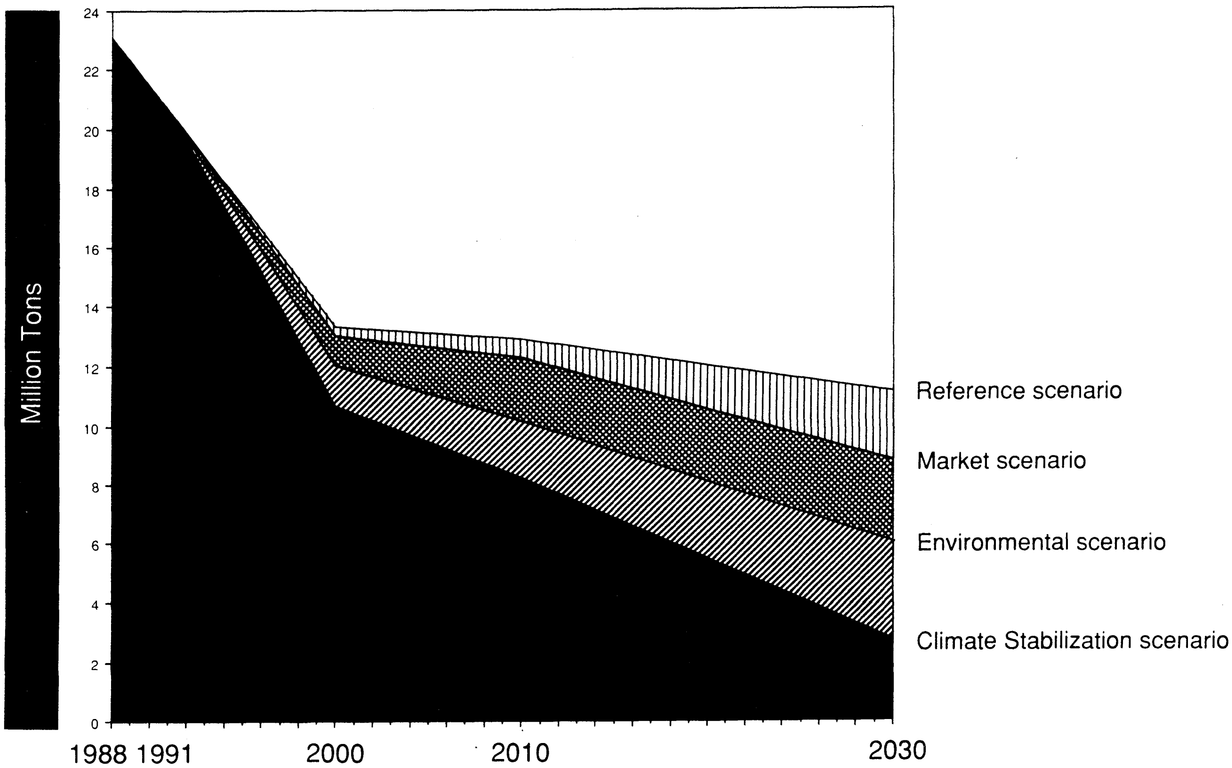
Pollutant Emissions

We generated emissions data for seven atmospheric pollutants but focused especially on CO_2, SO_2, and NO_X. The latter two are the prime causes of acid rain. In addition, NO_X is an important contributor to smog. CO_2 is by far the dominant greenhouse gas produced by energy use.

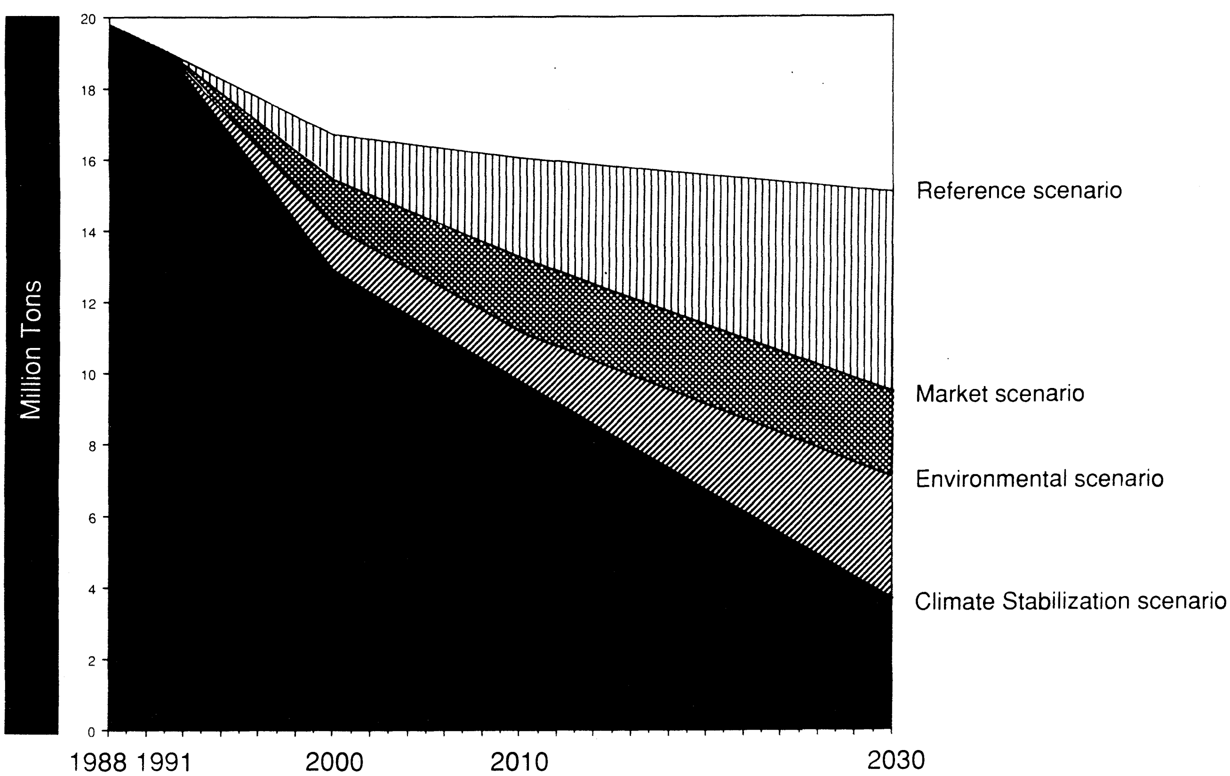
Our study projects that emissions of SO_2 and NO_X will decline even in the Reference scenario, principally because of the requirements mandated by the recently amended Clean Air Act. In the Reference scenario, SO_2 emissions decrease by 42 percent between 1988 and 2000, and NO_X emissions decrease by 16 percent. By 2030 in the Reference scenario, SO_2 emissions fall by 52 percent and NO_x emissions fall by 24 percent relative to 1988 emissions levels.

These emissions would be further reduced in the three other scenarios, with their increased energy efficiency and use of cleaner fuels. In the Environmental scenario, for example, dramatic reductions would be achieved: SO_2 emissions would drop nearly 75 percent between 1988 and 2030, while NO_X emissions would drop by nearly two-thirds. The Climate Stabilization scenario would see even further reductions in SO_2 and NO_X emissions, as a result of still-greater energy-efficiency gains and use of cleaner fuels and the retirement of substantial coal-fired generating capacity in the electric sector.

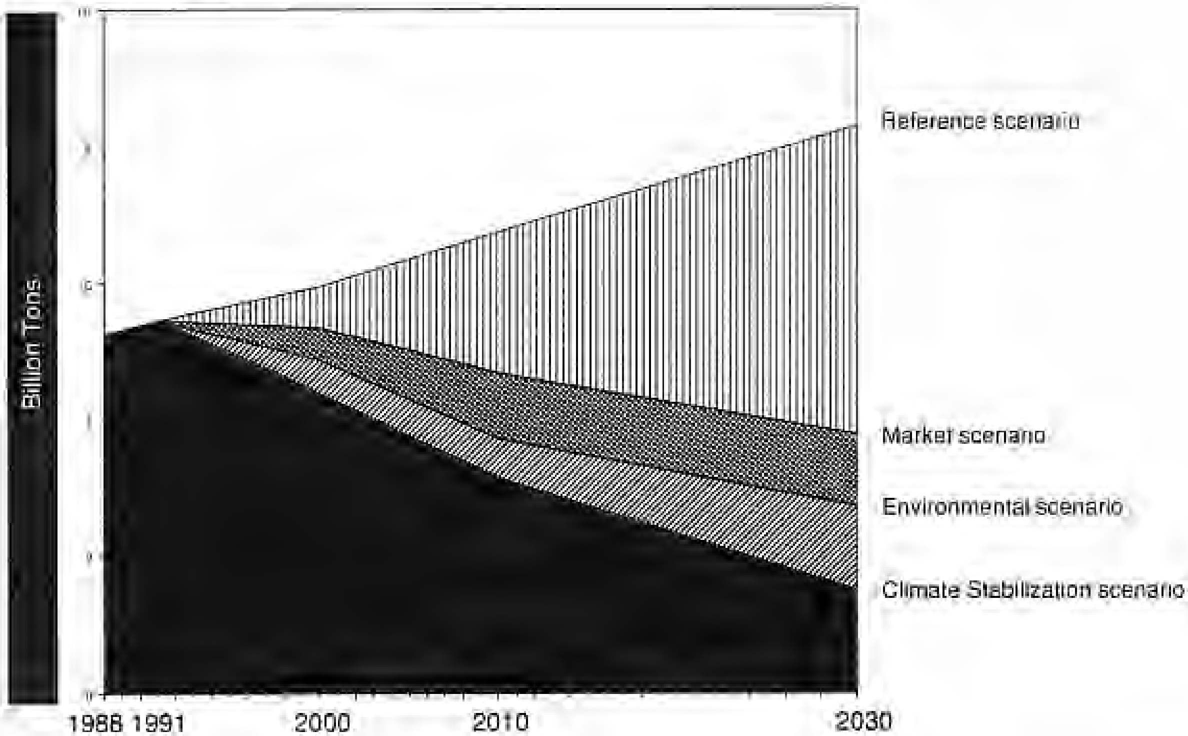
SO_2 Emissions



NO_x Emissions



CO_2 Emissions



In the Reference scenario, new electricity-generating technologies are predominantly coal-fired and have fairly stringent SO_2 and NO_x controls, but no restrictions on CO_2 emissions. The consequence is that while emissions of the first two pollutants decline between 1988 and 2030, CO_2 emissions *increase* nearly 60 percent as electricity demand and coal use grow.

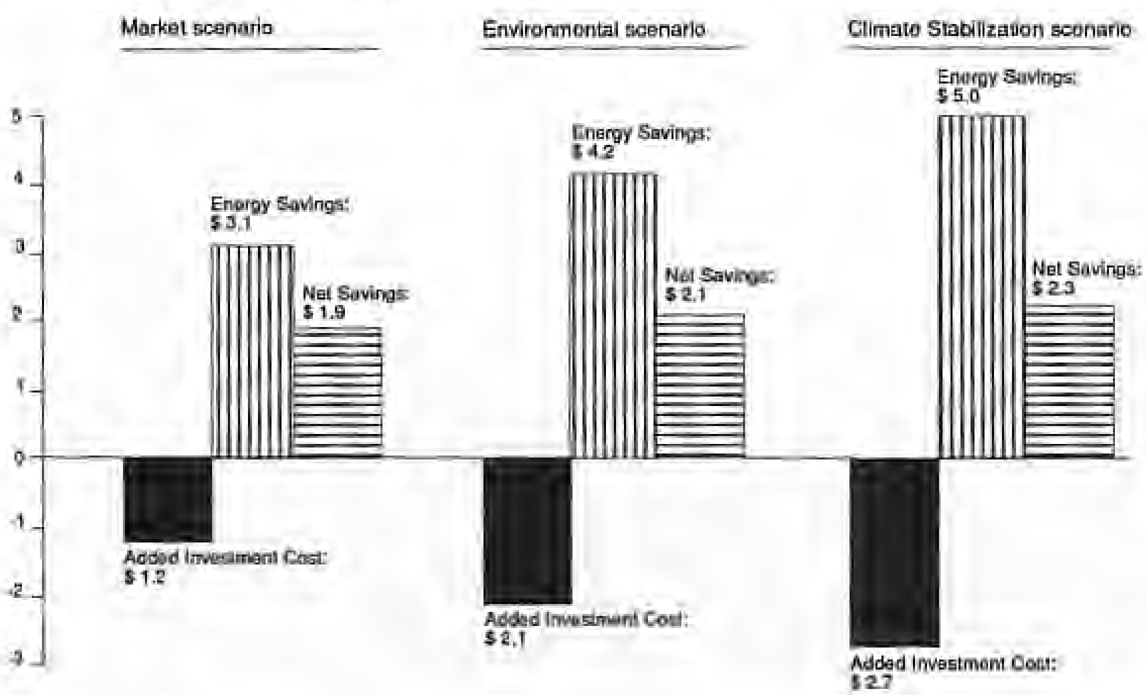
The Market and Environmental scenarios, on the other hand, project significant reductions in CO_2 emissions because of increased energy efficiency, switching from coal and oil fuels to natural gas, and increased use of renewable energy sources. In the Market scenario, CO_2 emissions decrease by 28 percent between 1988 and 2030; in the Environmental scenario, CO_2 emissions decrease by 48 percent over the same period.

The Climate Stabilization scenario leads to more than a 25-percent reduction in CO_2 emissions by 2005 and a 71-percent reduction from 1988 levels by 2030. This dramatic drop is attributable to additional efficiency improvements and further shifts from coal to gas as an energy source for electricity generation, shifts from coal to electricity as an industrial power source, the greater use of renewable fuels, and more efficient technologies for heating in the residential, commercial, and industrial sectors.

We compared our CO_2 emission results with those of six other recent assessments of national energy requirements and the potential for limiting future carbon dioxide emissions. Two of these scenarios were developed by DOE as part of its National Energy Strategy, two by the Office of Technology Assessment of the US Congress, one by ICF, Inc. for the US Environmental Protection Agency, and one by a group using the MARKAL model developed at Brookhaven National Laboratory. Among these, our study is unique in combining aggressive pursuit of both energy efficiency and renewable energy technologies. Also, our study used a lower discount rate for evaluating the cost-effectiveness of these technologies, reflecting our intent to

Costs and Savings Compared to Reference Case

Cumulative Present Value (Trillion 1990 Dollars) at 3% Discount



maximize long-term benefits to society. These differences explain why our Environmental and Climate Stabilization scenarios project greater reductions in CO_2 emissions than the other studies. In these other studies, CO_2 emissions in 2010 range from 13 percent higher to about 25 percent lower than base-year emissions. In our Climate Stabilization scenario, CO_2 emissions are 40 percent lower in that year.

Costs and Savings

Our study demonstrates that, far from being a costly drag on the economy, increased use of renewable energy technologies and energy efficiency can save American consumers and businesses hundreds of billions of dollars over the next 40 years. The savings in fuel and electricity that result in our non-Reference scenarios substantially exceed the investment costs in each case. The net savings in the Market scenario total about $1.9 trillion over the 40-year period, increasing to nearly $2.1 trillion in the Environmental scenario and nearly $2.3 trillion in the Climate Stabilization scenario. If a 7-percent discount rate is used instead of a 3-percent rate, the net savings are reduced to about $0.6 trillion in all three scenarios, reflecting the reduced value of future savings.

It may seem counterintuitive that the net savings are greatest in the Climate Stabilization scenario, especially since some higher-cost efficiency, fuel-switching, and renewable energy options are employed to achieve the additional carbon dioxide emissions reductions compared with the Market and Environmental scenarios. It turns out that the higher cost of these options at the margin is more than offset by the greater penetration of lower cost options assumed to result from more aggressive policy measures envisioned in this scenario. Our cost results do not include economic adjustment costs or economic benefits from reducing pollution.

While our cost results are approximate, they indicate that, far from being a burden, greater energy efficiency and accelerated development of renewable energy sources would provide society with significant economic dividends, as well as clear environmental benefits.

Analysis and Results by Sector

We now highlight the key assumptions and findings for each sector examined in the report: buildings, industry, personal and freight transportation, and electric utilities. The results are numerically presented in tables at the end of the Executive Summary.

Buildings. Our analysis reveals a tremendous potential for cost-effective energy savings in the residential and commercial buildings sectors. These savings would result from the use of more than 60 types of conservation technologies and measures currently available, ranging from more efficient lighting, windows, and appliances in existing residences to more efficient heating, ventilating, and air conditioning systems in new commercial buildings. We did not include measures that our analysts judged to be too uncertain in terms of availability, performance, and/or cost. The energy savings potential varies from 40 percent in new educational buildings to 87 percent for retrofit of existing electric-resistance-heated single-family homes. Commercial office space retrofits fall in-between, with savings averaging about 70 percent.

It will take time to develop the conservation programs and manufacturing and distribution capacity to implement these measures, as well as to commercialize some of the technologies. Our estimates of the rate at which the technologies will penetrate the market are based on a review of experiences with existing policies and programs, as well as anticipated results from new programs.

In addition to efficiency gains, we project greater use of renewable energy technology in the buildings sector. We evaluated solar water heating, passive solar building design, solar district heating with seasonal storage, and geothermal district heating options. Savings obtained from these options range from 20 percent to 50 percent of final heating and hot-water demand (depending on scenario and region). Firewood continues to supply a small but significant fraction of energy use in this sector.

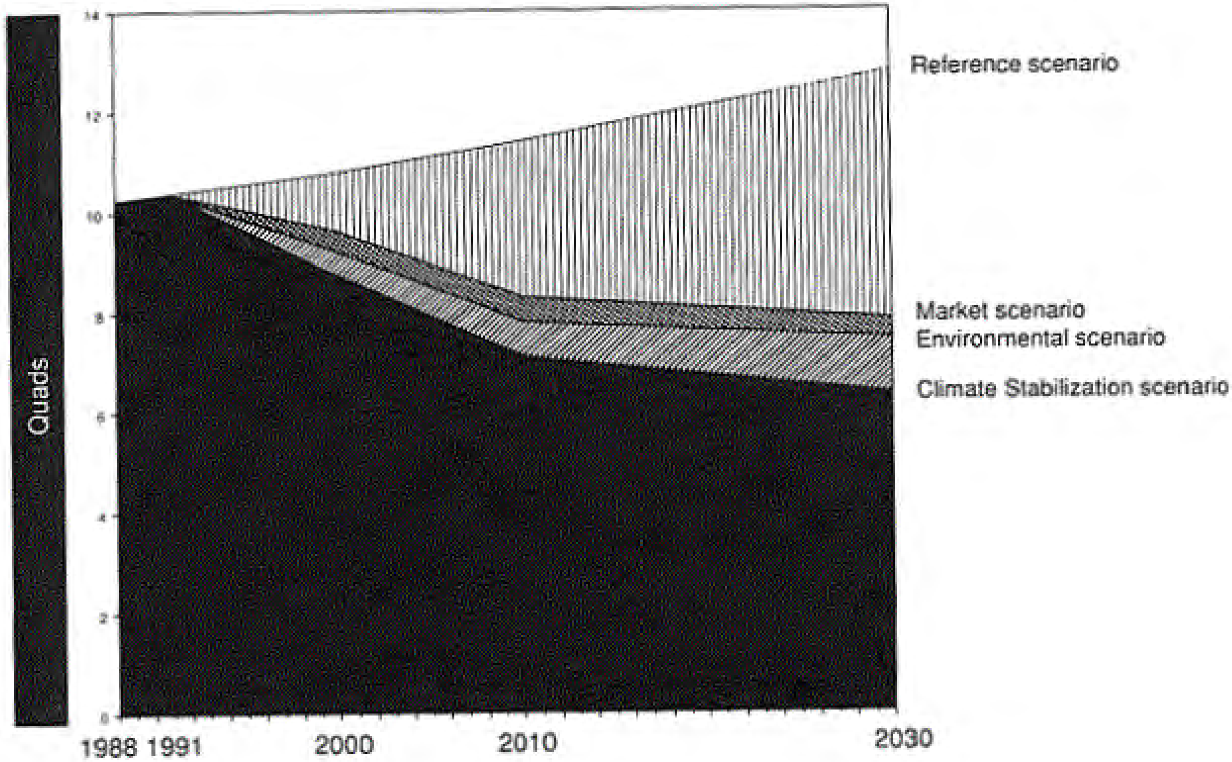
Energy use in residential buildings. In the Reference scenario, energy use in the residential sector increases from about 10 quads in 1988 to almost 13 quads in 2030. In contrast, energy consumption would fall 24 percent in the Market scenario, 27 percent in the Environmental scenario, and 38 percent in the Climate Stabilization scenario. In all our scenarios, electricity gradually increases its share of residential energy use while the shares of natural gas and oil decrease.

Renewable energy sources contribute between 11 percent of total residential energy supply in the Reference scenario to 33 percent in the Climate Stabilization scenario in 2030, compared to 9 percent in 1988.

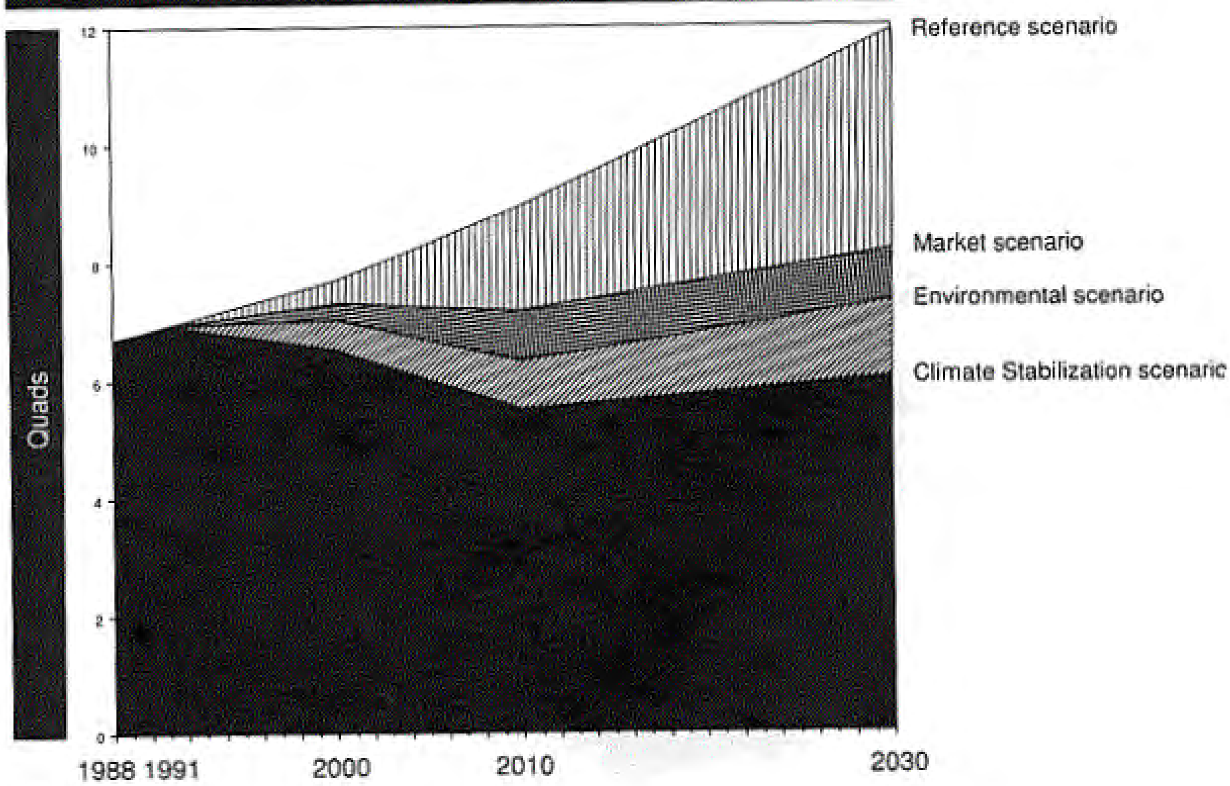
Energy use in commercial buildings. Energy use in the commercial sector increases 78 percent, from almost 7 quads in 1988 to almost 12 quads in 2030 in the Reference scenario. It rises in the Market and Environmental scenarios, but by much less—22 percent and 9 percent, respectively. The Climate Stabilization scenario projects a decrease of 10 percent. As in the residential sector, electricity provides a larger share of the energy over time, as do renewable energy sources.

Industry. There is enormous potential for US industries to improve their energy efficiency. However, the analysis was complicated by the fact that US industries are extremely heterogeneous and information about industrial processes is limited (and in many cases proprietary). Our analysis of energy efficiency thus relied primarily on assumed rates of energy-intensity reduction in various industrial subsectors, but was complemented by some analysis of specific efficiency measures. Three renewable energy resources were considered: wood wastes, solar-thermal energy, and geothermal energy.

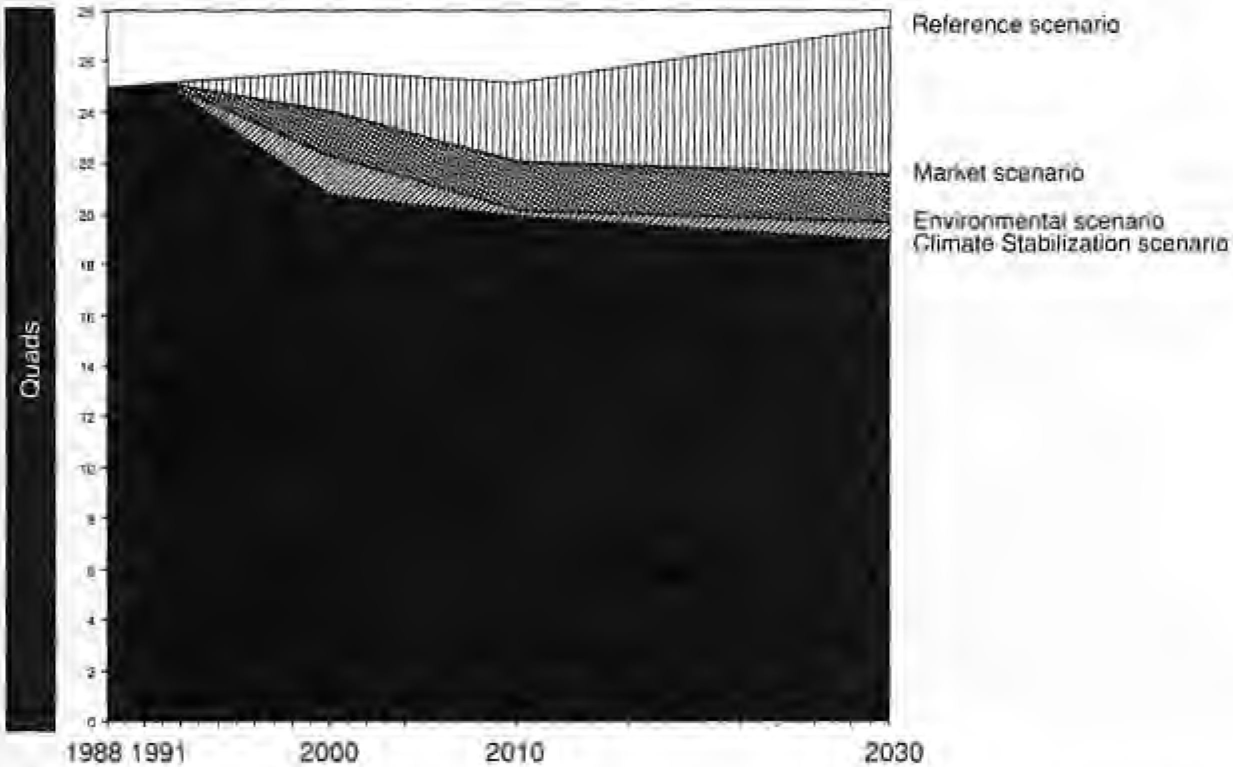
Residential Energy Consumption



Commercial Energy Consumption



Industrial Energy Consumption



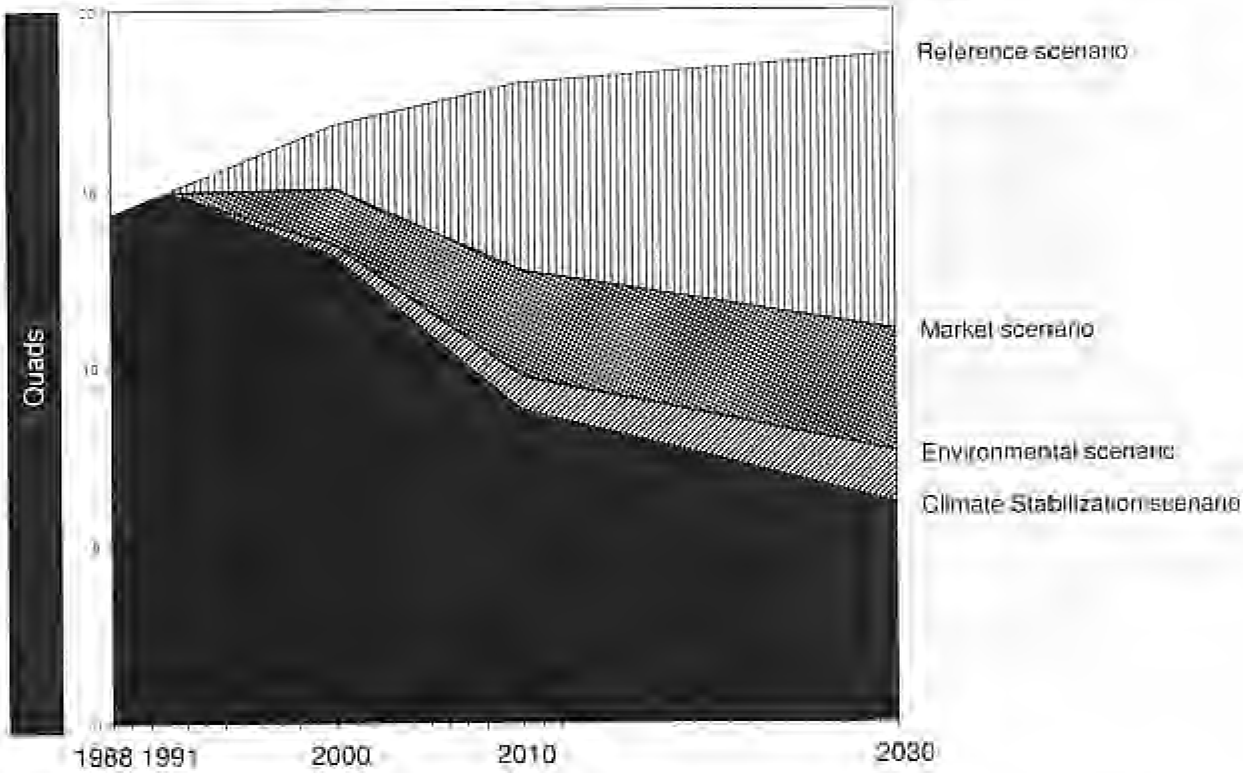
All the scenarios assumed the same increase in dollar output of basic materials such as steel or paper. It is important to note, however, that we did not follow the assumptions about growth in production of basic materials used by DOE, because we believe they fail to adequately reflect fundamental structural shifts that are taking place in the economy. Our assumptions regarding industrial output reflect trends indicating a steady and significant shift in economic output away from basic industries and toward light industry and the service sector.

The Reference case shows a modest increase in energy use in the industrial sector from 25 quads in 1988 to 27 quads in 2030. The other three scenarios indicate significant reductions from 1988 levels—14 percent in the Market scenario, 21 percent in the Environmental scenario, and 24 percent in the Climate Stabilization scenario. In addition to these energy savings through efficiency improvements, we project greatly expanded contributions to energy supply from cogeneration, solar, and geothermal resources, particularly in the Environmental and Climate Stabilization scenarios, where our assumptions about pollution taxes on fossil fuels improve the economic competitiveness of these resources.

Transportation sector. The aim of US transportation policy should be to move people and freight from one point to another in the most efficient manner possible without sacrificing convenience and safety.

Personal transportation. Our analysis covers all modes of personal travel—private passenger vehicles, public transit, and intercity air, rail, and bus. It demonstrates that energy efficiency can be increased by improving vehicle technology, by shifting to more efficient transportation modes, by changing land-use patterns, and by implementing measures that reduce wasteful travel (such as single-occupant commuting). At the same time, emissions of CO_2 and other pollutants can be reduced by improving efficiency and switching to less-polluting fuels.

Personal Transportation Energy Consumption

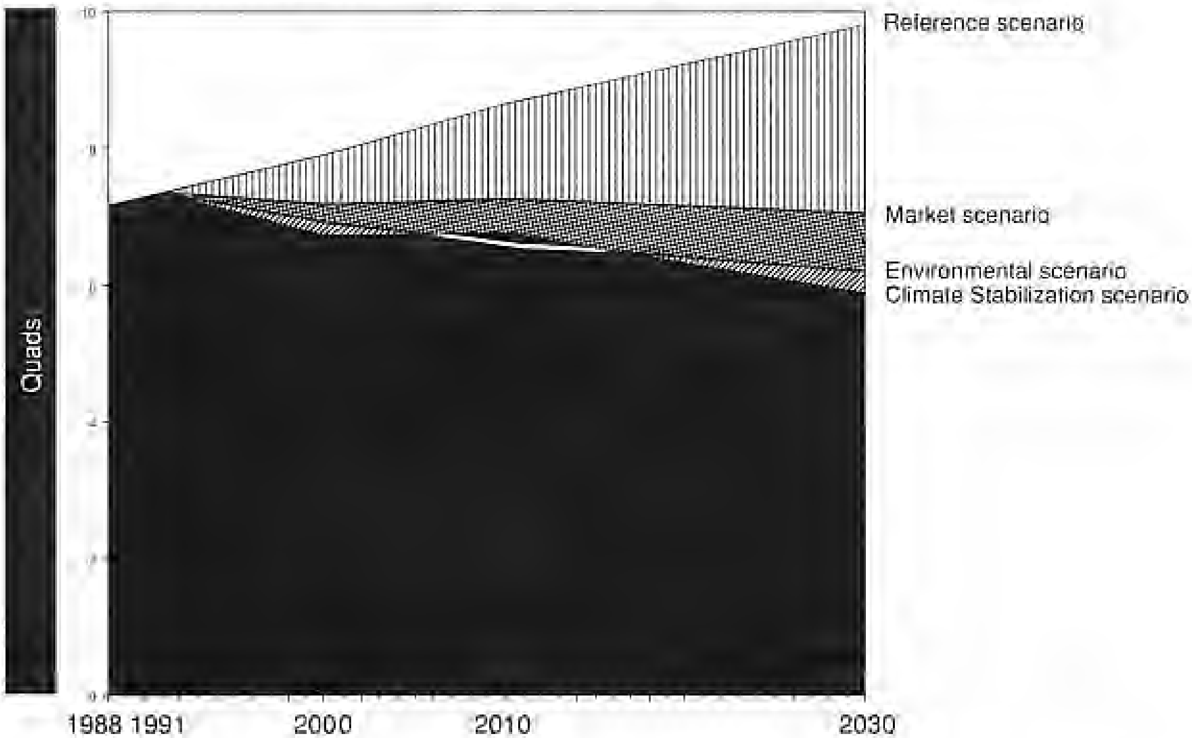


The fuel efficiency of light vehicles increases in each scenario, but at different rates. We assume the average rated fuel economy of new cars in 2010 reaches 37 miles per gallon (mpg), 50 mpg, 54 mpg, and 59 mpg in the Reference, Market, Environmental, and Climate Stabilization scenarios, respectively. We assume that by 2030 the average rated fuel economy of new cars is 41 mpg in the Reference scenario, 56 mpg in the Market scenario, and 75 mpg in the Environmental and Climate Stabilization scenarios. Also, we assume that the current gap between rated and actual on-road fuel economy declines in the three non-Reference scenarios because of revised test procedures. This implies even greater energy savings than suggested by the fuel-economy ratings alone.

In recent years, gains in automobile fuel efficiency have been offset by increases in the number of miles that Americans drive. Our Reference scenario assumes continuation of current transportation policies and urban-growth patterns, leading to a 60-percent increase in vehicle miles travelled (VMT) between 1990 and 2030 in the personal transportation sector. VMT is reduced in our other three scenarios because of expanded mass transit, land-use policies that increase urban density (especially along transit corridors), and implementation of transportation demand management measures such as high-occupancy vehicle lanes and parking restrictions. The combined effect of these assumptions is to limit growth in VMT over the 1990-2030 period to 32 percent in the Market scenario, 6 percent in the Environmental scenario, and 5 percent in the Climate Stabilization scenario.

In the Reference scenario, overall energy use in the personal transportation sector increases dramatically, from over 14 quads in 1988 to almost 19 quads in 2030. The other three scenarios project sharp declines instead: 23 percent in the Market scenario, 47 percent in the Environmental scenario, and 57 percent in the Climate Stabilization scenario.

Freight Transportation Energy Consumption



Much of the energy for personal transportation could be supplied by electricity and by biofuels such as methanol, ethanol, and hydrogen. We assume that biofuels would be produced from wastes or energy crops (such as short-rotation trees and grasses) that would be grown on a large scale and converted to fuel using thermochemical and biochemical processes now under development. Based on cost comparisons with conventional gasoline and diesel fuel, we projected that biofuels would begin penetrating the personal and freight transportation sectors within 10 years, and, by 2030, would account for 33 to 43 percent of total energy use for personal transport in our three alternative scenarios.

By 2030, petroleum consumption, which presently accounts for 98 percent of the energy used for personal transportation, drops to just 61 percent in the Market scenario, 50 percent in the Environmental scenario, and 42 percent in the Climate Stabilization scenario. The combination of efficiency gains and fuel substitution reduces 2030 petroleum consumption in the Climate Stabilization scenario to just 14 percent of the level projected for the Reference scenario.

Freight transportation. Because heavy trucks are the most energy-intensive mode of transportation, we performed an in-depth analysis of the cost-effectiveness of energy-efficiency measures for these vehicles. During the next 40 years, we anticipate that freight-transportation technologies will change significantly—diesel engines will incorporate turbocompounding and low-heat rejection technologies and gas turbines; electric vehicles will become more competitive; and fuel cells will become widely used. Fuel cells are an emerging technology that can supply useful energy from either alcohol or hydrogen, both of which can come from a renewable source. We project that natural gas will become a prominent fuel for moving freight.

Although we assume delivery of 35 percent more freight in 2030 than today, our analysis shows that efficiency improvements can more than compensate for this growth in service demand, resulting in stable or declining energy consumption and pollutant emissions. Although the cost projections for the technologies that will bring about those efficiency increases have large uncertainties, we estimate that these energy-use reductions would be cost-effective in every scenario. With changes in land-use patterns and urban-transportation policies, there could be additional savings, but we did not analyze the impact of those factors for freight transportation.

Overall energy use in the freight sector increases from more than 7 quads in 1988 to almost 10 quads in 2030 in the Reference scenario, as compared to reductions of 2 percent in the Market scenario, 14 percent in the Environmental scenario, and 18 percent in the Climate Stabilization scenario. As with personal transportation, the share of 2030 energy requirements supplied by petroleum falls from 89 percent in 1988 to 69 percent in the Market scenario, 58 percent in the Environmental scenario, and 19 percent in the Climate Stabilization scenario. Alternatives such as biofuels, natural gas, and electricity make up the difference.

Electricity supply. Each successive scenario reflects greater levels of efficiency and hence lower electricity requirements, greater shares of power supplied from renewable resources, and a shift to fossil-fueled power plants with lower pollutant-emission rates. We limited the power-supply options in the Reference, Market, and Environmental scenarios to near-term conventional and advanced fossil technologies and electric-generating facilities that use renewable resources. Some penetration of more advanced coal technology (fuel cells and magnetohydrodynamic facilities) was assumed in the Market and Environmental scenarios in later years. In the Climate Stabilization scenario, we included natural gas fuel cells as an option after 2010.

Our analysis of renewable energy considered 13 technologies—from hydroelectric-plant upgrades to advanced-geothermal technologies (geopressured and hot dry rock). We considered not only direct costs, but other factors such as physical limitations on the resource and the incremental cost of storage needed to compensate for variability of wind and solar output.

Our scenarios assumed neither the introduction of advanced nuclear-reactor designs nor the relicensing of existing nuclear power plants. The cost of construction and operation of existing plants has been rising. Insufficient information is available on the engineering design of advanced reactors to confidently project their costs. In addition, the problem of long-term waste disposal remains unresolved and is unlikely to be resolved anytime soon. Public opposition to new nuclear plant construction remains high, and the industry remains threatened by the possibility of a catastrophic accident at an existing plant.

The Bush administration's energy strategy assumes that these hurdles can be overcome, leading to a doubling of the nation's nuclear capacity by 2030. We instead adopt DOE's base-case assumption that nuclear's role in our mix of energy sources will steadily diminish, producing less than 10 percent of current output levels by the year 2030.

In the Reference scenario, new plant additions are primarily coal-fired and natural gas combined cycle units, with some expansion of renewable capacity and completion of those nuclear units now under construction. In the other three scenarios, efficiency gains hold down the need for increases in total generating capacity, and renewable generation fills in for the phase-out of nuclear output, as well as for the successively greater reduction in coal-fired generation as we move from the Market scenario to the Climate Stabilization scenario.

In the Reference and Market scenarios, we assume only about one-third of existing coal-fired plants are retired at the end of their design lifetimes. In the Environmental scenario, two-thirds are assumed retired because of the relatively high emissions costs of these plants. In the Climate Stabilization scenario, all of the current coal-fired capacity would be replaced by natural gas-fired plants, fuel cells, and renewable energy resources.

In the Reference case, overall electricity requirements increase by 90 percent between 1988 and 2030. In the Market scenario, total generation increases by just 12 percent over the same period, while in the Environmental and Climate Stabilization scenarios, total generation decreases by 8 percent and 14 percent, respectively. The non-Reference scenarios thus greatly reduce fuel combustion and the need for new capacity to meet demand.

In addition, renewable energy resources play an increasingly important role. In the Reference scenario, renewable energy sources supply nearly 14 percent of total electric generation by 2030; this share increases to 40 percent, 52 percent, and 61 percent in the Market, Environmental, and Climate Stabilization scenarios, respectively. Wind, solar, advanced geothermal, and biomass account for the largest shares of new renewable supply.

POLICIES FOR A CLEAN AND PROSPEROUS AMERICA

The results discussed above describe a range of *possible* energy futures for the United States. In the sections that follow, we summarize the energy policies that would move the nation from the Reference scenario toward a cleaner, more competitive, and more secure future.

Several of the policies described here are quantitatively linked to the energy scenarios; for example, the Environmental scenario incorporates increased taxes on gasoline, and new taxes on pollution, to reflect the environmental and national security costs of energy. Various of the scenarios also assume the implementation of such policies as the incorporation of environmental costs in utility planning, automobile efficiency standards, and energy-efficient building codes. Other policies are more difficult to model. For example, we could not reliably estimate the precise costs and savings of integrating land-use and transportation planning or establishing cooperative research and development (R&D) centers for energy-intensive industries.

We have therefore not attempted to estimate the effectiveness of each individual policy. Rather, we present sets of policies that appear consistent with achieving the cost-effective opportunities for increased efficiency and renewable energy production reflected in the scenarios. Some of the policies apply only to one or another of the scenarios, while other policies apply to all scenarios, although perhaps at different rates of implementation. While all of the authors and sponsoring organizations do not necessarily endorse each policy, we believe that the policies outlined show that the nation can move in the direction of our three non-Reference scenarios.

The policies presented here are broad-based and complex; they deserve further analysis and development. In the development of the next version of the national energy strategy, the Department of Energy—in conjunction with other federal agencies and the states—should employ least-cost principles and analyze the policies needed to achieve scenarios similar to the ones described in this report. To be truly successful, this effort must include publication of a draft policy document, including analysis of both selected and rejected options for comment. In turn, DOE should consider and respond to the comments received before issuing its final strategy and policy proposals.

The policies presented here do not call for a return to price controls and crash programs to promote specific fuels. But they recognize the market biases and barriers that currently favor energy production over energy efficiency: tax breaks and other subsidies for preferred energy technologies and fuels; lack of information on, or availability of, energy-saving and renewable energy technologies; the tendency among builders or equipment purchasers to minimize initial costs because they do not pay operating costs; the high costs of capital for consumers who want to invest in efficiency and renewable energy measures; and the widespread failure to reflect the true costs to society of environmental damage from energy production and use.

Some of the policies discussed here have already been implemented in a number of states and localities, and others are under active consideration. What is lacking is a coherent national policy that ensures the implementation of effective policies in all jurisdictions and reflects the public interest in affordable energy services, national security, and environmental protection.

Rather than asking "How can we produce enough energy?" energy policymakers should ask "How can we ensure that our energy system provides the services we want at the least cost?" Reformulating energy policy in this way recognizes the fact that no one is interested in energy for its own sake. Consumers want the services that energy helps to provide—light, comfort, mobility, and the ability to transform raw materials into useful products. From this perspective, energy not wasted is as valuable as energy produced.

In implementing energy policy, particular attention must be paid to issues of equity and fairness, as well as to the impact of the transition to a new mix of energy resources. For example, higher taxes on energy may well be justified to reflect the societal costs of pollution in energy prices, but some of the revenues from such taxes must be used to offset their disproportionate impact on lower-income and rural Americans. Similarly, while the nation (and the world) must shift away from reliance on coal and oil if we are to lessen the risk of ecologically disastrous rates of global warming, consideration must be given to the need for job retraining and economic conversion strategies for those workers and regions of the country that will be most affected by this shift.

The policies we present here reflect three guiding principles that the United States must follow in order to obtain the economic and environmental benefits of the non-Reference scenarios. Energy policymakers in the United States should:

- Harness market forces.
- Make efficiency the standard.
- Invest in the future.

These three basic approaches are described below.

Harnessing Market Forces

Ensuring effective competition among options for energy supply and efficiency, and reflecting environmental costs in energy markets, are essential steps in achieving our policy objectives. The elements of this strategy include ensuring that investments in efficiency are as profitable as those in supply, using market incentives and standards to promote efficient technologies, eliminating barriers (such as tax policies) that unfairly hinder the development of renewable resources, and shifting some of the tax burden from income to pollution.

Promote least-cost planning. State utility commissions should eliminate regulatory incentives for increased energy sales, require all utilities to develop least-cost plans that allow supply-side and demand-side measures to compete on an equal footing, and ensure that least-cost investments are the most profitable investments for the utility. By least-cost plans, we mean those that take account of environmental impacts.

The federal government can also play an important role, such as by requiring that wholesale power purchases, which are regulated by the Federal Energy Regulatory Commission (FERC), are consistent with the relevant state least-cost plans. The federal Power Marketing Administrations, which sell power produced at publicly financed dams and power plants, should be required to give preference in their power sales to utilities that engage in least-cost planning. In addition, the federal government should require the Tennessee Valley Authority to engage in meaningful least-cost planning.

Establish a production tax credit for renewable energy supplies. To help correct for the different tax treatment of fuel expenses versus capital investment (which biases energy choices away from capital-intensive renewable technologies towards fuel-intensive fossil technologies), and to help the renewable energy industries expand their levels of production so as to achieve significant economies of scale, the federal government should establish and expand production tax credits for renewable energy supply. A performance-based tax credit of 2.5 cents per kilowatt-hour for renewable electricity production, along with a tax credit of $2 per million Btu for heat supplied from renewable sources to large industrial and commercial users, would do much to accelerate renewable energy commercialization. These credits would be available for a limited time, and would be gradually phased out for the industry as a whole as the technologies matured. Additional federal and state tax credits should be implemented as needed to promote residential renewable investments, such as solar hot water.

Use market incentives to promote efficient technologies. One way to overcome consumer resistance to the higher up-front costs of some more-efficient technologies is to incorporate part of the long-term energy costs at the point of sale. This can be done by charging fees on inefficient technologies or providing rebates for efficient ones. When both are combined, the practice is known as a "feebate" system. Several utilities are already using this approach to encourage their customers to purchase high-efficiency appliances, lighting, and other equipment. The use of such incentives should be greatly expanded in all states and at the federal level.

Price incentives at the point of vehicle purchase, for example, can be an important complement to mileage standards in stimulating consumer demand for cleaner and more efficient vehicles. The present gas-guzzler tax, an established mechanism that has been effective in raising the fuel economy of low-mpg cars, should be expanded to a system of feebates linked to the efficiency of a model relative to the average fuel economy of the new vehicle fleet.

We also suggest the adoption of usage-based fees for automobile drivers, to reflect more fully the cost of automobile use. An example of such a fee is pay-as-you-drive insurance, which would charge a portion of insurance premiums on the basis of miles driven. Other examples include eliminating the tax exemption for employer-subsidized automobile parking at commercial lots, and increasing the use of highway tolls—which could include fees based on automated detection of passing vehicles.

Shift some of the tax burden from income to pollution. To reflect the environmental and national security costs of various energy sources, the government could assess fees on fossil-fuel consumption, with part or all of the revenues used to reduce income or other taxes. This would result in shifting a substantial portion of the nation's tax burden from labor to pollution.

In our Environmental scenario, the environmental and other societal costs of driving are reflected in prices through a 50-cent-per-gallon increase in gasoline taxes. For industrial and utility sources, emissions of NO_x, hydrocarbons, CO, TSPs, and SO_x from sources larger than a given size would be taxed. The taxes in this scenario would raise almost $150 billion at current levels of consumption and emissions. That amount represents more than 50 percent of current social security and unemployment insurance taxes.

A tax on the emissions of CO_2, levied at a rate of $25 per ton, or $92 per ton of carbon, in conjunction with the policies described in the Market and Environmental scenarios, appears to be of the right magnitude for achieving the emissions targets specified in the Climate Stabilization scenario. Such a tax might be set at a rate of about $1.50 per million Btu on gas, and $2.60 per million Btu on coal, with oil somewhere in-between; nonfossil fuels would pay no tax. In the near term, the tax would raise roughly $140 billion per year; total environmental tax revenues would then be $290 billion per year, or more than current social security and unemployment insurance taxes. An alternative to a CO_2 tax is to auction CO_2 emission permits equal in quantity to the target emissions levels in each year.

Making Efficiency the Standard

According to our analysis and numerous other studies, an enormous reservoir of cost-effective energy-efficiency measures exists in the United States. Efficiency standards can be extremely effective in accelerating the exploitation of this resource.

Increase automobile fuel-economy standards to cut US oil dependence. Corporate Average Fuel Economy (CAFE) standards have been the principal force behind a 75-percent increase in on-road automobile efficiency since 1973. Improved CAFE standards are now long overdue. Already-identified technological improvements can raise the fuel economy of new cars from 28 mpg to 46 mpg during the next 10 years, while maintaining vehicle size, performance, and safety. This can be done at an average cost of conserved energy of only about $0.50 per gallon—half the current price of gasoline. In addition, more stringent standards must be extended to light trucks and minivans. In the Market scenario, we assume that automobile CAFE standards will rise to 40 mpg in 2000; for the Environmental and Climate Stabilization scenarios, we assume more stringent standards. The CAFE standards for autos, minivans, and light trucks assumed in the Market scenario would result in oil savings of 2.5 million barrels per day by 2005.

Set building and equipment efficiency standards to minimize life-cycle costs. New standards for buildings, appliances, and other energy-using equipment can achieve large gains in energy efficiency at minimal administrative and enforcement costs. Standards should be set, and gradually raised over time, in such areas as new construction, existing building retrofits, appliances, lamps, and motors. The federal government should update and strengthen the national model energy code, require states and localities to meet or exceed this code, and require that federally financed or subsidized buildings also meet it.

Federal appliance standards already in effect will produce energy and cost savings. They should be extended to new products such as incandescent and fluorescent lamps, motors, light fixtures, showerheads, commercial refrigeration equipment, commercial heating-and-cooling equipment, distribution transformers, and office equipment.

Require effective energy management at federal government facilities. Government agencies are major occupants of buildings and users of transportation services. The federal government is the nation's largest energy consumer, spending $8.7 billion per year in its own facilities, and another $3.9 billion annually on the energy expenses of low-income households. Conservative estimates show that the federal government can save more than $850 million per year in its own buildings by making cost-effective efficiency improvements. Federal, state, and local governments should invest in such efficiency measures, as well as cost-effective renewable energy production, not only to save taxpayers' money but also to generate a market for state-of-the-art products. A revolving fund of at least $500 million, administered by DOE, would establish a means of financing cost-effective efficiency investments proposed by any federal agency.

Investing in the Future

Targeted investments in R&D, infrastructure, and educational programs are essential to realize the goals suggested in our scenarios. Funding allocations must be reoriented, an efficient transportation network must be developed, and expertise in the technologies and policies of energy efficiency and renewable energy must be expanded.

Give energy efficiency and renewables their fair share of federal R&D dollars. Scarce R&D funds should be allocated according to the potential contribution their recipients can make to providing least-cost energy services. To follow this principle, federal R&D efforts should shift away from the current, heavy emphasis on nuclear energy and fossil fuels, and more priority should be given to energy efficiency and renewable energy R&D. Increasing the share of DOE's R&D budget devoted to energy efficiency and renewable energy research from 15 percent to 67 percent during the next decade would provide the basis for sustained development of new technologies. This would imply an eventual funding level of about $2 billion per year, if the overall R&D budget remains constant. As part of this increase, DOE should expand the use of cost-shared joint ventures with private industry to help commercialize advanced energy-efficiency and renewable energy technologies.

Develop an integrated transportation network to increase access and cut congestion. A range of policies are needed to reduce the steady increase in vehicle miles traveled (VMT) by providing a wider range of transportation choices, and encouraging the use of the most cost-effective combination of transportation modes for each application. The policies include the market-based measures discussed above to ensure that automobile users pay the full costs of driving, and encompass zoning changes that would discourage sprawl and encourage in-fill development in cities, towns, and surrounding suburbs; high-occupancy-vehicle lanes and ridesharing programs that would increase passenger occupancy in personal vehicles; and substantial increases in funding for rail- and bus-transit projects.

Expand education, training, and certification programs in energy-efficient and renewable energy design and construction. One important barrier to increasing energy efficiency and renewable energy utilization is a lack of qualified personnel, from designers of national programs, to conservation program managers at utilities, to inspectors of construction sites for compliance with energy-efficient building codes. The federal and state governments, in conjunction with the private sector, should expand support for these types of educational and training programs and expand programs that effectively disseminate information.

Conclusion

It is up to the nation's energy policymakers, at all levels of government and in the private sector, to seize the opportunities outlined in this study so that our nation can realize a "win-win" energy future—one that combines prosperity and environmental integrity. By choosing an energy future based on energy efficiency and renewable energy, we can take a giant step towards leaving our children a cleaner planet and a more sustainable way of life.

The policies needed to achieve such a future are by no means simple: they involve basic changes in the way we price energy, construct buildings, manufacture goods, and transport ourselves. Changes of this magnitude are never easy to make, but the consequences of *not* moving forward will be increased oil imports, increased carbon emissions, and ultimately higher costs of using energy.

Chapter 1: Background

THE NEED FOR A NATIONAL ENERGY POLICY

The vast and complex system by which energy is produced and consumed is increasingly at the heart of the political, environmental, and economic challenges faced by the United States. During the last 20 years the United States has experienced three major political and economic crises related to our energy practices, particularly our dependence on oil. That excessive dependence remains as burdensome as ever. Our nation is now responsible for 26 percent of the world's global oil consumption but has only 3.5 percent of the oil reserves.[1] To insulate our economy from oil price shocks and supply cutoffs, we must use less oil.

Our current wasteful use of energy also threatens the United States' ability to compete in world markets. Imported oil is the single largest component of our trade deficit. Moreover, US industry remains less energy efficient than its competitors in Europe and Japan. Perhaps most important, world markets will increasingly demand appliances, motors, cars, and tools that use energy efficiently. In addition, the market will expand for products that generate and use renewable energy sources. Other nations are fast overtaking the United States in those technologies, even the ones that were invented here.

Energy production and use also damage the environment. To slow global warming, reduce acid rain, protect wilderness areas, and cut urban smog, we must change the ways in which we obtain and consume energy. Add-on technologies, such as scrubbers on power plants and catalytic converters on tail pipes, can help somewhat, but they are relatively costly and have a limited effect. In addition, they do not abate emissions of carbon dioxide (CO_2), the gas that is the largest contributor to global warming. Carbon dioxide is a fundamental by-product of burning coal, oil, and natural gas. The only effective way to cut CO_2 output substantially is to reduce the consumption of these fossil fuels. This can be done by increasing efficiency and shifting to other energy sources.

Unfortunately, for the last decade the United States has drifted with essentially no national energy policy to counter these economic, political, and environmental threats. The federal government passed from pursuing essentially all energy options simultaneously (1973-80) to proclaiming sole reliance on the market while subsidizing a few options with high costs and significant environmental risks. When the Reagan administration came into office in 1981, it tried to eliminate the Department of Energy (DOE). Although DOE survived, 90 percent of its renewable energy research and 60 percent of its energy-efficiency support did not.

As the federal government relinquished its responsibilities, state and regional institutions produced significant energy-policy innovations. Some state and local governments have demonstrated leadership in the way they have exercised their authority to regulate electric and gas utilities, adopt

[1] British Petroleum Company, *BP Statistical Review of World Energy*, June 1990.

efficiency standards, provide incentives for energy conservation and renewable energy use, and conduct land-use planning. Nevertheless, although much can be done at the state and local levels, these measures are no substitute for a coordinated national effort.

Such a national energy strategy need not be based on a return to price controls or on crash programs that promote specific fuels. But the United States cannot afford to continue to indulge in the fantasy that the "invisible hand" will solve all our problems. Energy markets are not "free." Electric and gas utilities are regulated monopolies; world oil prices are at least partly controlled by OPEC; and the failure of markets to reflect environmental impacts is a textbook case of "externalities." In general, current energy markets bias private investment decisions toward energy production rather than energy efficiency and toward commercial energy-supply technologies at the expense of innovative renewable ones. Moreover, because they lack important information, businesses and consumers often fail to take actions that are in their economic interest. Government policies can help to correct these various market imperfections.

But even if energy markets were fair and free, support for a "free market" would not be a sufficient energy policy. The government must choose meaningful, obtainable objectives and then harness market forces to accomplish them.

TWENTY YEARS OF ENERGY USE

The last two decades showed that energy efficiency could be a pillar of US energy policy. Between 1973 and 1986, total US energy consumption remained level—and CO_2 emissions actually dropped—while our economy expanded by almost 40 percent. Most of the large decline in energy use per dollar of GNP was the result of improvements in energy efficiency.[2] A typical refrigerator available today, for example, uses half the energy of a typical 1973 refrigerator.

Energy price increases during the 1970s and early 1980s helped spur the impressive efficiency gains, but other government actions during the 1970s also encouraged efficiency. Successful policies included the Corporate Average Fuel Economy (CAFE) standards for automobiles, state appliance-efficiency standards, new utility regulations to stimulate industrial cogeneration, and federal energy conservation research and development programs.

After the enormous progress from 1973 to 1986, energy-efficiency improvements slowed dramatically. Total (primary) energy use rose 2.4 percent per year from 1986 to 1990, only slightly less than the average annual increase in GNP. A plunge in world oil prices, a rebound by heavy manufacturing industries, and the de-emphasis under the Reagan administration of most energy-efficiency policy efforts all led to this leveling off of energy intensity. In the same period, federal support for renewable energy technologies was also slashed, despite their promise.

Recent changes in US energy use have consequently been troubling. The fuel efficiency of new cars and light trucks declined with the 1989 and 1990 model years, reversing a 12-year trend of improved efficiency. While the efficiency of residential space heating continues to improve, the

[2] The rest of the decline was caused by structural changes in the economy, behavioral factors, and a switch to fuels that are produced and used more efficiently. See L. Schipper, R. Howarth, and H. Geller, "United States Energy Use from 1973 to 1987: The Impacts of Improved Efficiency," *Annual Review of Energy 15*, 1990, pp. 455-504.

rate of improvement is less than one-quarter what it was in the early 1980s. Rising energy use is adversely affecting the nation in a number of ways.[3] In 1990 compared to 1986:

- The United States imported 1.8 million more barrels of oil per day ($12 billion per year at $18 per barrel). Of this, 1.5 million barrels per day (mbd) were from OPEC (a 51-percent increase). The United States is rapidly moving toward the day when over half its net petroleum use is imported.

- 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.

- Carbon emissions from fossil-fuel combustion increased by nearly 120 million metric tons (9 percent). This may accelerate global warming from the greenhouse effect.

THE ADMINISTRATION'S NATIONAL ENERGY STRATEGY

In 1989 we were optimistic that a new era in energy policy might be dawning. Energy Secretary James Watkins announced in July that he had been instructed by President Bush to develop a comprehensive national energy strategy (NES). We were encouraged by what appeared to be a new openness at DOE. Secretary Watkins conducted 15 public hearings between July 1989 and April 1990, when an interim report was issued. A wide range of individuals and organizations testified at these hearings and made formal and informal submissions to the Department.

This process revealed a broad-based consensus that energy efficiency should be at the core of the proposed national energy strategy. For example, reflecting very different constituencies, the nation's largest private utility, Pacific Gas and Electric (PG&E), joined with a major environmental group, the Natural Resources Defense Council (NRDC), to submit joint comments. They argued that "it is in energy savings that both NRDC and PG&E see America's largest, least-costly untapped resource option" but that the nation needs "major policy reforms to ensure that energy efficiency and energy production can compete on equal terms throughout the United States."[4] DOE heard similar messages from concerned citizens throughout America. In a brief summary of the results of the public hearings, DOE emphasized:

> People in all parts of the country expressed concern about what energy production and consumption are doing to our air, water, and land. We heard concern about acid rain, urban air pollution, oil spills, the safety of nuclear power plants, our ability to harmlessly dispose of radioactive wastes, and possible global climate change resulting from the use of fossil fuels. Many were concerned about the need to develop advanced technology to convert and control energy in an environmentally sound way. . . . The loudest single message was to increase energy efficiency in every sector of energy use. Energy efficiency

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[3] H. S. Geller, E. Hirst, E. Mills, A. H. Rosenfeld, and M. Ross, "Getting America Back on the Energy-Efficiency Track: No-Regrets Policies for Slowing Climate Change," ACEEE, Washington, D.C., September 1991.

[4] Joint Comments of the Natural Resources Defense Council and the Pacific Gas and Electric Company on the US Department of Energy's National Energy Strategy, July 1990.

was seen as a way to reduce pollution, reduce dependence on imports, and reduce the cost of energy.[5]

Unfortunately, the administration did not heed these energy-efficiency recommendations in its final NES report. The proposed energy strategy was not based on analysis of the least-costly means of providing energy services, and there is little explanation of why certain policies were selected while others were rejected. The NES report discusses the need for greater energy security and enhanced environmental quality, but it fails to incorporate policy initiatives that could achieve these objectives. Rather than continue the process of open discussion, the administration developed its final proposals without any opportunity for public review or comment.

Although some of the NES proposals would improve the markets in which energy resources are developed, there is virtually no attention to end-use market barriers. The NES largely rejects both standards and financial incentives that could promote the adoption of cost-effective energy-efficiency and renewable energy technologies.

The administration's program recognizes that markets are unlikely to "give adequate weight" to health, environmental, and national security concerns, yet it does not include policies to correct this problem. In fact, many of the proposals, such as restrictions on the states' ability to review the environmental implications of new energy projects, remove or undercut policies that help compensate for market failures. And the NES does not attempt to tackle global warming, even though the administration had previously identified the NES as an important component of its policy on climate change.

The administration's National Energy Strategy thus fails to confront the nation's energy challenges. Rather than reducing US oil dependence, it projects a 13-percent increase in total oil consumption by 2010. Rather than decreasing carbon dioxide emissions, it anticipates a 26-percent increase over the same period. In fact, these high projections of oil dependence and CO_2 emissions probably underestimate the likely results of the NES. In addition, the NES assumed more domestic oil production and use of alternative fuels than could be expected to result from its chosen policies, and it counted on an unlikely revival of nuclear power plant construction that would triple US nuclear capacity by 2030. Late changes in the policies selected and inconsistencies in the underlying analysis both suggest that NES projections overstate the positive impacts of the proposed policy initiatives.[6]

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[5] Department of Energy, *Interim Report, National Energy Strategy: A Compilation of Public Comments*. DOE/S-0066P, April 1990, p. 4.

[6] The NES claims that its policies will reduce oil consumption by 3.4 million barrels per day (mbd) compared with baseline projections for 2010. Seventy percent of these projected savings are supposed to be due to use of alternative fuels and oxygen-containing compounds (oxygenates) in reformulated gasoline. But requirements to actually use any alternative fuels were stripped from the final NES, and the projected use of oxygenates is driven by the Clean Air Act, not the NES. The remainder of the projected savings is presumed to result from research and development activities that increase automotive fuel economy. However, projecting such savings is highly speculative.

Energy efficiency and renewable energy industries must dominate the 21st century if America is to be clean, prosperous, and secure. Yet instead of fostering their development, the NES calls for continued subsidies for the oil and nuclear industries—a policy that will only aggravate our nation's energy problems.

MISSED OPPORTUNITIES

If implemented, the NES would be unlikely to produce even the small gains in efficiency and renewable energy production that it projects. Many important policy proposals, such as increasing automobile fuel-efficiency (CAFE) standards, were dropped early on because of Cabinet and White House opposition. In addition, at least five specific proposals intended to promote energy efficiency or renewable energy were deleted between the time a draft was circulated to the Cabinet in January 1991 and the time the final NES was unveiled in March. A brief description of these five changes shows how the final NES falls short and indicates the opportunities that exist to easily and cost-effectively save energy and promote renewable energy.

In the first case, the draft NES would have prevented the Internal Revenue Service (IRS) from taxing rebates paid to utility customers who purchase energy-efficient equipment. The final NES only exempts from income taxation nonrefundable discounts on utility rates or bills. Hundreds of utilities currently provide rebates for energy-conserving equipment or payments for energy savings, and until recently these rebates were not subject to income tax. Taxing utilities' conservation payments would increase the cost of saving energy at a time when energy efficiency must be promoted. It would unfairly penalize utility investment in energy-savings measures as compared to investment in energy supply.

Second, the draft NES would have required DOE to establish an efficiency standard for electric lights, but the final NES prohibits DOE from issuing a standard. During the public hearings, DOE was urged to set standards for lights as well as for such products as electric motors, commercial water heating systems, and space heating, cooling, and ventilation systems. The NES calls for labeling this equipment, but explicitly prohibits setting standards—even though standards could cut peak electrical demand in 2010 by 30,000 megawatts and result in net economic savings of around $40 billion.[7]

The draft NES would also have established a revolving fund to finance energy efficiency improvements in federal buildings. The final NES report says that government managers should increase efficiency in federal buildings and test promising new technologies, but it does not propose an implementation or funding plan. Following the release of the NES, the president issued an executive order directing federal agencies to save energy, but he did not provide them with any resources to accomplish this major task.[8] Federal agencies could save over $800 million in energy

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[7] Howard Geller, ACEEE, testimony before the Energy and Power Subcommittee, US House of Representatives, May 29, 1991.

[8] One exception is the Department of Defense, where agencies are now allowed to keep two-thirds of their energy savings; half of that must be reinvested in efficiency improvements, and half may be used for improvements for welfare and morale.

costs each year from cost-effective investments,[9] but without a means of funding these projects, most are unlikely to be undertaken.

To compensate for the different tax treatment of fossil-fueled power plants and renewable energy sources, the draft NES would have established a performance-based tax credit of 2 cents per kilowatt-hour for electricity produced from new renewable energy sources (solar, wind, and certain geothermal and biomass technologies). Such a significant financial incentive could give a tremendous boost to these emerging technologies. Yet the final NES would only extend the existing 10-percent investment tax credit for solar and geothermal for one year. Wind and biomass systems are not included.

Finally, the draft NES would have required that most vehicles purchased for use in fleets after the year 2000 be capable of running on alternative fuels and that they use alternative fuels 90 percent of the time. The final NES retains the requirement that the vehicles have alternative-fuel capability, but does nothing to require, or even encourage, them to actually use these fuels. It also proposes that automobile manufacturers be allowed to earn unlimited fuel-economy credits by selling flexible-fueled vehicles. This would undermine existing CAFE standards without any guarantee that alternative fuels would be used.

CONCLUSION

The United States can do much better than either current energy policy or the proposed NES. A well-prepared energy strategy would apply the same tests to all policy options and show why recommended policies were better than rejected ones. The public should then have the opportunity to review and comment on these tentative conclusions.

The president's national energy strategy is short-sighted and incomplete. Our study can help complete the picture and point the nation's policymakers in the right direction. In the next chapter we develop four scenarios that compare the current direction of the United States with its potential. We show that America's energy choices can have an enormous impact on our country's economic well-being, our own environment, and our contribution to global environmental concerns.

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[9] Mark Hopkins, "Energy Use in Federal Facilities," Alliance to Save Energy, January 1991.

Chapter 2: Analyzing possible energy paths for the United States

DESCRIPTION OF FOUR SCENARIOS

The objective of this study is to examine the role that energy efficiency and renewable energy technologies can play in meeting the nation's economic and environmental challenges. For this purpose, we developed four scenarios representing plausible energy futures for the US over the next 40 years.

We start with a **Reference** scenario, adapted from Department of Energy projections that reflect current policies, practices, and trends. The Reference scenario represents a "business-as-usual" future which reflects expected GNP growth, changes in population, changes in energy prices, and underlying changes in energy use (including some energy-efficiency improvements). Our Reference scenario differs from DOE's with regard to implementation of the Clean Air Act, assumptions about vehicle use in the transportation sector, and assumptions about the quantity of industrial output produced in future decades.

Our three alternative scenarios are all designed to deliver the same level and quality of energy services as the Reference scenario, but they aim to do so at lower financial and environmental costs by employing greater levels of end-use energy efficiency (conservation), efficient new power supplies, and renewable energy technologies. The rate at which new technologies come into widespread use varies among the scenarios.

The **Market** scenario examines the impact of policy-driven accelerated use of efficiency and renewable energy technologies that are estimated to be cost-effective based on market prices and a 3-percent real (inflation-adjusted) discount rate. The penetration of new technologies is limited by the rate at which equipment is replaced as well as the rate at which markets typically accept innovations. While we assume accelerated market acceptance of efficiency and renewable technologies (encouraged by the policies described in chapter 6), we do not assume any acceleration of equipment replacement in the Market scenario.

We have designed two additional scenarios to reflect growing national and international concerns about energy security and the environmental degradation caused by energy production and use. The **Environmental** scenario incorporates additional energy-efficiency and renewable energy technologies, which become cost-effective when energy security and environmental costs are added to market energy prices. To construct this scenario, we estimated the air pollutant emissions of various energy resources and assigned monetary values to several of these pollutants—sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), methane (CH_4), total suspended particulates (TSP), and volatile organic compounds (VOC). In addition, we assigned a conservative value to the energy security risks associated with petroleum consumption. This scenario also assumes further market acceptance of cost-effective technology compared with the Market scenario and somewhat more rapid equipment replacement, particularly in the utility sector.

We did not ascribe monetary values to carbon dioxide and the other "greenhouse gases" in the Environmental scenario, as a fourth scenario was constructed specifically to meet CO_2 reduction targets consistent with an effective international program to control global warming. This **Climate Stabilization** scenario was designed to achieve a 25-percent reduction in CO_2 emissions by 2005 from current levels and at least a 50-percent reduction by 2030. The Climate Stabilization scenario incorporates additional technologies aimed specifically at cutting CO_2 emissions, as well as more rapid market penetration of technologies included in the other scenarios. Our choices were guided by an assumption that additional measures costing up to about $25 per ton of CO_2 avoided might be needed.

ANALYTICAL APPROACH

Our analysis of US energy-efficiency potential is based on a well-established methodology for cost-benefit analysis of energy investments.[1] It begins with a list of energy-efficiency measures, their incremental costs, and their impacts on energy consumption. The measures are ranked in order of incremental cost per unit of energy saved, or "cost of saved energy." The relationship of the incremental costs to the cumulative energy saved is a "conservation supply curve," which may be drawn for various end-uses, groups of end-uses, sectors, or groups of sectors.[2] The curves indicate the amount of energy savings that can be realized by investing in efficient technology up to a given cost. The savings obtained from investing in all measures considered, no matter how high the cost, is the *technical* potential.

We define a cost-effective conservation measure as one whose incremental cost of saved energy is below the long-term marginal cost of new energy supply. In order to estimate what portion of the conservation supply curve is cost-effective—the *economic* potential—we compared the cost of saved energy for each option to the incremental cost of energy supply, that is, to the "avoided cost" of not having to generate the saved energy. We estimated the avoided cost as the levelized real (inflation-adjusted) cost of each type of delivered energy (e.g., electricity, natural gas, coal, and oil). The avoided-cost values are national averages of the marginal cost of each fuel type for each end-use sector (housing, transportation, etc.).

We also used supply curves to examine opportunities for displacing conventional energy sources with renewable fuels in the buildings, industrial, transportation, and electric-utility sectors. We analyzed the technical and economic potential for the development of renewable resources, and then estimated the potential for those resources within the utility and end-use sectors. In addition to renewables, the electric-utility analysis considered life-extension of existing power plants and

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[1] For example, see Peter Miller et al., *The Potential for Electricity Conservation in New York State*, NYSERDA, Albany, 1989; J. G. Koomey et al., *The Potential for Electricity Efficiency Improvements in the US Residential Sector*, Report LBL-30477, Lawrence-Berkeley Lab, Berkeley, 1991.

[2] An energy end-use can be described as the energy service or task that is provided by equipment that uses energy. For example, refrigerators, air conditioners, and lamps provide food preservation, comfort, and lighting in the residential sector.

implementation of advanced fossil-fuel-fired power plants to determine the appropriate capacity mix for each of the scenarios. Capacity factors (i.e., the fraction of time particular generating options are assumed to operate) were set to satisfy the electricity requirements of each scenario, consistent with technical and economic factors.

By and large, we did not consider the option of switching from one conventional fuel to another—such as from electric to gas for space heating. However, we did consider some oil-to-gas switching for industrial cogeneration, as well as switching from coal to electricity for some industrial processes.[3]

This process of comparing the costs of conservation and renewable alternatives to the avoided cost of traditional energy supplies provided the basic "screen" by which technologies were selected for inclusion in each scenario. In the Environmental scenario, the avoided cost included the costs of pollution (also known as environmental externalities) and national security as well as market costs. Finally, in the Climate Stabilization scenario, more costly energy-efficiency and renewable energy technologies were added to the point necessary to meet the carbon constraints. The marginal cost—the net present cost of the last technology selected calculated at market prices—increased from each scenario to the next.

We did not assume that adoption of cost-effective efficiency and renewable technologies would be universal and immediate. Rather, we assumed that a shift to those technologies would occur over time within the constraints of equipment turnover, consumer behavior, and institutional inertia. The rate at which new technologies penetrate the market was based upon the literature and the experience and judgment of the analysts comprising the study team. In general, the differences in adoption rates among the scenarios result from the successive inclusion of higher-cost options in the Environmental and Climate Stabilization scenarios, as well as the more rapid penetration of less-expensive options in those scenarios because more vigorous programs and policies are assumed.

Because our aim was to indicate plausible energy futures, we did not attempt to make precise predictions or to derive optimal solutions. The Reference scenario is not intended to be a prediction of the future, but is rather a reasonable reflection of "business as usual" trends and policies. It serves as a point of departure for the construction of the other three scenarios.

For our Reference case, we adopted many assumptions directly from the Personal Computer-Annual Energy Outlook (PC-AEO) model used to produce the *1990 Annual Energy Outlook* by the DOE Energy Information Administration (EIA).[4] In three areas—Clean Air Act Amendments,

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[3] Such options—choosing among gas, oil, coal, and electricity—raise a number of complex sector-specific and region-specific issues that are related to equipment costs, ambient conditions, and various aspects of the tasks performed with the energy; those issues were beyond the scope of this study.

[4] The PC-AEO model was also used as a point of departure for DOE's National Energy Strategy "Current Policy Base" scenario. The final NES results were not available when our Reference case was constructed, so some discrepancies exist.

personal vehicle travel, and output of energy-intensive industries—our assumptions differ from those in the PC-AEO model and the NES. The basis for our changes are explained in chapter 4.

The projections of energy demand by sector in our Reference scenario, the *1990 Annual Energy Outlook*, and the recently published Technical Annex to the NES are compared in the following table. The underlying economic, demographic, and fuel-price assumptions in the Reference scenario are maintained throughout this study.

Reference Case Energy Projections

(End-Use Energy Demand by Sector, in Quads)

	1990	2000	2010	2030
RESIDENTIAL				
This Study	10.3	10.8	11.4	12.8
EIA	10.7	11.0	11.6	-
NES	10.2	11.3	12.0	13.0
COMMERCIAL				
This Study	6.8	7.7	8.9	11.9
EIA	6.8	7.4	8.2	-
NES	6.7	7.8	9.0	11.5
INDUSTRIAL				
This Study	25.1	25.6	25.1	27.3
EIA	25.3	29.0	32.2	-
NES	24.5	27.8	32.0	38.6
TRANSPORTATION				
This Study	22.0	24.7	26.6	28.6
EIA	22.4	24.3	26.9	-
NES	22.0	25.8	31.8	37.1
TOTAL				
This Study	64.2	68.8	72.1	80.6
EIA	65.2	71.7	78.9	-
NES	63.4	72.6	84.3	100.2

Sources: *1990 Annual Energy Outlook*, DOE/EIA-0383(90), Energy Information Administration, US DOE, 1990; NES, Technical Annex 2, DOE/S-0086P, 1991.

Modeling Technique

The model used for integrating the energy, economic, and environmental analyses of the study team was the Long-Range Energy Alternative Planning (LEAP) system and Environmental

Database (EDB) of the Stockholm Environment Institute-Boston Center at Tellus Institute.[5] The sector analysts on our team used their own sector models to develop some of the inputs to LEAP (see the Technical Appendixes). LEAP/EDB is a computer model designed to explore alternative energy futures, along with their costs and principal environmental impacts. As a "bottom-up model," its principal elements are the energy and technology characteristics of end-use sectors and supply sources.

The LEAP model has two important advantages. First, it allows very detailed specifications for key physical parameters in each end-use sector. Thus, our four scenarios embody the impact of a variety of factors—including energy prices, technological change, demographic variables, and structural shifts in the economy—on energy use. Second, the accounting framework in LEAP enables its results to be internally consistent. For example, a reduction in petroleum use in the transport sector automatically leads to reductions in distribution losses and energy use for petroleum refining. Similarly, LEAP can keep track of the energy requirements for, and pollution resulting from, the extraction, processing, and distribution of the fuels that provide the energy for each end-use.

Unlike many econometric models, the LEAP model does not integrate the price and income effects that would ensure an equilibrium between supply and demand for each scenario. As energy efficiency increases, for example, the demand for energy falls, and some reduction in fuel prices would be expected. Likewise, as the cost of energy services is reduced by the use of cost-effective efficiency technologies, the demand for energy can, in turn, rise slightly. We did not account for the former effect; thus, our analysis is conservative in that it probably underestimates the full economic benefits that result from the implementation of energy-efficiency and renewable energy measures. We made adjustments for the latter phenomenon, sometimes referred to as the "take-back effect," in those cases where we expected it to be significant.

The literature suggests that for most end-uses in the residential and commercial buildings sectors, energy demand is not very sensitive to changes in the cost of energy services.[6] For residential heating and cooling, studies indicate that there may be some take-back in response to efficiency improvements. We do include this effect in our analysis. In addition, transportation demand is thought to be somewhat responsive to reduced driving costs, and our transportation-sector analysis assumes a small increase in vehicle miles traveled as the fuel-related cost of driving declines.

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[5] LEAP comprises a set of flexible computer modules covering demand (sector, subsector, end-use/technology, and fuel), transformation (electricity supply system and other sources of energy supply), and resource (land-use and biomass resources). LEAP development was originally undertaken for the Beijer Institute for Energy and Human Ecology of the Royal Swedish Academy of Sciences, funded by the Swedish International Development Agency. LEAP is administered by the Stockholm Environment Institute-Boston Center (SEI-B) at Tellus. EDB is a computerized database of energy-related environmental impacts (coefficients for air and water pollutant emissions, land-use impacts, solid waste generation, and on-site health impacts). EDB was originally funded by the United Nations Environmental Programme (UNEP), which administers this database along with SEI-B at Tellus.

[6] J. Henly, H. Ruderman, and M. D. Levine, "Energy Savings Resulting from the Adoption of More Efficient Appliances: A Follow-up," *The Energy Journal* 9 (2), 1988, p. 163.

Efficiency improvements in highly energy-intensive industries might reduce the cost of production sufficiently to increase output. But because demand for industrial products is limited by structural changes in the economy, we expect this effect to be small, and we have not included it.

Models that simultaneously solve for price and demand usually do so through either an econometric analysis of historical behavior or an optimization program. Because econometric models (often called "top down" models in contrast to the approach used by LEAP) are based on historical relationships, they are unable to reflect changes in the variety of technologies available, or any other structural shifts that differ from historical trends. In addition, econometric models forego detail about changes specific to each end-use of energy, and such changes can have major effects on overall energy use.[7] Optimization models mathematically find the economically optimal mix of technologies for a set of inputs under given constraints. This approach can be rich in technical detail and forward-looking in its technological assumptions. The complexity of the mathematical algorithms, however, often requires that key aspects of the energy system be simplified. To some degree, both top-down and bottom-up models can be and have been extended to reflect the strengths of the other approach. Inputs to LEAP, for example, can be based on either macroeconomic or econometric model results.[8]

Each of these approaches—the scenario approach of LEAP, econometric models, and optimization models—can inform policy development and analysis. Regardless of the model selected, however, the results are primarily determined by the assumptions and judgments of the analysts, and should be evaluated with this in mind.

Discount Rate

We discounted future costs and savings at a real (excluding the effects of inflation) discount rate of 3 percent per year to reflect the fact that investments made today can increase the amount of goods and services available in the future. The 3-percent rate is intended to reflect the cost of capital to society based on the long-term average yield on US treasury bonds. A 3-percent discount rate has also been selected for the analysis of energy-efficiency policies by a number of public

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[7] In Manne and Richels' Global 2100 model, for instance, an energy-supply curve is developed from technology-specific data, and price signals determine the amount of energy consumption by fuel type. Individual end-use sectors, however, are not modeled, so important shifts within and among sectors can be overlooked. Changes in end-use efficiencies are largely reflected through a single variable, the "autonomous energy efficiency index" (AEEI) in the Global 2100 model. Information about end-use technologies can be used to inform the selection of an AEEI, but the choice of efficiency options is not directly compared to supply options in the model itself. See A. S. Manne and R. G. Richels, "CO_2 Emission Limits: An Economic Cost Analysis for the USA," *The Energy Journal 11* (2), 1990, p. 51, and a critique of that paper, R. H. Williams, "Low-Cost Strategies for Coping with CO_2 Emission Limits," *The Energy Journal 11* (3), 1990, p. 35.

[8] LEAP itself has a simplified macroeconomic model as an option for driving the energy system. This feature was not used for this study, however, as we used the macroeconomic results of DOE/EIA as inputs to LEAP.

institutions, including the California Energy Commission and the Northwest Power Planning Council.[9]

By using a single discount rate, we remove any distortional effects of different interest rates in different markets for evaluating energy-efficiency or energy-supply investments. To get a picture of what the investments and savings in our four scenarios would look like from a private perspective, we recalculated these net cost and savings for each scenario, basing the recalculation on a 7-percent real discount rate. This approach tested the robustness of our economic results without altering the investments undertaken in each scenario.

Selecting a societal discount rate is controversial. Frequently suggested real rates range from a low of 0 percent to a high of 10 or 13 percent. There are several reasons why societal discount rates should be different, and typically lower, than private rates, which are based on the cost of borrowing capital.[10] The reasons include imperfections in capital markets due to credit restrictions and/or tax distortions, differing perceptions of risk from private and public perspectives, and different values placed on future consumption. Society may prefer to treat consumption for all generations as equally valuable, in contrast to individuals, who may value current consumption more highly than future consumption.[11]

Estimating the Dollar Cost of Pollution and Oil Security

Assigning monetary values to those costs that are not reflected in prices—such as the pollution or other environmental impacts of an energy source—has emerged recently in the context of least-cost utility planning. Clearly, society bears the burdens of environmental impacts caused by energy systems, even when those systems are in compliance with environmental regulations. For example, the air pollution that a company is allowed to emit under the terms of the Clean Air Act still have an impact. These burdens can occur as indirect economic loss, as deterioration of public health and amenity, and as the degradation of natural environments, habitats, and biota. Their costs could be that of the damages themselves, the economic losses that ensue from the damages, the remediation of or response to the damages, and/or the intrinsic loss of value in destroyed or radically altered environments—be they natural or cultural.[12]

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[9] Staff Report: 1992 Energy Efficiency Standards for Low-Rise Residential Buildings, California Energy Commission, Sacramento, CA, May 10, 1991; Northwest Conservation and Electric Power Plan, Northwest Power Planning Council, Portland, OR, 1991.

[10] Robert Lind, *Discounting for Time and Risk in Energy Policy*, Resources for the Future, 1982.

[11] Having no time preference for consumption is not the same as assigning no time value to investments, however. Resources such as capital, labor, or regenerated natural resources, when used as investments, increase the productivity of resource use in the future, and thus expand the consumption opportunities for future generations. It is this element of intertemporal choice that we attempt to reflect in our discount rate.

[12] This is the case even when there is significant uncertainty or a small probability of a large deleterious impact. Some means to reflect society's unwillingness to subject itself to such risk—the high cost of being wrong—is required, and this unwillingness should be measured against the costs of risk reduction. In direct monetary terms alone, prudent planning might take account today of

If society places any value on reducing the environmental damages that result from the use of an energy resource further than required by current regulations, then the direct economic costs of energy that planners and purchasers use in their decisions are too low, and some measure of that discrepancy—the cost of pollution—is needed. One way to take that cost into account is to ascribe a monetary value to it. Ultimately, if an option with higher direct costs, but more benign environmental impacts, is found preferable to an option with lower direct costs, this implies that the value of the environmental impacts is at least as high as the difference between the direct costs of the options.

Recently, a number of state utility regulatory agencies have adopted procedures for incorporating those costs that are currently external to the market—known as environmental externalities—in energy planning.[13] Some involve the use of "monetary adders" (additions to energy prices) to reflect emissions of certain pollutants. Those adders are used in the selection of resource options, but are not directly applied to energy prices.[14] Public utility commissions in Massachusetts and Nevada have adopted values based upon the "regulators' revealed preferences" approach, which takes the marginal cost of control required by existing regulations as the approximate value of emissions damages avoided at the margin. If the regulators were willing to require technology with a given cost for the last pound of pollutant removed, then they must reckon the value of environmental damages associated with that last pound of pollutant to be at least that cost. The highest cost society is willing to pay at the margin for pollution abatement is thus the current value of the marginal avoided damages. This method presumes that the value of environmental damages associated with the last pound of pollutants is at least as large as the cost of the last unit of emissions abated.

In this study, we assigned values for air-pollutant emissions based on the values developed by the Tellus Institute[15] and adopted by Massachusetts and Nevada. Values were assigned for SO_2, NO_X, CO, CH_4, TSP, and VOC; these values were developed through a regulators' "revealed preferences" analysis of existing and/or emerging air-quality regulations. This approach analyzes the costs of existing and proposed environmental regulations to estimate the value society implicitly or explicitly places on environmental impacts; this value can be taken as a lower bound to actual

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potential investment requirements that could be imposed in the future by stricter environmental regulations. This need not be purely speculative, as the past two decades in the acid-gas debate, and the current situation in the greenhouse gas debate, have provided a basis for incorporating risk mitigation in energy planning.

[13] Stephen Wiel, presentation on environmental externalities, Proceedings of the Demand-Side Management and the Global Environment Conference, Arlington, VA, April 22-23, 1991.

[14] If the incorporation of environmental externalities leads to the selection of a resource that would not be acquired if only direct costs were considered, then energy prices will rise somewhat as a consequence. Full incorporation of these costs (e.g., through pollution taxes) would increase prices still further. It would also generate pollution-related revenues that could be used for environmental remediation, investment in clean technologies, or to offset reductions in other taxes.

[15] S. Bernow and D. Marron, *Valuation of Environmental Externalities for Energy Planning and Operations: May 1990 Update*, Tellus Institute, Boston, MA, May 18, 1990.

damage costs, assuming that regulators have made a reasonable assessment of the regulation's costs and benefits to society.

The cost we ascribe to NO_X emissions is based on the costs of selective catalytic reduction on a facility already using steam/hot-water injection; the SO_2 cost represents scrubbing technology; the TSP cost represents baghouse technology; the VOC cost represents a range of controls; and the CO costs represent the use of oxygenated fuels. These costs are listed below:

Air Pollutant Values Used in This Study

SO_2	$0.40/lb
NO_X	$2.92/lb
CH_4	$0.06/lb
CO	$0.41/lb
TSP	$1.05/lb
VOC	$1.38/lb

A cost for CO_2 emissions was not added to the direct cost of alternative resources, as was done for other pollutants in the Environmental scenario; rather, a value of $25/ton, based on costs of tree planting, was used as a rough guideline for exploring additional options that could help achieve the CO_2 emissions reductions targets in the Climate Stabilization scenario.

Although large changes in pollutant emission levels may lead to significant changes in those values, we have assumed that the value of eliminating a unit of pollutant output will be constant over time and across all of our scenarios. This could tend to overestimate future values if the marginal avoided damages fall significantly as total pollutant emissions fall. On the other hand, the natural environments that are damaged by those pollutants are limited resources, just as are fossil fuels. And, as with fuel costs, pollutant values could increase over time. Moreover, society's recognition of environmental risk tends to increase, even as its willingness to accept environmental damage tends to decrease, over time.

We also assign an externality value to petroleum-based fuels in the Environmental and Climate Stabilization scenarios to reflect the national security costs associated with the use of those fuels. We assume a modest national security premium of $2.50 per barrel of petroleum.[16] The total price "adder" to account for environmental, security, and other externalities for petroleum-based transport fuels is $0.50 per gallon.

Incorporation, and monetization in particular, of environmental and other externalities in energy planning is still in a nascent stage. Efforts are under way in the United States (by the DOE, EPA, Federal Energy Regulatory Commission [FERC], and various states), in Europe (by the EEC), and

[16] For justification of a national security premium of this magnitude or greater, see H. Broadman and W. Hogan, "Oil Tariff Policy in an Uncertain Market," Energy and Environmental Policy Center, Harvard University, Cambridge, MA, 1986; or H. Broadman and W. Hogan, "Is an Oil Tariff Justified? An American Debate: The Numbers Say 'Yes,'" *Energy Journal*, July 1988.

at the World Bank to explore this issue with the aim of finding acceptable means of implementing this concept within energy-planning procedures—for example, via energy/pollution taxes, or pollution-reduction targets. While a number of approaches to valuing environmental externalities have been suggested and used,[17] the approach applied in this study is gaining favor in the United States.

It is important to note that a number of environmental impacts—including effects on land, water resources, and ecological systems beyond those impacts embodied in the monetized air pollutant emissions—are not monetized in this analysis. Also, nonenvironmental externalities are not included, except in the case of the national security premium included for petroleum-based fuels.

Cost-Benefit Analysis

The costs and benefits of each of the three non-Reference scenarios were calculated relative to the Reference case. Costs and benefits can be represented in a variety of ways. Here we estimated the incremental investments in end-use equipment as costs, and the net reduction in fuel costs as benefits. In this treatment, the differential costs of electric power supply resulting from both end-use efficiency increases and changes in the power-supply mix, including the shift to renewable fuels, are reflected on the benefits side as a net reduction in electricity costs.

Fuel costs were obtained from the DOE/EIA *1990 Annual Energy Outlook*. Electric-power supply costs were obtained primarily from the Electric Power Research Institute (EPRI) for conventional and advanced fossil technologies. Supplementary information was obtained from the power-supply service report issued by DOE in conjunction with its NES.[18] The costs of renewable power supplies and fuels, and more-efficient energy-using equipment, were developed by the study team, based on a variety of sources, including EPRI, DOE, Office of Technology Assessment, Solar Energy Research Institute, and other governmental, industry, national laboratory, and independent analysts.

Unfortunately, it was not possible to obtain costs for all of the energy-efficiency technologies embodied in the alternative scenarios. Comprehensive and detailed cost information was used for the buildings and utility sectors for all scenarios. For the industrial and transport sectors, somewhat less-detailed cost information was available. Generally, where the costs of energy-efficiency measures based on prevailing conditions were available, they were not reduced over time to reflect potential production, distribution, and market efficiencies that might occur in response to the policies that would implement the scenarios.

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[17] P. Chernich and E. Caverhill, "Methods of Valuing Environmental Externalities," *The Electricity Journal 4* (2), March 1991. S. Bernow, B. Biewald, and D. Marron, "Environmental Externalities Measurement: Quantification, Valuation, and Monetization," in O. Hohmeyer and R. L. Ottinger, eds., *External Environmental Costs of Electric Power*, Springer-Verlag, Berlin, 1991. D. W. Pearce and A. Markandya, *Environmental Policy Benefits: Monetary Valuation*, OECD, Paris, 1989. R. Ottinger, et al., *Environmental Costs of Electricity*, Oceana Publications, Inc., Dobbs Ferry, NY, September 1990.

[18] Electricity Supply: Supporting Analysis for the National Energy Strategy, SR/NES/90-03, Energy Information Administration, US Department of Energy, January 1991.

In some cases, there may be significant administrative costs for implementing energy-efficiency measures, such as those installed as a result of utility promotion and marketing programs. Administrative costs will vary widely depending on sector, implementation strategy, experience, and other factors. Efficiency measures that can be implemented through national standards will have very low administrative costs, and can be implemented fairly rapidly. In contrast, measures that require further development, and that will be implemented through incentive programs, will have substantial associated costs and will be implemented over a longer time frame. In order to account for administrative costs, we added 10 percent to the direct cost of efficiency measures in the buildings and industrial sectors. This is intended to represent an approximate average of standards programs with administrative costs of 1 percent or less, and utility incentive programs with higher administrative costs.[19] No administrative costs are assumed in the transportation sector.

[19] In a recent study of utility programs for the commercial and industrial sectors, the ratio of administrative to conservation-measure costs was found to average 1.36. This survey included a large fraction of pilot programs for which, in comparison to full-scale programs, administrative costs are relatively high. See S. Nadel, *Lessons Learned: A Review of Utility Experience with Conservation and Load Management Programs for Commercial and Industrial Customers*, ACEEE, Washington, 1990.

Chapter 3: Primary energy requirements, air pollution, and costs and savings

The Market, Environmental, and Climate Stabilization scenarios all lead to substantial reductions in energy requirements and pollutant emissions from the Reference scenario; they also produce substantial cost savings for US consumers and business.

PRIMARY ENERGY REQUIREMENTS

The Reference scenario projects a 41-percent increase in primary energy use, from about 85 quads in 1988 to 120 quads in 2030. This increase is led by coal consumption, which increases by 122 percent to 44 quads in 2030. Coal's share of primary energy requirements increases dramatically over this period, from about 23 percent to about 37 percent. Nuclear power is assumed to be almost entirely phased out by 2030, while fossil fuels produce about 87 percent of total requirements. Energy production from renewable resources more than doubles over this period, from about seven quads to over 15 quads or 13 percent of the total by 2030.

As shown in the following tables, total energy requirements and the share of those requirements provided by fossil fuels both decline progressively as we move from the Reference to the Climate Stabilization scenario. In the Market scenario, total primary energy use decreases gradually from about 85 quads to 82 quads in 2030, or 32 percent below Reference levels in that year. Much of this reduction is due to a moderation of coal demand, which remains roughly constant in both absolute amount and share of total consumption. Lower coal demand in this scenario is primarily a function of lower electricity generation, which is 41 percent below the Reference level in 2030. The overall fossil-fuel share drops from 84 percent in 1988 to 64 percent in 2030 in this scenario, with renewable resources providing the remaining 36 percent.

The Environmental scenario envisions even more significant changes in both fuel requirements and fuel mix by 2030. Total primary energy requirements decline by about 15 percent by 2010, with further modest reductions from 2010 to 2030. Total primary energy demand in 2030, about 70 quads, is 42 percent below that in the Reference case. Fossil-fuel consumption drops significantly from 1988 to 2030—coal use in particular falls by 38 percent between 1988 and 2030, compared to the 122 percent increase projected in the Reference scenario and the constant level projected in the Market scenario. The gap is made up almost entirely by renewables, as no new nuclear plants are assumed. By 2030, renewables have grown about fourfold, and constitute a 42-percent share of the total primary energy supplies in the Environmental scenario.

These trends are intensified in the Climate Stabilization scenario. Total energy requirements decline gradually between 1988 and 2010 to 69 quads, decreasing further to 62 quads in 2030, about 27 percent below current levels and just over half of the Reference scenario projections for

REFERENCE CASE PRIMARY ENERGY REQUIREMENTS*

(Quads)

	1988	2000	2010	2030
NATURAL GAS	18.70	21.20	20.11	21.59
PETROLEUM	33.51	36.70	37.41	38.73
COAL	19.84	22.55	30.31	44.01
NUCLEAR	5.84	6.19	5.90	0.35
MUN. SOLID WASTE	0.02	0.03	0.05	0.05
BIOMASS	4.46	5.78	6.62	8.48
SOLAR	0.09	0.18	0.42	1.38
HYDRO	2.48	3.40	3.40	3.54
GEOTHERMAL	0.31	0.34	0.55	1.16
WIND	0.03	0.05	0.18	0.86
FOSSIL SUBTOTAL	72.05	80.45	87.83	104.33
RENEWABLE SUBTOTAL	7.40	9.79	11.22	15.48
TOTAL	85.29	96.43	104.95	120.16

MARKET CASE PRIMARY ENERGY REQUIREMENTS*

(Quads)

	1988	2000	2010	2030
NATURAL GAS	18.70	18.35	14.95	13.37
PETROLEUM	33.51	33.26	27.63	20.22
COAL	19.84	21.12	20.75	19.25
NUCLEAR	5.84	5.59	5.29	0.35
MUN. SOLID WASTE	0.02	0.10	0.28	0.88
BIOMASS	4.46	5.78	8.60	15.03
SOLAR	0.09	0.32	0.97	3.66
HYDRO	2.48	3.36	3.55	3.71
GEOTHERMAL	0.31	0.36	0.71	3.03
WIND	0.03	0.27	0.66	2.72
FOSSIL SUBTOTAL	72.05	72.73	63.34	52.83
RENEWABLE SUBTOTAL	7.40	10.18	14.76	29.02
TOTAL	85.29	88.50	83.39	82.21

* Includes transformation and distribution losses.

ENVIRONMENTAL CASE PRIMARY ENERGY REQUIREMENTS*

(Quads)

	1988	2000	2010	2030
NATURAL GAS	18.70	16.12	13.19	13.00
PETROLEUM	33.51	30.21	22.66	15.27
COAL	19.84	19.82	16.07	12.25
NUCLEAR	5.84	5.46	5.21	0.35
MUN. SOLID WASTE	0.02	0.11	0.26	0.88
BIOMASS	4.46	5.84	8.99	14.12
SOLAR	0.09	0.43	1.23	4.26
HYDRO	2.48	3.36	3.49	3.75
GEOTHERMAL	0.31	0.44	0.83	3.28
WIND	0.03	0.42	0.79	3.00
FOSSIL SUBTOTAL	72.05	66.16	51.92	40.52
RENEWABLE SUBTOTAL	7.40	10.60	15.57	29.28
TOTAL	85.29	82.22	72.71	70.15

CLIMATE STABILIZATION CASE PRIMARY ENERGY REQUIREMENTS*

(Quads)

	1988	2000	2010	2030
NATURAL GAS	18.70	15.25	13.12	14.91
PETROLEUM	33.51	27.78	20.00	11.16
COAL	19.84	17.43	12.45	2.74
NUCLEAR	5.84	5.52	5.30	0.33
MUN. SOLID WASTE	0.02	0.17	0.36	0.84
BIOMASS	4.46	7.08	10.15	16.58
SOLAR	0.09	0.57	1.58	4.35
HYDRO	2.48	3.42	3.58	3.57
GEOTHERMAL	0.31	0.54	1.13	3.59
WIND	0.03	0.64	1.21	3.44
HYDROGEN	0.00	0.00	0.04	0.35
FOSSIL SUBTOTAL	72.05	60.46	45.58	28.81
RENEWABLE SUBTOTAL	7.40	12.42	18.05	32.72
TOTAL	85.29	78.41	68.93	61.86

* Includes transformation and distribution losses.

that year. The share of this energy demand supplied by fossil fuels drops to 47 percent by 2030, and natural gas becomes the leading fossil fuel, even as its consumption declines by 20 percent from about 19 quads currently to about 15 quads in 2030. Petroleum and coal consumption decline drastically in both absolute terms and as shares of total energy supplies. Coal use declines from about 20 quads to less than three quads, while petroleum declines from about 33 quads to about 11 quads over the study period. Finally, renewables increase by a factor of 4.4, to a 53-percent share by 2030.

The table below summarizes the main results of the scenario analysis comparing primary energy, net CO_2 emissions,[1] energy demand per unit of GNP, and net CO_2 emissions per unit of energy for each scenario over time. In the Reference scenario, energy intensity—as measured by primary energy per dollar of GNP—decreases by 42 percent by 2030, or about 1.3 percent per year, while net CO_2 intensity—as measured by net CO_2 emissions per unit energy—increases by 12 percent by 2030, or 0.3 percent per year. The increase in CO_2 intensity is largely due to the growing contribution that coal makes to electric energy supplies.

Summary Results

	1988	2000	2010	2030
GNP* (Billion 1990$)	5,292	7,090	8,941	12,792
Reference Case				
Primary Energy (Quads)	85.3	96.4	105.0	120.2
Primary Renewable Energy (Quads)	7.4	9.8	11.2	15.5
CO_2 (Billion tons)	5.3	6.0	6.8	8.3
Energy/GNP (kBtu/$)	16.1	13.6	11.7	9.4
CO_2/Energy (lb/MMBtu)	124.3	123.4	128.6	138.0
Market Case				
Primary Energy	85.3	88.5	83.4	82.2
Primary Renewable Energy	7.4	10.2	14.8	29.0
CO_2	5.3	5.4	4.7	3.8
Energy/GNP	16.1	12.5	9.3	6.4
CO_2/Energy	124.3	121.1	112.5	92.2
Environmental Case				
Primary Energy	85.3	82.2	72.7	70.2
Primary Renewable Energy	7.4	10.6	15.6	29.3
CO_2	5.3	4.9	3.7	2.7
Energy/GNP	16.1	11.6	8.1	5.5
CO_2/Energy	123.3	118.7	102.6	78.1
Climate Stabilization Case				
Primary Energy	85.3	78.4	68.9	61.9
Primary Renewable Energy	7.4	12.4	18.1	32.8
CO_2	5.3	4.4	3.2	1.5
Energy/GNP	16.1	11.1	7.7	4.8
CO_2/Energy	123.3	112.0	91.7	48.8

* GNP growth is taken from DOE's *1990 Annual Energy Outlook*.

[1] Net CO_2 emissions exclude CO_2 from bioenergy sources. It is assumed that these fuels are produced on a renewable basis.

In the three other scenarios, energy requirements and net CO_2 intensities decline over time at progressively greater rates from scenario to scenario. These intensities are the result of efficiency improvements in both end-use and supply, as well as shifts to less carbon-intensive fuels. Thus, in the Market scenario, energy intensity decreases by 60 percent and CO_2 intensity decreases by 25 percent by 2030. In the Environmental scenario, energy intensity decreases by 66 percent and CO_2 intensity decreases by 37 percent by 2030. In the Climate Stabilization scenario, energy intensity decreases by 70 percent and CO_2 intensity decreases by 60 percent by 2030.

The rates of energy intensity reduction in our non-Reference scenario are not unprecedented. Energy intensity decreases 2.2 percent per year, 2.5 percent per year, and 2.8 percent per year on average during 1988-2030 in our Market, Environmental, and Climate Stabilization scenarios, respectively. For comparison, energy intensity in the US fell 2.4 percent per year on average during 1973-86. In fact, energy intensity has declined since early in the 20th century, although not as rapidly as during the post-1973 period.[2]

The rates of transition from fossil to renewable fuels that we outline in our non-Reference scenarios also have precedent in terms of historical energy transitions. Over a 40 year period, renewable energy sources increase their share of total energy supplies from about 9 percent to 35 percent (Market case), 42 percent (Environmental case), and 53 percent (Climate Stabilization case). For comparison, there was just as strong a shift from coal to petroleum and natural gas during the middle of the 20th century. The share of total US energy supplies provided by coal declined from over 70 percent in 1920 to less than 20 percent by 1970. Virtually all of this coal was replaced by petroleum and natural gas.[3]

Likewise, our renewable energy growth rates are reasonable when compared to growth rates for other major energy sources during periods of their ascent. In our Climate Stabilization scenario, renewable energy supplies increase about 3.6 percent per year on average during the next 40 years. This is less than the rates of growth of natural gas and petroleum consumption in the decades prior to the 1973 oil price shock. Thus, even our Climate Stabilization scenario is consistent with historical energy transitions and growth rates.

EMISSIONS

The pollutant emissions (in short tons) for our four scenarios are summarized on the next page. Here we present only three of the seven air pollutants that we analyzed: CO_2, SO_2, and NO_X. Emissions of the other four air pollutants analyzed, as well as breakdowns into the contributions from each sector, are provided in the Technical Appendixes.

SO_2 and NO_X

The results embody two main phenomena: 1) reductions in emissions over the 1990 to 2010 time period due to new technologies and current regulations such as the 1990 Amendments to the Clean

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[2] S. H. Schurr, "Energy Use, Technological Change, and Productive Efficiency: An Economic-Historical Interpretation," *Annual Review of Energy* 9, 1984, pp. 409-25.

[3] *Energy Security: A Report to the President of the United States*, DOE/S-0057, US Department of Energy, Washington, D.C., 1987.

CO_2 **Emissions** (Billion Tons)

	1988	2000	2010	2030
Reference Case	5.26	5.95	6.75	8.29
Market Case	5.26	5.36	4.69	3.79
Environmental Case	5.26	4.88	3.73	2.74
Climate Stabilization Case	5.26	4.39	3.16	1.51

SO_2 **Emissions** (Million Tons)

	1988	2000	2010	2030
Reference Case	23.10	13.30	12.90	11.10
Market Case	23.10	13.03	12.30	8.81
Environmental Case	23.10	12.06	10.18	6.01
Climate Stabilization Case	23.10	10.70	8.23	2.71

NO_x **Emissions** (Million Tons)

	1988	2000	2010	2030
Reference Case	19.81	16.72	16.03	15.05
Market Case	19.81	15.47	13.25	9.47
Environmental Case	19.81	14.16	11.19	7.07
Climate Stabilization Case	19.81	12.09	9.78	3.67

Air Act, and 2) reductions in emissions across the scenarios and over time owing to the policies, practices, and technologies that come into effect through the scenarios. The emissions of SO_2 and NO_X decline from 1990 through 2000 as a result of the Clean Air Act requirements, particularly in the electric sector, which accounts for almost 76 percent of SO_2 emissions and 36 percent of NO_X emissions. By 2030, SO_2 declines by 52 percent and NO_X by 24 percent in the Reference scenario.

SO_2 and NO_X emissions decline further over time in the Market scenario, as greater levels of energy efficiency are implemented and cleaner fuels are used. In the Environmental scenario, still greater penetration of efficiency technologies in electricity and fossil-fuel use, and the shift to renewables and cleaner fuels, is complemented by more cogeneration and rapid retirement of currently existing coal-fired power plants after 2000. Together, these have the effect of reducing SO_2 and NO_X emissions, particularly in the 2000 to 2030 period, significantly below the levels of the Market scenario. Overall by 2030, SO_2 emissions are reduced by almost 74 percent and NO_X emissions are reduced by 64 percent compared to 1988 levels.

Further reductions occur in the Climate Stabilization scenario, where still greater use of efficiency technologies and cleaner fuels is achieved. By 2030 in this scenario, SO_2 emissions are reduced by 88 percent and NO_X by 81 percent, relative to 1988 levels.

CO_2

The results for CO_2 exhibit a somewhat different behavior. First, the Clean Air Act Amendments do not affect CO_2 directly as they do SO_2 and NO_X.[4] Moreover, on a direct-cost basis, we have assumed in the Reference scenario that new electric-generating technologies would be predominantly coal-fired, with fairly stringent SO_2 and NO_X controls. Since the electric sector accounts for about 38 percent of net CO_2 emissions currently, the consequence is that while emissions of the first two pollutants decline over time, overall CO_2 emissions increase rapidly as electricity requirements grow, and coal is used to meet that demand. In addition, fuel use generally increases in every sector. Thus, total CO_2 emissions increase 58 percent from 1988 to 2030 (1.1 percent per year on average) in the Reference case.

Emissions of CO_2 are much lower in the Market and Environmental scenarios as a result of greater energy-efficiency improvements, switching from solid and liquid to gaseous fuels, and use of additional renewable energy resources—which contribute no net CO_2 emissions.[5] In the Market scenario, total CO_2 emissions are essentially stabilized until 2000 and decrease thereafter. CO_2 emissions are 28 percent below the 1988 level by 2030 in this case. Still greater reductions in CO_2 emissions are achieved in the Environmental scenario. Relative to the 1988 level, emissions decline 7 percent by 2000 and 48 percent by 2030.

In the Climate Stabilization scenario, more efficiency improvements occur and renewable energy supplies expand relative to the other scenarios. To achieve larger near-term reductions in CO_2

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[4] In fact, the use of scrubbers, while sharply reducing SO_2 emissions, could slightly increase CO_2 emissions because of lowered power-plant efficiency.

[5] Renewables such as solar and wind do not emit CO_2 when providing energy for power production, and emissions of CO_2 from biomass combustion are offset by absorption of CO_2 from the atmosphere by the growth of that biomass, if it is produced sustainably.

emissions, somewhat more rapid retirement of existing coal capacity is assumed, replaced primarily by efficient gas-fired capacity. We have also added some coal-to-electricity fuel switching in the industrial sector in later years. In this scenario, CO_2 emissions decline 17 percent by 2000, 40 percent by 2010, and 71 percent by 2030, relative to 1988 emissions.

COSTS

In the figure below, we present the estimated costs and benefits of the non-Reference scenarios, relative to the Reference case. In each case and in each sector, direct fuel costs—which include the costs of biomass-derived fuels—were estimated explicitly. The benefits from increasing reliance on energy efficiency and renewable energy sources reflect direct economic savings, and do not include any monetary value that society could place on the cleaner air and less-congested highways that would be part and parcel of the non-Reference scenarios. We did, however, estimate certain environmental costs and use them to select resources in the Environmental and Climate Stabilization scenarios.

To reduce primary energy requirements and fossil-fuel consumption to the levels projected in the Market scenario, the United States must invest in more-efficient end-use equipment and renewable energy technologies. The net present value of those investments from 1990 to 2030 would equal nearly $1.2 trillion relative to the Reference case. That additional investment, however, would yield fuel and electricity savings of $3.1 trillion during the same period, resulting in net benefits of $1.9 trillion. In the buildings sectors alone, for which the best cost information is available, net benefits would be $0.5 trillion. For electric utilities, the reductions in capital, fuel, and operating costs would yield a total economic savings of $1.2 trillion—about $0.9 trillion from sectoral end-use reductions and $0.3 trillion from lower-cost electric supply.

The Environmental scenario requires even more additional investment, but the return is also greater. In this scenario, there is additional investment of $2.1 trillion, compared to the Reference scenario. This level of investment would provide benefits to consumers of $4.2 trillion, yielding a net savings very close to the net additional investment required by the scenario. The lower cost for energy services would be accompanied by markedly lower emissions of SO_2, NO_X, and other pollutants. In addition, CO_2 emissions would be reduced in this scenario relative to the previous two scenarios.

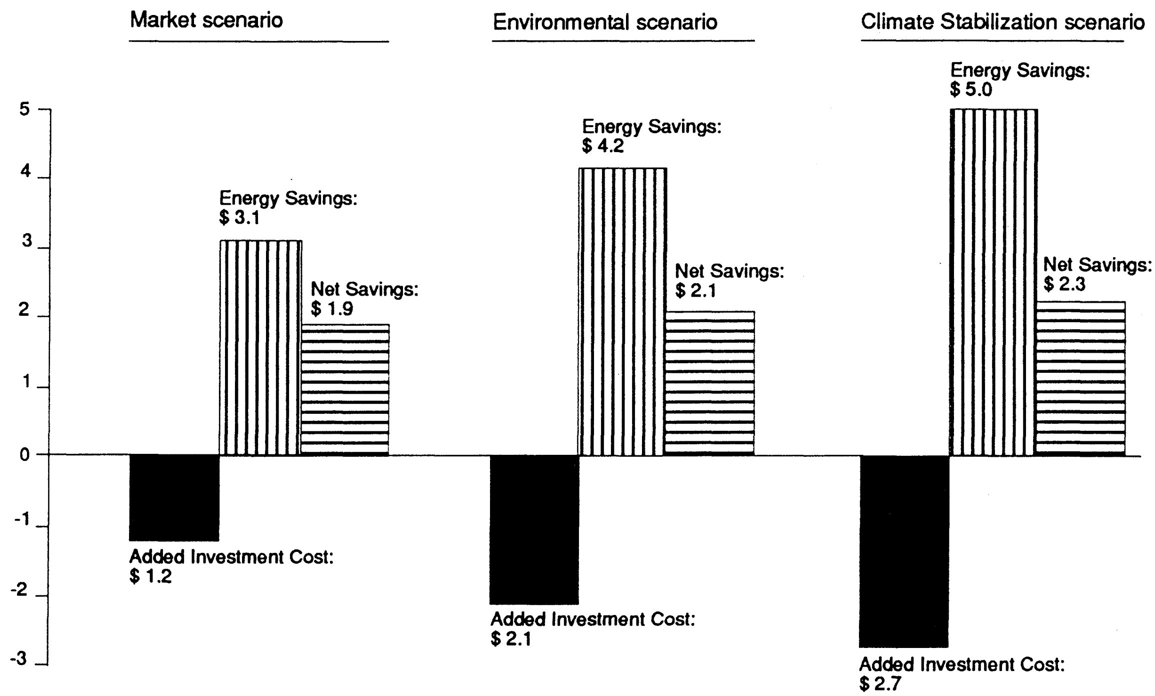
In the Climate Stabilization scenario, the additional required capital investments in energy efficiency and renewable energy measures would be more than $0.6 trillion above those of the Environmental scenario, but the savings in energy cost to consumers would increase by about $0.8 trillion above the Environmental scenario, and yield net private benefits of $2.3 trillion, or about $0.2 trillion more than would have been the case in the Environmental scenario. Net benefits in the buildings sector would be more than $0.7 trillion. This scenario would have still lower emissions of CO_2, SO_2, NO_X, and other air pollutants.

In advancing from the Market to the Environmental and Climate Stabilization scenarios, one might expect that there would be successive *decreases* in the net private savings, in contrast to the clear increases indicated in the foregoing discussion. After all, investment in more-costly technologies is necessary to provide the environmental benefits of the more aggressive scenarios. However, the policy initiatives we assume would stimulate adoption of both higher-cost technologies and more extensive penetration of the lower-cost options as we proceed from scenario to scenario. Also, we assume that some cost-effective efficiency measures are implemented sooner in the Climate

Stabilization scenario. This greater use of lower-cost technologies and measures more than offsets the higher-cost investments embodied in the Environmental and Climate Stabilization scenarios.

Costs and Savings Compared to Reference Case

Cumulative Present Value (Trillion 1990 Dollars) at 3% Discount



The bottom line for the Climate Stabilization scenario is cumulative savings equal to around $20,000 per household in today's dollars relative to the Reference case over the next 40 years. Society would enjoy these economic benefits even as net emissions of CO_2 would decline from 5.26 billion tons in 1988 to 1.51 billion tons in 2030.

The results presented above are based on a real discount rate of 3 percent. However, as explained in the methodology section, we also calculated the overall economic results on the basis of a 7-percent discount rate. In this sensitivity run, we assumed no changes in technology choices or energy requirements. Relative to the Reference case, the net economic benefits that would accrue between 1990 and 2030 would equal about $0.54 trillion in the Market scenario, about $0.59 trillion in the Environmental scenario, and about $0.56 trillion in the Climate Stabilization case. The net economic benefits are still positive, but are only one-quarter to one-third as large as those estimated on the basis of a 3-percent discount rate. Also, rather than increasing in successive cases, the net economic benefits are relatively constant among the three alternative scenarios.

In selecting measures to achieve the Climate Stabilization targets, we were not able to ensure that marginal costs were the same in all sectors. In general, we accepted measures with a net cost of up to $25 per ton of CO_2 removed ($92 per ton of carbon). However, most energy-efficiency measures for which reasonable cost estimates were available did not approach this avoided cost. The highest cost measures were employed in the electricity sector, where significant carbon reductions are achieved by switching from coal to gas-fired electricity production. According to our analysis, these replacements have net costs of $16-25 per ton of CO_2 removed.

COMPARISON WITH OTHER STUDIES

We compared our results with the results of six other studies--two prepared by DOE as part of its work on the NES, two by the US Office of Technology Assessment, one by ICF, Inc. for the US Environmental Protection Agency, and one by a group using a model known as MARKAL, which was developed at Brookhaven National Laboratory.[6]

Each of the above studies—except that used to analyze the administration's NES policy proposals, which we identify as NES1—develop a least-cost scenario (similar to our Market case) and several scenarios that more stringently reduce carbon emissions. The figure on the next page illustrates the carbon emissions associated with the most stringent carbon reduction scenario from each study. The NES policy scenario is included for comparison. Because of inconsistencies from study to study in how carbon emissions were calculated, each study is reported here with initial-year carbon emissions set equal to one. Two of the studies did not report complete CO_2 emissions. In those two cases—ICF and OTA2—carbon emissions were estimated on the basis of reported energy consumption, with adjustments made for feedstock energy use.

With the exception of the two NES analyses, all of the studies conclude that carbon emissions can be at least held constant through 2000, and three of the studies hold emissions nearly constant through 2010. Our study concludes that measures that are cost-effective from the private perspective would continue to reduce carbon emissions at least through 2030.

All of the non-NES studies show declining carbon emissions throughout the study period in their most stringent case. Carbon emissions drop more quickly in our study than in the others, but nevertheless follow the same basic path. However, the assumptions used to develop the most stringent scenario vary enormously from study to study. The ICF study, for example, included

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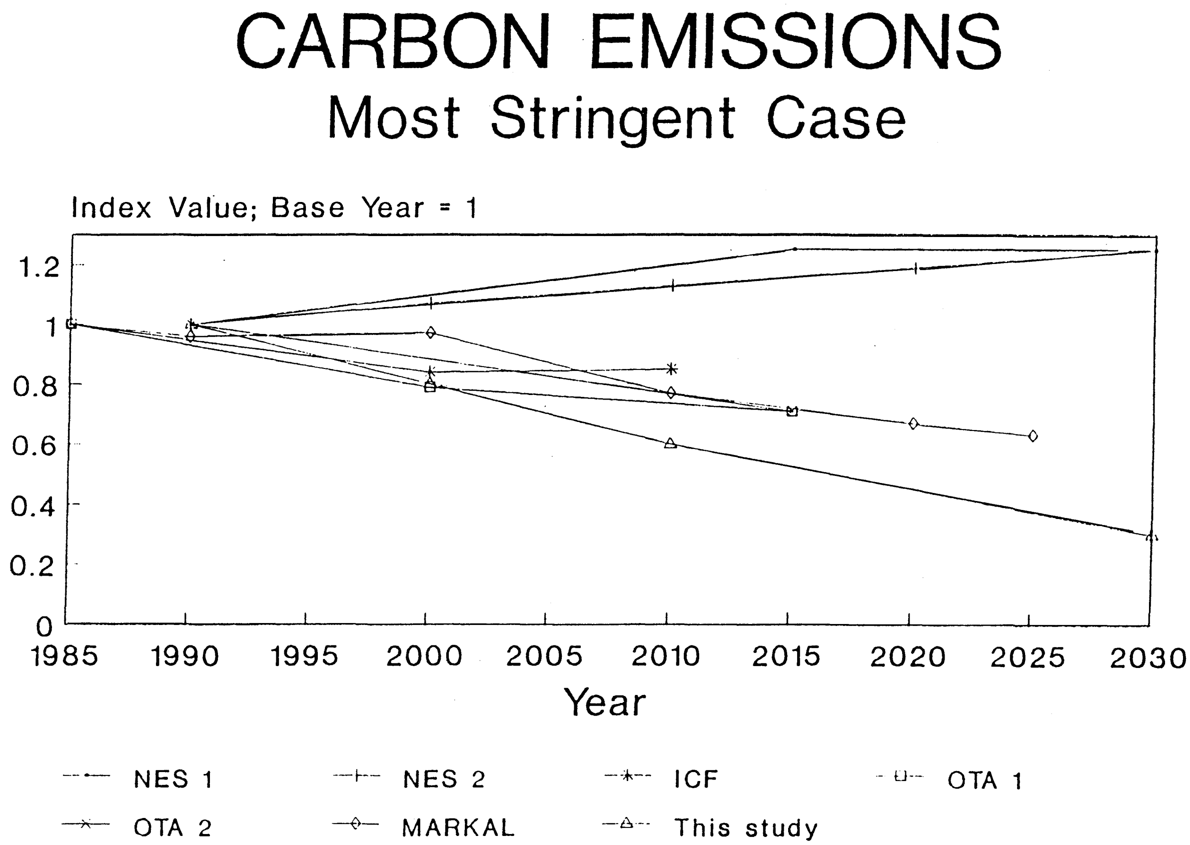
[6] The studies analyzed were:
NES1: US DOE, National Energy Strategy; Powerful Ideas for America, First Edition 1991/1992, Washington, D.C., 1991.
NES2: EIA, Energy Consumption and Conservation Potential: Supporting Analysis for the NES, SR/NES/90-02, December 1990.
ICF: ICF Incorporated, *Preliminary Technology Cost Estimates of Measures Available to Reduce US Greenhouse Gas Emissions by 2010*, submitted to US EPA, August 1990.
OTA1: US Congress, Office of Technology Assessment, *Changing By Degrees, Steps to Reduce Greenhouse Gases, Congress of the United States*, OTA-O-482, February 1991.
OTA2: US Congress, Office of Technology Assessment, *Energy Technology Choices, Shaping Our Future*, July 1991.
MARKAL: S. C. Morris, B. D. Solomon, D. Hill, J. Lee, and G. Goldstein, "A Least-Cost Analysis of US CO_2 Reduction Options," in *Energy and the Environment in the 21st Century*, MIT, 1990 (MARKAL, numbers updated by Samuel Morris, September 1991).

carbon-reduction measures without regard to cost. MARKAL, on the other hand, stopped adding carbon-reduction measures when emissions were reduced to 70 percent of 1990 levels. Our Climate Stabilization scenario is premised on achieving a 25-percent reduction in carbon emissions by 2005 and at least a 50-percent reduction by 2030.



(Base years vary from 1985 to 1990)

In addition to differing specifications for model runs, differences in results among the studies are due to differences in 1) the discount rate used to analyze cost-effectiveness, 2) the technology base from which potential carbon-reduction measures are selected, and 3) the rate at which new technologies are assumed to penetrate the market. Our study was the only one that used a 3-percent discount rate to evaluate technologies; other studies typically used a 7-percent rate. The choice of discount rate has an effect on the cost-effectiveness of efficiency and renewable energy technologies, especially for longer-lived measures.

The set of technologies incorporated into each scenario differed significantly from study to study. ICF considered the technology base of their study to be "preliminary," representing information on carbon-reduction measures available from a literature search. NES1 limits reductions in carbon emissions to those associated with the policies included in NES. MARKAL has a more extensive technology base, but the technologies do not change or improve over time. Overall, it appears that our study contains the most comprehensive set of CO_2 reduction options.

The studies also differ in terms of their overall scope for reducing CO_2 emissions. Carbon dioxide emissions can be reduced by switching from fossil to nonfossil fuels, switching from more to less carbon-intensive fossil fuels, and by improvements in energy efficiency. NES2 and OTA2 include only energy-efficiency measures.[7] Of those studies that provide for both fuel switching and efficiency improvements, efficiency improvements appear to play the larger role for ICF and OTA1, especially in the Market cases. On the other hand, fuel switching dominates as the source of reductions in CO_2 emissions for the MARKAL and NES1 analyses. Our study includes both substantial improvements in efficiency and fuel switching, especially from coal to renewable energy sources in the Climate Stabilization scenario. This is a principal reason why CO_2 emissions are lower in our study than in the others.

The importance of fuel switching can be most easily measured through examining changes in the carbon intensity of energy use, a quantity measured in terms of tons of carbon emitted per quad of energy consumed. Base-case carbon intensities rise, although slowly, in all of the studies. Carbon intensity falls in the least-cost cases, but by less than 20 percent, even in the outyears. Carbon intensity falls much more in the stringent cases, especially in the MARKAL study and in our study.

The importance of energy efficiency can be measured by evaluating changes in total primary energy requirements. Total energy use rises sharply in all of the base cases. Our Reference case indicates a 23-percent rise in energy use by 2010, and the NES policy case indicates a 31-percent increase in energy use during the same span of time. Total energy use continues to rise in the least-cost scenario in all of the studies other than this one, in which it stays fairly constant through 2030. Energy use in the most stringent cases, however, falls in OTA2 and this study; it holds fairly constant in ICF's study.

LIMITATIONS

There are three important areas that we were unable to explore adequately in this study. In each case, however, the unaccounted-for factors work in both directions; that is, some may result in increased energy requirements, emissions, and/or costs, while others lower those requirements, emissions, and/or costs. Each of these areas deserve further analysis.

Estimating Costs

Two issues arose in estimating the costs of new technologies. First, it was difficult to assess the costs of getting new policies or programs up and running. Second, it was difficult to assess the savings associated with economies of scale or accumulation of experience in using new technologies. Those costs and savings are largely not reflected in this study.

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[7] Both studies included separate analyses of the potential for renewable energy, analyses that indicate that additional reductions in CO_2 emissions are possible. However, energy efficiency and renewable energy measures are not analyzed in an integrated manner in the studies.

Program costs include expenditures other than the purchase of the technology itself, such as the costs of developing new building codes, or of informing people about the availability of a rebate. Those costs tend to be larger early on, but may be no more costly than current policy in the long run. For example, while there may be costs associated with training building officials about new code requirements, the cost of enforcing a more stringent code is not necessarily greater than that of enforcing a less stringent one. To reflect administrative costs, we added a 10-percent surcharge to the cost of energy-efficiency measures in the buildings and industrial sectors.

On the other hand, the costs of many new products fall as the volume of production increases, and as people gain experience installing and using the products. In the scenarios presented here, many technologies move from the small number of uses they currently have to encompassing large portions of their markets. Compact fluorescent light bulbs, for example, are often manufactured with integrated ballasts in order to accommodate existing fixtures designed for incandescent bulbs; with greater market saturation and dedicated fixtures, more ballasts would be reused and costs would fall.

Feedback Effects

Some of the changes in energy use that are reflected in the non-Reference scenarios may have secondary impacts on energy costs and use, and we have not made an attempt to incorporate those impacts in this study. Those secondary, or feedback, effects can both increase and decrease energy use. Most important, our analysis does not take into account the fact that energy prices will tend to fall as demand falls. This in turn will contribute to economic growth, because of the consequent reductions in the cost of production and services. Similarly, as the cost of energy services falls in the non-Reference scenarios—through both least-cost policies and the effect of lowered demand on energy prices—efficiency improvements may be partially offset by subsequent increased demand for energy services. As discussed above, we make selected adjustments in our analysis for this so-called "takeback effect."

Consumer Preferences

In general, we are only able to evaluate changes in market costs, not changes in consumer welfare. Some of the technologies we evaluated may have qualities other than improvements in energy efficiency, qualities that change the value of the product to consumers. The change in consumer value can be either positive or negative. More-energy-efficient buildings for instance, can be more comfortable as well as less expensive to operate. More-efficient lamps, on the other hand, may provide poorer color rendition than less-efficient lamps.

Consumer preference is actually not an issue for most of the technologies we considered. In many cases, consumers are indifferent—no one particularly cares about the appearance of the insulation in their walls or attic, or the burner in their furnace. Where consumer preferences might play a role, we compared current products as much as possible to more efficient alternatives that share characteristics such as size, amenities, capacity, and appearance. For personal transportation, we considered technology changes with minimal impact on car size and performance (at least through 2000). Assessing the characteristics of automobiles after 2000 is much more difficult, however.

In mass transit, it is likely that future investments in greater coverage will increase the overall desirability of mass transit systems. A long-promised light-rail system running from northern Virginia to Washington, D.C., for example, would be so preferable to current driving options that there are already more people hoping to take the train than could be accommodated by the planned capacity!

Consumer preferences are particularly difficult to include in analyses of energy demand over time, because they are not static; they change as the world around us changes. When incandescent bulbs were first introduced, for instance, many people found their light too harsh and white by comparison to candlelight. Today, candlelight is often too dark and yellow for most people. Consumers who do not want to use public transit systems given current land-use patterns might find them preferable to driving if land-use planning is integrated with public transportation to provide convenient food, housing, recreation, and employment opportunities.

Chapter 4: End-use energy demand

RESIDENTIAL AND COMMERCIAL BUILDINGS

Overview

Our analysis of the technical potential for energy savings in the buildings sector is based on the potential improvement in energy efficiency from the use of more than 60 types of conservation measures, which are described in detail in the Technical Appendixes. Some of those measures are already available commercially. The rest exist as prototypes for which estimates of cost and energy savings potential are available. We did not include advanced measures when substantial uncertainty existed regarding those measures' availability during the next 40 years, or when the performance or cost of the measures was very speculative.[1] Moreover, our analysis did not exhaust the pool of currently available energy-efficiency measures; examples of measures not considered include combined space- and water-heating systems and passive solar designs for new buildings.

We estimated potential energy savings for individual end-uses and fuel types based on average US consumption levels. Space heating and cooling savings estimates for both the residential and commercial sectors were based on prototype buildings in the climate zones of either Washington, D.C., or New York City. These prototype buildings are typical of the US building stock, and the climate zones are representative of the national average. A more comprehensive analysis would entail a greater level of regional disaggregation, both in terms of building-stock characteristics and climatic variation. This would provide useful detail for those working at the regional level and for follow-on studies, but would not significantly change the national results.

Our estimates of cost and savings from the conservation measures were aggregated by end-use in supply curves of conserved energy, and we ranked the measures in order of their cost of saved energy (CSE) for each end-use.[2] We constructed those supply curves from estimates of incremental energy savings for each measure, and by assuming that all previous (lower-cost) measures had been installed. This approach accounts for the sometimes-significant interactions between measures; for example, reducing the lighting loads in a commercial building provides savings in the energy used to cool the building, but also reduces the benefits of measures that improve cooling-system efficiency. The detailed supply curves for the building sectors are presented in tabular form in the Technical Appendixes.

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[1] Some examples of advanced energy-efficiency measures that may become commercially available and cost-effective within five to 10 years, but were excluded from this study, include gas-fired residential heat pumps, vacuum-insulated windows, and electrodeless fluorescent lamps. A. Rosenfeld, "Energy-Efficient US Buildings and Equipment: Progress Toward Least Lifecycle Cost," *Energy 12* (10/11), pp. 1017-28, 1987.

[2] CSE can be expressed in terms of either dollars per million Btu ($/MBtu, or $/MMBtu) of primary energy saved, or dollars per megawatt-hour ($/MW-hr) of end-use energy saved.

The overall potential for cost-effective energy savings, and the average CSE for each building type or appliance, are summarized on the next page. These savings potentials are based on the avoided energy costs in the Environmental case. Savings range from 37 percent in new educational buildings to 87 percent for retrofitting an existing single-family home that contains electrical resistance heating. Potential savings from commercial office space retrofits fall in-between, at about 70 percent. Those potentials reflect no assumptions about penetration rate—that is, they are independent of a particular implementation strategy. Obviously, the conservation measures cannot be installed overnight. It will take time to develop the requisite programs, and the manufacturing and distribution capacity, to implement these measures. It will also take time to commercialize some of the technologies. The supply-curve estimates in the table below do not include the administrative and other nonhardware costs that are associated with implementation efforts. As noted earlier, such costs are added across all measures, at the level of 10 percent of equipment costs.

The least-cost ordering in the supply curves does not presume that efficiency measures will be installed in this order. In practice, the order and timing of measure installation will vary widely. Rather than projecting different penetration rates for each individual measure, our analysis is based on the average cost and total savings potential for each end-use. In other words, for each end-use we have assumed that energy can be saved at the weighted-average CSE of all cost-effective measures in the supply curve for that end-use. The percent savings available from each end-use is equal to the percent savings from all cost-effective measures in the supply curve for that end-use.[3]

Our estimates of the penetration rates of conservation measures are based on a review of experiences with existing policies and programs, as well as of anticipated results from improved building codes, appliance standards, utility programs, and the like. We do not project penetration rates for specific measures, but rather for the package of measures available for each end-use. Given the wide variation in expected penetration rates, the process of developing estimates depends to a significant degree on judgment. To the extent possible, we have attempted to base our estimates on well-documented results. The actual penetration-rate estimates and details regarding their derivation are provided in the Technical Appendixes.

Results

Residential buildings. In the Market scenario, total energy use in the residential sector is reduced by 27 percent in 2010 and by 39 percent in 2030 from Reference scenario levels, while total consumption in 2030 is 24 percent below that of 1988. In the Environmental scenario, the reductions in total energy consumption relative to the Reference scenario are 32 percent in 2010 and 42 percent in 2030, and total consumption in 2030 is 27 percent below that of 1988. Finally, in the Climate Stabilization scenario, the reductions in energy consumption relative to the Reference scenario are 38 percent in 2010, and 50 percent in 2030, and total consumption in 2030 is 38 percent below that of 1988.

[3] For example, the supply curve for new office buildings contains a variety of measures with CSEs ranging from $0/MBtu to $6.30/MBtu of primary energy. Under the Environmental scenario, the average CSE of all measures deemed cost-effective is $2.74/MBtu, and the installation of those measures would result in an estimated savings of 67 percent of on-site energy use.

Energy Savings Potential in Buildings
Environmental Scenario

Commercial Buildings Summary

	Cost Effective Savings			Levelized	Average	Base Case	Base Case
	Electricity	Fuel	Site	Cost	Site	Site	Site
					CSE	Electric	Fuel
Commercial -- Retrofit	%	%	%	1990$	$/MBtu	kBtu/sf	kBtu/sf
B19. Office	74.0	67.5	70.9	59,338	2.71	79.0	71.8
B21. Hospital	54.8	58.7	56.9	84,434	2.88	72.3	88.6
B23. Hotel	60.3	33.9	44.2	56,100	4.40	45.0	69.9
B27. Education	45.2	31.5	37.4	61,418	7.36	40.9	53.2
B29. Retail	66.2	41.7	52.7	49,193	4.15	67.9	83.0
B31. Small Building	64.2	21.1	55.7	560	9.16	25.2	6.1
B33. Grocery	51.0	36.7	45.5	6,859	2.60	182.1	114.7
Commercial -- New							
B38. Office	77.7	33.7	67.4	44,521	2.74	46.2	14.2
B40. Retail	55.7	34.9	50.6	19,220	3.51	51.3	16.7
B42. Warehouse	65.5	36.3	47.0	4,342	2.07	40.1	69.3
B45. Education	50.8	34.5	39.7	22,025	4.89	32.2	68.4

Residential Buildings Summary

	Cost Effective Savings			Levelized	Average
					Site
Heating and Cooling	Electricity	Fuel	Site	Cost	CSE
Multi-Family -- Retrofit	%	%	%	1990$	$/MBtu
B47. Fuel Heat	58.7	51.1	51.7	44.4	1.48
B48. Electric Heat	62.3	69.1	68.2	128.9	6.14
Multi-Family -- New					
B49. Fuel Heat	51.8	54.4	54.2	73.8	2.84
B50. Electric Heat	52.3	71.8	69.1	134.2	7.51
Single-Family -- Retrofit					
B51. Gas Heat	56.2	65.0	64.0	209.2	3.68
B52. Electric Heat	78.7	89.0	87.4	518.1	9.11
B53. Heat Pump	80.9	67.8	71.2	256.9	8.93
Single-Family -- New					
B54. Gas Heat	55.7	62.9	62.0	160.7	4.95
B55. Electric Heat	54.9	78.4	74.6	146.2	5.27
B56. Heat Pump	67.9	69.1	68.8	204.7	11.98
Residential Appliances					
B57. Refrigerator-freezers	76.1	- - -	76.1	25.7	10.35
B58. Freezers	72.6	- - -	72.6	21.0	10.65
B59. Water Heating -- Electric	74.9	- - -	74.9	82.1	7.94
B61. Water Heating -- Gas	- - -	38.7	38.7	21.0	2.41
B62. Lighting	76.0	- - -	76.0	17.7	6.83
B63. Clothes Washers	45.8	- - -	45.8		
B64. Clothes Dryers -- Electric	85.7	- - -	85.7	29.8	9.62
B65. Clothes Dryers -- Gas	- - -	59.4	59.4	10.5	4.90
B66. Overns/Cooktops - Electric	38.9	- - -	38.9	6.9	6.98
B67. Ovens/Cooktops - Gas	- - -	44.9	44.9	4.0	4.37

Electricity use will increase, and natural-gas use will decrease, as a portion of residential energy use over time in all four scenarios. In 1988, electricity accounted for 29 percent, and natural gas for 46 percent, of total residential energy use. In the Market scenario, for example, electricity accounts for 33 percent and natural gas for 32 percent of total energy consumption in 2030. By 2030, renewable energy sources contribute 11 percent of total energy consumption in the Reference scenario, about 30 percent in the Market and Environmental scenarios, and 33 percent in the Climate Stabilization scenario. By comparison, renewable energy sources contributed about 9 percent of residential energy consumption in 1988.

Commercial buildings. In the Market scenario, total energy use in the commercial buildings sector is reduced by 20 percent in 2010, and 31 percent in 2030, compared to the Reference scenario, with total consumption in 2030 rising to about 22 percent above that in 1988. By comparison, total energy consumption increases by 78 percent between 1988 and 2030 in the Reference scenario. In the Environmental scenario, the reductions from the Reference scenario are 29 percent in 2010 and 39 percent in 2030, with total consumption in 2030 at 9 percent above that of 1988. Finally, in the Climate Stabilization scenario, the energy consumption in 2010 is 38 percent less, and in 2030 is 49 percent less, than that of the Reference scenario, and total consumption in 2030 is 10 percent below that of 1988. As in the residential sector, the fraction of total energy use provided by electricity increases over time in all four scenarios.

Residential Energy Consumption (Quads)

	1988	2000	2010	2030
Reference Case	10.23	10.80	11.38	12.76
Market Case	10.23	9.63	8.29	7.82
Environmental Case	10.23	9.23	7.79	7.44
Climate Stabilization Case	10.23	8.76	7.11	6.33

Commercial Energy Consumption (Quads)

	1988	2000	2010	2030
Reference Case	6.70	7.70	8.94	11.91
Market Case	6.70	7.32	7.17	8.18
Environmental Case	6.70	7.04	6.34	7.31
Climate Stabilization Case	6.70	6.52	5.51	6.03

INDUSTRIAL SECTOR

The aggregate energy intensity of industry, or the ratio of industrial energy use to production, fell by more than one-third between 1972 and 1985. In manufacturing, it is estimated that about 60 percent of this improvement was due to more efficient use of energy, and the remaining 40 percent was due to structural shifts.[4] Since the mid-1980s, however, the decrease in energy intensity has slowed overall, and has actually reversed in some subsectors.[5] The recent trend has occurred despite the enormous potential that still remains for improvement in the energy efficiency of US industries. The magnitude of this potential was illustrated in a study that compared the average integrated steel plant in the United States to a plant in which the "best practice" was used.[6] Producing roughly the same mix of products, the latter consumed 39 percent less energy than the typical US steel plant.

From a thermodynamic standpoint, even the most efficient industrial processes currently in use consume four to six times their theoretical minimum energy requirements.[7] Some processes, such as the attachment of one metal part to another in nonprocess industries, theoretically require no energy at all. Furthermore, there is no fundamental reason why most finished materials, once separated from raw forms, cannot be recycled many times over. Although the second law of thermodynamics indicates that recycling cannot be 100-percent efficient, there is no defined efficiency "ceiling" below 100 percent. Recycling bypasses the most energy-intensive step in manufacturing—the conversion of raw materials such as feedstocks and ores into basic materials. Even more efficient than recycling post-consumer waste back into the manufacturing process, is re*using* post-consumer materials wherever possible, such as with standardized refillable containers. This skips the production process altogether, and requires minimal energy input.

Industry consists of a vast array of activities involving thousands of different site-specific processes. Whereas the buildings and transportation sectors can utilize a limited number of energy-conservation measures, apply them widely, and dramatically reduce energy consumption, the industrial sector requires a case-by-case approach. Generic technologies that cut across industries—such as adjustable-speed motor drives and computerized process control—represent only a fraction of the full range of opportunities.[8] There has been little attempt at organizing information about industrial process retrofits or model facilities, primarily because most of this information has been deemed proprietary by industry. These obstacles make it difficult to develop a comprehensive analysis of the available energy-efficiency opportunities.

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[4] L. Schipper, R. Howarth, and H. Geller, "United States Energy Use from 1973 to 1987: The Impacts of Improved Efficiency," *Annual Review of Energy 15*, 1990.

[5] W. U. Chandler, *Carbon Emission Control Strategies*, 1990, p. 201.

[6] M. Ross, "Improving the Efficiency of Electricity Use in Manufacturing," *Science 244*, April 21, 1989, p. 313. In this analysis, electricity is evaluated in terms of primary energy production.

[7] M. Ross, "Industrial Energy Conservation," *Natural Resources Journal 24*, April 1984.

[8] Even these generic technologies are customized for particular applications.

In order to determine the overall potential for improved energy efficiency in the different scenarios, we employed two approaches—a "top-down" approach and a "bottom-up" approach. Both use the structural format of the PC-AEO model, which divides industry into 11 subsectors. Those subsectors are based on the two-digit Standard Industrial Classification (SIC) system, and include eight manufacturing categories—chemicals and rubber; paper and pulp; primary metals; food and kindred products; petroleum and coal products; stone, clay, and glass; metal durables; and "other"—and three nonmanufacturing categories—agriculture, mining, and construction.[9] Feedstocks are considered separately. The top-down method relies on assumptions about changes in production levels and industrial energy intensities by subsector, which are disaggregated to give fuel-specific energy consumption between 1990 and 2030. The bottom-up approach is similar to the end-use analysis performed in the buildings sector, involving consideration of specific energy-efficiency measures. We relied primarily on the top-down approach for deriving the Reference and Market scenarios, and used end-use analysis to help distinguish between fuel and electricity savings potentials, as well as to calculate costs of saved energy. The bottom-up approach was then used to develop the Environmental and Climate Stabilization scenarios.

The growth rates of industrial production used in this study (see table on the next page) are lower than those used by DOE. DOE's assumptions are considered to be too high by some analysts.[10] The manufacturing of basic materials is roughly 10 times as energy-intensive as the rest of the industrial sector. The share of GNP contributed by the production of basic materials declined in the United States in recent decades.[11] We believe that our economy is undergoing a fundamental structural shift, leading to continuing growth of services relative to industry. Furthermore, within the industrial sector, there will continue to be a shift away from materials processing toward fabrication and assembly.[12] In addition, materials are being used more efficiently, manufacturers are making products from less material, and improved materials are increasing the durability of products. Because we reduce growth of industrial output relative to DOE's analysis (see table), we increase services sector activity across the board in order to maintain DOE's projections of GNP.[13]

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[9] Chemicals and rubber: SIC 28 & 30; paper: SIC 26; primary metals: SIC 33; food: SIC 20; petroleum and coal products: SIC 29; stone, glass, and clay: SIC 32; metal durables: SIC 34-38; "other": SIC 21-25,27,31,39; agriculture: SIC 1-9; mining: SIC 10-14; construction: SIC 15-17.

[10] See E. Larson, R. Williams, and M. Ross, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy 12*, 1987, pp. 99-144.

[11] Besides the factors discussed in the text, part of the shift away from basic materials production was caused by an increase in the percentage of materials that were imported in recent years.

[12] Office of Technology Assessment, US Congress, *Technology and the American Economic Transition*, Washington, D.C., 1988; R. Herman, S. A. Ardekani, and J. H. Ausubel, "Dematerialization," in *Technology and Environment*, J. H. Ausubel and H. E. Sladovich, eds., National Academy Press, Washington, D.C., 1989.

[13] In particular, we increased the rates of growth in the service sector by 0.33 percent per year from 1990 to 2010, and 0.17 percent per year from 2010 to 2030, relative to the growth rates used by DOE.

The industrial production levels are kept constant in all four scenarios.[14] The only factors that change from scenario to scenario are the rates of change in energy intensity at the subsector level and the introduction of cogeneration and fuel switching in the Environmental and Climate Stabilization scenarios. Energy intensity is expressed in terms of site energy-use per dollar of output (adjusted for inflation). Changes in electricity and fossil-fuel intensities are specified separately for each industry type (see the Technical Appendixes).

Growth Rates of Industrial Output (percent per year)

	DOE		This study	
Subsector	1988-2010	2010-2030	1988-2010	2010-2030
Chemicals and rubber	3.0	1.9	0.8	0.75
Paper	2.4	1.6	0.6	0.25
Primary metals	1.3	0.4	(0.6)	(0.25)
Food	1.7	1.9	0.3	0.25
Petroleum refining	0.2	0.0	(0.6)	(0.25)
Stone, clay, and glass	1.9	1.9	(0.5)	(0.25)
Metal durables	3.7	2.2	2.6	1.35
Other manufacturing	2.3	1.4	1.2	0.75
Total manufacturing	2.80	1.85	1.60	1.00
Nonmanufacturing industries	1.45	1.77	1.45	1.77
Total industry	2.48	1.84	1.56	1.23

Note: The growth rates are based on net contribution to GNP by each industrial subsector. Except for the petroleum refining subsector, these industrial subsector growth rates are assumed to prevail in all four scenarios. Refinery activity would change as oil consumption changes. Here we give only the Reference case.

Sources: DOE—"Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy," Service Report SR/NES/90-02, Energy Information Administration, Washington, D.C., December 1990. This study—Personal communication with Dr. Marc Ross, University of Michigan, August 1991.

Top-Down Approach

We used a simple spreadsheet model to calculate two-digit SIC energy consumption, basing our calculations on energy-price assumptions, growth rates in production for each subsector, and

[14] This is the case except for petroleum refining, which is a function of total petroleum consumption, and which varies from scenario to scenario.

energy intensities for each subsector.[15] Energy price assumptions were taken from the PC-AEO model, and remain unchanged between the Reference and the three other scenarios. A price elasticity of demand of minus 0.25 was assumed for the industrial sector in each of the scenarios (i.e., the percentage change in energy demand for a percentage change in energy price). This value is toward the low end of the range used in other recent studies,[16] adopted to avoid double counting non-price-induced intensity reductions.

The 11 industrial subsectors that we analyzed account for 67 percent of industrial end-use energy consumption, the remainder being feedstocks and energy use in other subsectors. No intensity reductions were assumed for feedstocks in any of the scenarios, so our reductions in intensity for industry as a whole are conservative. Historical experience, as well as projections of economically justified intensity reductions, are presented in the Technical Appendixes for nine of the subsectors we analyze. In most subsectors, future rates of improvement are not expected to be as high as they were during the 1970s and early 1980s, because many of the least-expensive "housekeeping" measures have already been performed, and because energy prices are projected to be more stable in the future than in the past two decades.

The table on the next page shows the assumed rates of energy-intensity reduction in each of our scenarios. The rate of intensity reductions in our Reference scenario (adopted from DOE/EIA) are significantly below the level deemed economically justified in the analyses we examined. Subsector intensity-reduction rates range from 0.1 percent per year to 1.8 percent per year in the period to 2010, with an (energy-use-weighted) average rate of 0.9 percent per year. After 2010, the average rate drops to 0.4 percent per year. Considering total end-use consumption masks an important trend toward electrification in the Reference scenario; from 1988 to 2010, average electricity intensity drops only 0.1 percent per year, while fuel intensity drops by 1.6 percent per year (see the Technical Appendixes for details).

In the Market scenario, we assume that intensity reductions can be accelerated to levels consistent with those found to be economically justified by other analysts.[17] Intensity reductions given for total end-use energy were disaggregated by first applying the electricity improvements suggested by EPRI and then deriving fuel-intensity reductions to achieve the balance of the energy savings. Because EPRI identifies substantial opportunities for electricity savings, this scenario yields a smaller gap between electricity and fuel-intensity reductions—1.3 percent per year and 2.0 percent per year, respectively, from 1988 to 2010, for an overall average of 1.7 percent per year.

For the Environmental and Climate Stabilization scenarios, further and more rapid efficiency improvements are assumed. In the Environmental scenario, we project an average energy intensity

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[15] Adapted from a model developed by Oak Ridge National Laboratory. See *Energy Efficiency: How Far Can We Go?*, ORNL/TM-11441, Oak Ridge, TN, January 1990.

[16] Ibid.

[17] Two factors caused our assumed intensities to diverge slightly from those proposed by other analysts. First, electricity savings in our Market strategy are linked to EPRI's estimates. (*Estimates of Electricity Savings: Maximum Technical Potential*, March 1990). Second, assumptions about energy price and industrial growth, which vary among studies, influence the potential for energy-intensity reductions.

reduction of 2.3 percent per year to 2010. In the Climate Stabilization scenario, we assume that cost-effective technology will penetrate the market more quickly, yielding an average intensity reduction of 2.5 percent per year to 2010. After 2010, the average intensity reductions are assumed to be 1.4 percent per year in both cases, although there are slight differences in some subsectors. The Environmental and Climate Stabilization scenarios also incorporate additional cogeneration, which causes rapid reductions in purchased electricity in the paper and petroleum-refining industries, and moderate reductions in the chemicals, primary metals, food, and metal durables industries (see the Technical Appendixes). In addition, we assume a 20-percent shift from coal and oil to electricity—that is, greater electrification—in the Climate Stabilization scenario.

Rates of Industrial Energy Intensity Reduction (percent per year)

	Reference Case		Market Case		Environmental Case		Climate Stabilization Case	
	1990-2010	2010-2030	1990-2010	2010-2030	1990-2010	2010-2030	1990-2010	2010-2030
Manufacturing								
Chemicals/Rubber	1.8	2.1	2.4	2.2	2.9	3.3	2.3	4.1
Primary Metals	1.0	1.0	2.1	1.8	3.1	1.9	3.7	2.0
Paper & Pulp	1.2	0.3	1.7	0.9	2.0	0.5	2.1	0.5
Stone/Glass/Clay	1.3	0.7	2.2	1.3	3.3	2.2	3.6	2.0
Food	0.8	0.8	1.9	1.8	4.3	3.0	4.5	2.8
Petroleum Refining	0.2	-0.2	1.3	0.8	1.3	1.2	2.2	1.1
Metal Durables	0.2	0.5	1.6	1.0	2.7	1.4	2.8	1.4
Other Manufacturing	0.1	-0.3	1.4	0.6	1.4	0.6	1.4	0.6
Non-manufacturing								
Agriculture	0.9	0.3	1.6	1.5	2.1	1.1	2.5	1.1
Construction	0.8	0.2	1.5	1.3	2.0	1.9	2.4	1.9
Mining	0.2	0.2	1.4	1.2	1.8	0.4	1.8	0.7
TOTAL	0.9	0.4	1.7	1.3	2.3	1.4	2.5	1.4

Bottom-Up Approach

In the bottom-up approach, individual energy-efficiency measures were analyzed on a sector-by-sector basis in order to quantify some of the cost-effective opportunities for specific energy-efficiency improvements. Examples of these measures include high-efficiency motors, adjustable-speed motor drives, sensors and controls, process heat recovery, and boiler improvements. Although the method of calculating costs and savings of individual measures is similar to that described in the buildings section, some caveats apply.

First, it must be stressed that the list of energy-efficiency measures considered for the industrial sector is far from complete. The measures are simply examples of what can be done to improve the efficiency of industrial processes. As described earlier, industry covers a wide range of activities, and literature is not available that thoroughly explores the potential for energy savings and the cost-effectiveness of energy-savings measures. Although our analysis reflects the best available data, it is not comprehensive.

Second, we estimate typical or average savings for specific measures in each industrial subsector. There is little likelihood that any specific facility will achieve the precise savings we estimate for a particular measure, nor is the measure likely to cost the equivalent dollar amount per unit of energy saved that we have assigned to it.[18] These estimates should be thought of as the center of a broad distribution, because each industrial facility is different.

In our technology assessment, electricity-saving and fuel-saving measures were considered separately. Most of the electricity savings and costs were derived from estimates made by EPRI.[19] In addition, energy savings due to expanded use of cogeneration are included in the Environmental and Climate Stabilization scenarios. Fuel savings numbers were derived from a variety of sources, especially draft and final reports for the DOE's Office of Industrial Technologies.[20] For most of the measures, we have not made assumptions concerning the fraction of savings implicit in the Reference scenario. With recycling, however, we have explicitly assumed that 30 percent of the savings suggested at the recycling rates specified for glass, aluminum, steel, paper, and plastics are embodied in the Reference scenario.

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[18] For example, computerized process control in the production of steel and aluminum, which are the key energy consumers in the primary metals subsector, is designated an average CSE of $3.53 per million Btus saved. In our Market strategy, it has been conservatively estimated that this measure could save 25 trillion Btu in the year 2000 for the two industries considered (see the Technical Appendixes). Applying controls to certain processes within an integrated steel mill in all of its complexities, will result in a different CSE than would applying controls to different processes in the aluminum-production facility. Even so, single cost and savings values are designated for this measure.

[19] EPRI, *Estimates of Electricity Savings.*

[20] DOE Office of Industrial Programs, *Industry Profiles*, Draft Reports, December 1990.

Efficiency potentials in the Market scenario were generally based on a "most likely" mix of state-of-the-art and advanced technologies.[21] State-of-the-art is defined as the most efficient technologies and process changes that have already been successfully demonstrated in existing plants, and that are considered technically and economically feasible. Advanced technologies are those that are in the conceptual or developmental stage, and that have demonstrated potential for energy savings and industry acceptance. Generally, those energy savings that are available *now* were phased into the Market scenario by 2010 at a penetration rate of 1 to 2 percent per year. Thereafter, additional savings result from continued adoption of these conservation measures, as well as from presently undefined improvements. A slow penetration of additional savings measures, between 1 and 2.5 percent per year, was chosen for the period 2010 to 2030 because of the unknown make-up of those improvements. The technical potentials for electricity conservation estimated by EPRI were applied in the Market scenario by assuming that EPRI's "low" case for 2000 was not fully implemented until 2010, and EPRI's "high" case for 2000 was achieved by 2030.

The savings potentials in the Environmental and Climate Stabilization scenarios generally assume a mixture of 25 percent state-of-the-art and 75 percent advanced technologies.[22] EPRI's "high" case for electricity savings was assumed to be achievable by 2010, with a 2 percent per year increase in electricity savings thereafter. Increased use of cogeneration was also assumed in this case, with 40 percent of the available boiler fuel diverted to cogeneration systems in 2010, and 80 percent in 2030. In the Climate Stabilization scenario, we also assume that 20 percent of oil and coal use will switch to electricity, which—for the applicable end-uses, ignoring losses in electricity production and distribution—is about three times as efficient as use of oil or coal.[23]

Results

The overall results of our scenarios in the industrial sector are presented in the table on the next page. In the Market scenario, total energy use in the industrial sector is reduced by 12 percent in 2010 and by 18 percent in 2030 from Reference levels, with total energy consumption in 2030 11 percent below that of 1988. By comparison, industrial energy consumption in 2030 is 9 percent above that of 1988 in the Reference scenario. In the Environmental scenario, the reductions from the Reference scenario are 19 percent in 2010 and 26 percent in 2030, with total energy consumption in 2030 at 19 percent below that of 1988. Finally, in the Climate Stabilization scenario, energy consumption in 2010 is 19 percent less and in 2030 is 28 percent less than that of the Reference scenario, with total consumption in 2030 at 21 percent less than that of 1988.

In addition to the efficiency improvements, in the Environmental and Climate Stabilization scenarios, cogeneration, solar, and geothermal resources expand their contribution to industrial energy supply. In the Climate Stabilization scenario, those three renewable energy sources will provide nearly two quads per year more energy in 2030 than in the Reference scenario.

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[21] Ibid., based on "Business-As-Usual" scenario as defined in these reports.

[22] Ibid., based on a combination of the state-of-the-art and advanced-technology scenarios given in these reports.

[23] M. Ross et al., "Modeling the Energy Intensity and Carbon Dioxide Emissions in US Manufacturing," in *Energy and the Environment in the 21st Century*, MIT Press, 1991.

Industrial Energy Consumption (Quads)

	1988	2000	2010	2030
Reference Case	24.98	25.58	25.13	27.33
Market Case	24.98	24.04	22.06	21.60
Environmental Case	24.98	22.28	20.14	19.64
Climate Stabilization Case	24.98	20.76	19.88	18.96

PERSONAL TRANSPORTATION

Personal travel involves a number of transport modes: private passenger vehicles, public urban transit, intercity modes such as bus, rail, and air, and the nonmotorized modes of walking and bicycling. Energy efficiency can be increased by improving the technology of all modes, shifting to the more efficient modes, changing land-use patterns, and implementing measures that reduce demand for travel via the less-efficient modes—such as single-occupant automobiles. The potential for improving the efficiency of light vehicles is discussed first. Next we focus on the potential for reducing the demand for urban and suburban private-vehicle travel and shifting to urban-transit modes. The last section addresses the potential for efficiency improvement in intercity travel through technology improvement, as well as the potential for shifting to high-speed rail. Further details are provided in the Technical Appendixes.

Light-Vehicle Technology

For the Reference scenario, vehicle fuel-economy projections are based on DOE figures.[24] The rate of technology improvement is specified as the EPA-rated fuel economy for new cars, which reaches 33 mpg by 2000 and 41 mpg by 2030 (see the table on page 68). Actual on-road fuel economy is projected using estimates of the gap, or shortfall, between on-road performance and EPA test-cycle performance due to congestion, greater share of urban driving, higher speeds, and poor maintenance. The fuel economy of the entire vehicle fleet—or all cars and light trucks in use—is calculated using a stock turnover model (see the Technical Appendixes). In the Reference case, the on-road fuel economy of the automobile fleet increases from the present estimate of 21 mpg to 28 mpg in 2030; light trucks are assumed to have a similar improvement, from 15 mpg on-road at present to 21 mpg by 2030. Over the 40-year horizon, the overall average rate of improvement is 0.76 percent per year.

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[24] "Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy," SR/NES/90-02, Energy Information Administration, Washington, D.C., 1990, Table G-3.

The basis for subsequent calculations is the average of automobile and light-truck on-road fuel economy, in mpg, for the whole vehicle stock, converted to energy intensity, in kBtu per mile. For all cases, we have assumed that the fraction of vehicle miles traveled (VMT) due to light trucks continues to grow until 2010, after which it levels off at 32 percent (EIA, 1990). Because cars and light trucks are not further differentiated in the analysis, shares of VMT, and relative efficiencies by alternative fuel, are assumed to be the same for both cars and light trucks. Relative efficiencies by fuel type are converted, for consistency, to energy intensity on an end-use basis.

Market scenario. Compared to the Reference scenario, we estimate that a significant improvement in fuel economy is cost-effective to the year 2000, with ongoing improvements afterwards. The technologies for improving automobile efficiency, and their CSEs, are based on an ACEEE analysis.[25] In this analysis, average vehicle size and performance are based on the characteristics of the new car fleet in 1987. The analysis includes state-of-the art technologies in production plus some new technologies that have already been demonstrated. New technologies now in development are not included, even though some of these could be commercialized within the next 10 years.

The ACEEE analysis (see the Technical Appendixes) indicates a cost-effective fuel-economy level of 43 mpg for new autos in 2000, at an average CSE of $0.44 per gallon relative to frozen efficiency. Because of the obstacles to full implementation, we assume that new passenger cars will achieve a rated fuel economy of 40 mpg by 2000. Since the promotion of more-efficient vehicles through efficiency standards and other federal policies involves minimal administrative costs, the economic analysis for this sector is based solely on the direct cost of efficiency measures.

Regarding efficiency improvements after 2000, we rely on a technology assessment published by independent experts in 1990 (the EEA study).[26] Unfortunately, this study does not contain any economic analysis. The EEA study identifies three "risk levels" related to judgments about the likelihood of commercialization by 2010. EEA's baseline for 2001 is 38 mpg, comparable to our 40-mpg estimate, and higher than the Reference level of 33 mpg in 2000. The low- medium- and high-risk fleet-average EPA-rated fuel economies for new cars in 2010 are 46, 53, and 75 mpg, respectively.

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[25] M. Ross, M. Ledbetter, and F. An, "Options for Reducing Oil Use by Light Vehicles: An Analysis of Techniques and Policy," American Council for an Energy-Efficient Economy, Washington, D.C., June 1991.

[26] "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010," draft report prepared by Energy and Environmental Analysis, Inc., Arlington, Virginia, for the US EPA, June 1990.

Projected Fuel Economies of New Automobiles

	1988	2000	2010	2030
EPA composite test fuel economy (55/45), in mpg				
Reference[a]	28.6	33	37	41
Market[b]	28.6	40	50	56
Environmental[c]	28.6	43	54	75
Climate Stabilization[c]	28.6	46	59	75
Gap between on-road and rated mpg, in percent				
Reference[d]	20	20	25	30
Market[e]	20	20	20	0
Environmental[e]	20	20	10	0
Climate Stabilization[e]	20	20	10	0
Annual rates of on-road improvement, in percent[f]				
Reference	4.1[g]	1.1	0.7	0.5
Market	4.1	3.0	2.9	1.7
Environmental	4.1	4.3	3.7	2.1
Climate Stabilization	4.1	5.3	3.7	1.8

Notes:
a) "Energy Consumption and Conservation Potential," EIA 1990, Table G-3.
b) For 2000, authors' target based on Ross et al.[27]; 2010-2030, the medium-risk and high-risk estimates, respectively, given by EEA,[28] adjusted downward to reflect the increasing gap between rated and on-road fuel economy.
c) As in note (b), with a more ambitious schedule and assuming further technical improvements such as vehicle reoptimization and improved driving conditions, so that the gap between rated and on-road fuel economy is eliminated by 2030.
d) "Energy Consumption and Conservation Potential," EIA 1990, p. 85.
e) Authors' targets, as discussed in notes (b) and (c).
f) For new vehicles, from previous year to projection year, as calculated from the mpg-test ratings and the shortfall assumptions.
g) The rate of improvement for new automobiles from 1977 to 1988.

We assume a rated fuel economy of 50 mpg for 2010 in the Market scenario, midway between EEA's low- and medium-risk levels. These are EPA-rated values with the assumed shortfall of 20 percent persisting until 2010, but declining thereafter assuming the test procedure is modified. We scale back the rated fuel-economy levels in proportion to the shortfall, so that no additional technical burden is assumed in making the rated fuel economy conform to the on-road fuel economy. The resulting levels are shown in the table above, with rates of on-road improvement being 3 percent per year in the near term, decreasing to 1.7 percent per year from 2010 to 2030.

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[27] M. Ross et al., "Options for Reducing Oil Use by Light Vehicles."

[28] EEA, "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010."

Lacking a conservation supply curve for light trucks, we assumed that the same rates of improvement, relative to current fuel economy, will be cost-effective. Assuming that the current pattern of light truck usage—73 percent for strictly personal transportation according to a 1987 survey—does not change, the fraction of light trucks having justifiably high load requirements is small. Furthermore, because light trucks have been leniently regulated in the past, their current level of fuel economy is well behind the technology levels already demonstrated in automobiles. Therefore, it is probably conservative to assume that the rate of cost-effective fuel-economy improvement for light trucks will keep pace with that of automobiles.

The estimated fuel economies and VMT shares for alternative-fueled vehicles are based on the "high conservation" projections by the Department of Energy.[29] We assume that alcohol-fueled vehicles will start entering the fleet, reaching 2 percent by 2000, and growing to nearly 50 percent of light-duty vehicles by 2030. Electric vehicles also start appearing, reaching 21 percent of new vehicles by 2030. Since our conventional vehicle fuel economies are higher than DOE's, we scaled down the alternative-vehicle fuel efficiencies relative to the Reference values, as described in the Technical Appendixes.

Environmental and Climate Stabilization scenarios. For the Environmental scenario, we adopt the ACEEE estimate of 43-mpg fuel economy for passenger cars in 2000, and the EEA "high risk" estimate for 2010 of 75 mpg for our 2030 projection.[30] The 4.3 percent annual rate of fuel-economy improvement through 2010—when automobiles will achieve 54 mpg on average—is comparable to the average fuel-economy improvement of 4.1 percent per year that the United States realized between 1977 and 1988. Prototype passenger vehicles with size characteristics and other features comparable to today's vehicles have already been built with fuel economies in the 75-100 mpg range, so our projected average fuel economy for 2030 has already been demonstrated. Since cost information is not available for 2010, and neither cost nor technology assessments are available for 2030, we assume that a continuing but slower rate of improvement is cost-effective in the latter half of our assessment period.

For the Climate Stabilization scenario, we assume that automobiles achieve the same average fuel economy as in the Environmental case—75 mpg by 2030—but with an initial rate of improvement that is somewhat higher. Specifically, we assume an average of 46 mpg by 2000 and 59 mpg by 2010. In addition, we assume that the majority of new vehicles will run on biofuels or electricity in the post-2010 period.

In claiming that these fuel-economy levels can be cost-effective on a societal basis, we are, in effect, assuming that the rate of innovation in technologies for efficiency will be sufficient to keep pace with rising avoided fuel costs, taking into account the costs of "externalities" such as pollution and national security. The technologies for efficiency that we are assuming include both new engineering developments (and the ability to economically bring the technologies into production) and shifts in the types of vehicles that transport Americans and their goods. Avoided-cost assumptions were given earlier in the document; in 2010, for example, the projected levelized cost

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[29] EIA, "Energy Consumption and Conservation Potential."

[30] M. Ross et al., "Options for Reducing Oil Use by Light Vehicles," and EEA, "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010."

of gasoline to society is $1.69 per gallon. Our assumption is that, at a cost of conserved energy no greater than that value, technologies will be available for new automobiles to reach the assumed efficiency levels.

In projecting 75 mpg for new automobiles in 2030, we assume continuously increasing fuel-economy standards, market incentives, and revised rating procedures that would better reflect the actual conditions of driving. Implementing better test procedures could lead manufacturers to reoptimize vehicles in accordance with actual driving conditions. In addition, auto manufacturers could place greater emphasis on technologies for improving part-load efficiency, such as optimal transmission control or variable valve timing, as well as new technologies such as electric hybrid drive and regenerative braking. Reduced highway speeds and improved vehicle maintenance are also assumed to improve on-road fuel economy.

Light-Vehicle Travel Demand

A demographically based projection of VMT is used as the measure of light-vehicle transportation demand by individuals. The population growth that underlies VMT is not generally taken to be a matter of energy policy, although it certainly determines the overall level of transportation activity and energy use. Our Reference scenario VMT projection is based on the analysis described in the Technical Appendixes. It differs from that used by DOE and EIA primarily because of our estimated maximum vehicle ownership level of 1.1 vehicles per driver, and our estimate of a negligible increase in distance driven as personal income rises. The table on the next page summarizes our travel-demand analysis and the resultant impacts on light-vehicle VMT and passenger miles of travel (PMT).

The Reference case projection assumes a continuation of the urban growth patterns of the recent past—primarily suburban sprawl driven by road construction, housing-finance policies, and zoning policies. Those growth patterns are still strong, even with localized reactions against the loss of natural areas and agricultural lands. While it is most obvious in sprawling sunbelt cities, even the older cities of the rust belt are now surrounded with sprawl. Leveling-off of population and slower growth in the number of vehicles per capita lead to the reduced VMT growth rate, compared to the recent trend. The resultant VMT growth rate averages 1.2 percent per year from 1990 to 2030—EIA's projections average 1.6 percent per year—significantly lower than the 3.3-percent average VMT growth rate of the past 20 years.

In the Environmental scenario, recent growth patterns are assumed to persist until 1995, with a phase-in of effective mixed-use infill strategies thereafter. After 2000, growth in auto mileage is reduced by the suppression of new sprawl, so that 25 percent of new development is infill into vacant land in the suburbs, and 75 percent of development is higher-density mixed-use infill along transit corridors. Furthermore, with those urban development patterns, we assume that one passenger mile of mass transit use replaces six vehicle miles of car travel.[31] This degree of substitution results because infill and transit access reduce the average length of trips, and allow more travel by foot and bicycle. In the Environmental scenario, increased population density is estimated to cut total VMT by 5 percent by 2000, and 21 percent by 2030, relative to Reference case levels. In the Market scenario, impacts equal to half of those are assumed.

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[31] J. Holtzclaw, "Explaining Urban Density and Transit Impacts on Auto Use," Sierra Club, San Francisco, Calif., April 1990.

Assumptions Related to Personal Travel

	1990	2000	2010	2030
Population, age 16 and over, in millions	193	210	227	246
Reference scenario personal VMT, in trillions	1.76	2.25	2.61	2.82
Reference scenario transit PMT, in billions	42	46	49	53
Market Scenario				
VMT		2.11	2.20	2.32
VMT as percent of Reference case		94	84	82
PMT		65	110	125
PMT average annual growth rate from 1990		4.4%	4.8%	2.7%
Environmental Scenario				
VMT		1.96	1.82	1.87
VMT as percent of Reference case		87	70	66
PMT		90	174	200
PMT average annual growth rate from 1990		7.6%	7.1%	3.9%
Climate Stabilization Scenario				
VMT		1.77	1.80	1.85
VMT as percent of Reference case		79	69	66
PMT		122	177	204
PMT average annual growth rate from 1990		10.7%	7.2%	4.0%

The Market and Environmental scenarios also assume market-based incentives, called transportation demand management (TDM), to discourage inefficient (single-occupant) driving and encourage more efficient modes. A list of the TDM measures and their estimated impacts is provided in the Technical Appendixes. Our estimates are based on studies by the San Francisco Metropolitan Transportation Commission.[32] TDM yields another 13-percent reduction in VMT by 2030 in the Environmental scenario. The Market scenario assumes one-half of this VMT reduction, while the Climate Stabilization scenario assumes the same reduction in 2030 as in the Environmental scenario. However, the reductions are phased in sooner in the Climate Stabilization scenario, assuming immediate increases in population density and enactment of TDM policies.

Some TDM measures reduce the direct costs of transportation by providing better transit alternatives. Other measures increase the direct costs of driving in order to induce mode substitution, thereby reducing the externalities—such as air pollution, resource depletion, and

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[32] G. Howey, *Transportation Control Measure Plan,* Metropolitan Transportation Commission, Oakland, California, November 1990.

congestion—that are associated with driving. A change in public expenditures is also needed to expand mass transit capacity, shifting revenues away from highways. In our Environmental scenario, few or no new highways would be needed after 1995, since new development is shifted into areas where roadway infrastructure is already in place. A proportionately greater share of highway funding would be directed toward maintenance and improvements to make roadway infrastructure more conducive to efficient modes—including high-occupancy vehicle lanes, roads feeding mass transit nodes, and roadways that are less hostile to pedestrians and bicyclists.

Intercity Public Transport

Reference case projections of personal air travel through 2010 were obtained from the Department of Energy.[33] Activity levels and fuel efficiency were extrapolated from 2010 to 2030 in a way broadly consistent with pre-2010 trends and the NES results. Demand is measured in PMT, and the resulting Reference case annual growth rates for air PMT are 3.5 percent from 1988 to 2010, and 2.5 percent from 2010 to 2030. The Market, Environmental, and Climate Stabilization paths were developed from assumptions regarding improvements in aircraft efficiency, as well as a general shift from air to high-speed rail for trips of less than about 600 miles.

Significant improvements in aircraft efficiency are possible, especially over the long run as the stock is replaced.[34] The market incentive for improving aircraft fuel economy is strong compared to that for light vehicles. In both the Reference and Market cases, we assume that fuel economy improves 1.6 percent per year. For our Environmental case, we assume a greater rate of improvement, to stock average performance of 73 seat-miles per gallon (SM/G) by 2010 and 100 SM/G by 2030. An improvement to 150 SM/G is assumed in the Climate Stabilization case by 2030. We did not specifically analyze fuel-substitution possibilities; in other words, continued use of petroleum fuels is assumed.

In the Reference case, airline travel is expected to more than triple over the next 40 years—to nearly 1.8 trillion PMT. Moreover, it is assumed that new airport construction will be limited in the future, given that no new, major airport has been built since Dallas-Fort Worth in 1974, and the new Denver airport has taken more than a decade to obtain a permit. Thus, air-traffic congestion could reach severe proportions. The explosive growth in air travel has prompted several states and regions to consider high-speed ground transportation as a component of a balanced transportation system. High-speed rail offers the potential to address the growing intercity travel needs of Americans, especially at distances of 600 miles or less. Furthermore, high-speed rail can consume as little as one-third of the total energy used by aircraft over shorter distances.

Today, roughly 33 percent of all PMT by aircraft are flown on trips of 600 miles or less; that percentage represents 585 billion PMT. Those short trips are prime candidates for mode shifting. Presuming that the portion of air travel under 600 miles remains the same, we make the following assumptions about how shifts to high-speed rail occur. We assume a shift of one-third of the short-trip PMT from air to high-speed rail by 2030 in the Market case, where the total would be 195

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[33] DOE, *The National Energy Strategy.*

[34] D. L. Greene, "Energy Efficiency Improvement Potential of Commercial Aircraft to 2010." Report ORNL-6622, Center for Transportation Analysis, Oak Ridge National Laboratory, June 1990.

billion PMT on high-speed rail. One-half of short-trip PMT currently carried by air—or 293 billion PMT—would shift to high-speed rail in the Environmental case, and two-thirds—or 390 billion PMT—in the Climate Stabilization case. Shifts to high-speed rail are phased in linearly between 2000 and 2030. A summary table for intercity travel is provided in the Technical Appendixes.

Results

The overall results of our personal-transportation analysis are presented in the table below. In the Market scenario, total energy use for personal transportation is reduced by 29 percent in 2010, and by 41 percent in 2030 from Reference levels. This corresponds to total energy consumption in 2030 that is 23 percent below that of 1988, compared to a 31-percent increase between 1988 and 2030 in the Reference scenario. In the Environmental scenario, the reduction from the Reference case reaches 46 percent in 2010, and 59 percent in 2030. Finally, in the Climate Stabilization scenario, energy consumption for personal transport drops by 57 percent from the 1988 level by 2030. Compared to the Reference case, consumption is 51 percent lower by 2010, and 67 percent lower by 2030.

In addition to the efficiency improvements, there is growing substitution of biofuels and electricity for traditional petroleum-based fuels in each successive scenario. The share of petroleum, which presently accounts for essentially all personal-transportation energy use, drops in 2030 to 61 percent of end-use consumption in the Market case, 50 percent in the Environmental case, and 42 percent in the Climate Stabilization case. In the Climate Stabilization scenario, petroleum use in 2030 is only about 2.6 quads—just 14 percent of the petroleum use in the Reference scenario for that year.

Biofuels—ethanol, methanol, hydrogen, or biodiesel—represent the major new source of energy for personal transport in our three non-Reference scenarios. Total biofuel use reaches 1.6 to 1.7 quads by 2010, and 2.6 to 3.7 quads in 2030. Combined with the structural changes and aggressive efficiency improvements in the Environmental and Climate Stabilization cases, biofuels provide more than 15 percent and 40 percent of the energy for personal transport in 2010 and 2030, respectively.

Personal Transportation Energy Consumption (Quads)

	1988	2000	2010	2030
Reference Case	14.28	16.78	17.97	18.76
Market Case	14.28	15.03	12.69	11.02
Environmental Case	14.28	13.47	9.73	7.61
Climate Stabilization Case	14.28	13.11	8.77	6.16

Considering the total energy savings of the Environmental case in 2030 relative to the Reference case levels, improved efficiency is responsible for three-fourths of the savings, with shifts to more efficient transport modes accounting for the remainder. This is significant, in part because the majority of the technologies necessary for the improvements have already been identified, although the projection is for 40 years in the future. While improved technologies can provide the bulk of the energy savings, structural changes in personal transport can make a sizable difference as well.

FREIGHT TRANSPORTATION

The standard of living in the United States is supported by moving more than 30 tons of freight per capita each year—a figure that represents 16,000 ton-miles of haulage per capita. As of 1988, about 7.2 quads of energy were consumed for freight movement, giving an average intensity of 1600 Btu per ton-mile. Our analysis of freight transport starts with a set of freight-service demand levels, in ton-miles per year, by industrial subsector.[35] Those statistics are used instead of activity-by-mode statistics (for example, truck VMT, rail ton-miles) in order to estimate mode-shifting potential.

The demand for freight services is driven by the amount and types of industrial output. Our industrial projections assume less physical output than DOE's projections, reflecting the general trend towards decreases in materials intensity. Therefore, the energy requirement for freight movement in our Reference case is some 23 percent lower than DOE/EIA's projection for 2030.[36] We maintain the same level of freight service demand, in ton-miles, in all of our scenarios.

Our results reflect only the impacts of efficiency improvements and mode changes within the freight-transportation sector, other things being unchanged in the rest of the economy. In our analysis, the modal energy demands are partitioned into renewable and nonrenewable fuels. Our estimates of efficiency improvements are shown in the table on the next page. Further details are provided in the Technical Appendixes.

Regarding technology costs, a formal cost-benefit analysis was performed only for near-term heavy-truck efficiency potential.[37] Trucking is the most important mode from an energy perspective, and among the major modes it is the most energy intensive. (Air freight is more energy intensive, but includes only a small and specialized fraction of all shipping, most of which is carried as cargo on passenger aircraft.)

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[35] This analysis is based on the 1985 recalibration of the Argonne National Laboratory FRATE model (A. Vyas, personal communication, December 1990).

[36] The reduction assumes equivalent mode shares among truck, rail, and boat for domestic freight. Pipeline use and international shipping are excluded from this adjustment—i.e., we assume EIA's values in our Reference case.

[37] H. M. Sachs, J. M. DeCicco, M. Ledbetter, and U. Mengelberg, "Fuel Economy Improvement for Heavy Trucks: A View of Existing Technology, Future Possibilities, and the Potential Improvement," American Council for an Energy-Efficient Economy, August 1991.

Freight Sector Assumptions

	1990	2000	2010	2030
REFERENCE				
Energy intensity, in Btu per ton-mile for 1990, then indexed				
Truck	2,808	0.945	0.896	0.811
Rail	443	0.961	0.929	0.869
Boat	402	1	1	1
Pipeline	2,710	1	1	1
Air	18,810	0.793	0.648	0.512
MARKET				
Energy intensity, indexed to 1990				
Truck	2,808	0.857	0.735	0.541
Rail	443	0.919	0.842	0.700
Boat	402	0.975	0.950	0.900
Pipeline	2,710	0.975	0.950	0.900
Air	18,810	0.793	0.648	0.512
ENVIRONMENTAL				
Energy intensity, indexed to 1990				
Truck	2,808	0.815	0.664	0.498
Rail	443	0.895	0.796	0.612
Boat	402	0.950	0.900	0.800
Pipeline	2,710	0.950	0.900	0.800
Air	18,810	0.793	0.512	0.373
CLIMATE STABILIZATION				
Energy intensity, indexed to 1990				
Truck	2,808	0.781	0.664	0.464
Rail	443	0.895	0.796	0.612
Boat	402	0.950	0.900	0.800
Pipeline	2,710	0.900	0.800	0.700
Air	18,810	0.793	0.474	0.249

Note: "Indexed to 1990" is the fraction of the energy intensity in 1990.

With respect to efficiency improvements for heavy trucks, we exhaust the technologies for which cost information is known at a cost well below the avoided cost of fuel consumption. Measures up to that level, 15.9 mpg, are therefore cost-effective in all scenarios through 2000.[38] Differences

[38] The 15.9-mpg figure corresponds to the maximum cost-effective fuel economy level for all freight trucks. Our detailed analysis only pertains to heavy trucks, for which the corresponding level of fuel economy is 9.6 mpg (see the Technical Appendixes).

among scenarios depend on assumed rates of penetration rather than differences in the cost-effective energy-efficiency potential. Since we do not have cost data for 2010 and 2030, we assumed that the efficiency levels reached are cost-effective at the avoided fuel costs during those years. Furthermore, in the Environmental and Climate Stabilization scenarios we assumed that truck speed limits would be reduced from 65 mph to 55 mph, which raises the average fuel economy of freight trucks to 17.3 mpg.

Mode Shares

Of the 2.8 trillion ton-miles of *intercity* freight shipped in 1989, rail carried 37 percent, trucks 26 percent, oil pipelines 21 percent, domestic water shipping 16 percent, and air 0.35 percent.[39] (The bulk of *intracity* freight is carried by truck.) We part from the Reference case assumptions of no mode shifting by moving some truck freight to intermodal rail in our non-Reference cases. At present, a small fraction—probably less than 5 percent—of domestic freight moves in intermodal service. This occurs using containers or trailers on flatcars, or dedicated vehicles, and "carless" trailers. There are many barriers to increasing the intermodal fraction, of which the most important is that intermodal service takes longer than single-mode freight delivery for hauls of less than 500 or 600 miles.

Rail shipping uses about one-fourth as much energy per ton-mile as trucks, so increasing intermodal transportation involving a combination of rail and truck transport can save energy. By examining intermodal potential by commodity subsector, we estimated that a maximum of 12 percent of intercity truck ton-miles could switch to rail by 2030 in the Environmental scenario. We held this to a 5-percent switch in the Market scenario.

Modal Efficiency Projections

The current energy intensities of freight modes vary greatly—270 Btu per ton-mile for pipelines, 400 for domestic boats, 440 for rail, 2,800 for trucks, and 19,000 for air freight (see the table above). Our Reference case efficiency projections match the weighted averages of those used by DOE.[40] Fuel-intensity projections for our other cases are generally based on DOE conservation excursions, except for truck and air, for which we based our efficiency assumptions on Sachs et al. and Greene, respectively.[41]

We obtained our projections for the fuel requirements of international shipping from the Department of Energy, and added them to the freight modes discussed above. International shipping accounted for 0.7 quads in 1988, and is projected to grow to just over one quad by 2030. We did not analyze this mode, however, so no additional efficiency improvements or fuel switching are reflected in our non-Reference scenarios.

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[39] F. Smith, *Transportation in America* (8th edition), Eno Foundation for Transportation, 1990.

[40] EIA, "Energy Consumption and Conservation Potential."

[41] H. M. Sachs et al., "Fuel Economy Improvement for Heavy Trucks"; D. L. Greene, "Energy Efficiency Improvement Potential of Commercial Aircraft to 2010."

The Role of New Technologies and Fuels

Fuel categories are aggregated because of the uncertainties regarding the technologies that will become available. For convenience, we consider all renewable fuels to be derived from biomass, leaving the final energy carrier—be it alcohol, hydrogen, or other—undefined. Although we assume moderate increases in the use of natural gas as a land-freight fuel, its contribution could be significantly higher than shown in the present analysis, particularly for meeting near-term urban air pollution and CO_2 reduction goals. Natural gas is widely available, is relatively inexpensive, and burns rather cleanly. Compressed or liquified natural gas may be suitable for fleet vehicles, heavy trucks, and rail—where liquified natural gas might be carried in tanks behind the locomotive.

During the next 40 years, we anticipate that freight-transportation technologies will change significantly. Diesel engines will incorporate turbocompounding and low heat-rejection technologies that will improve energy efficiency.[42] Gas turbines may begin to replace internal combustion engines in the "heavy" freight sectors—such as rail, water, and heavy trucks. But widespread implementation of the gas turbines in vehicles will be dependent on the development of appropriate fuels and subsidiary technologies, such as high-temperature materials. Because high-efficiency turbines use expensive materials, costs are uncertain, particularly in smaller sizes. Turbines are adaptable to many fuels, including natural gas, diesel, and alcohol. Besides gas turbines, fuel cells are an emerging technology for powering vehicles that can use alcohol or hydrogen, both of which may come from a renewable source.

Results

The end-use energy requirements for the freight sector are summarized by scenario in the table on the next page. In the Reference case, freight sector end-use energy consumption grows from the current 7.2 quads to 9.8 quads in 2030. This corresponds to an average growth rate of 0.7 percent per year, compared to 2.1-percent-per-year average growth in GNP. The difference represents a projected downward trend averaging 1.4 percent per year in the energy intensity of freight in the US economy. This breaks down into a 0.5-percent-per-year reduction due to structural shifts in the economy, specifically the need to move less freight per unit of GNP over time, and a 0.9-percent-per-year reduction due to efficiency improvements in freight-mode energy use in the Reference case.

Our three non-Reference scenarios show significant reductions in energy consumption for freight movement, compared to the Reference case. The Market and Environmental scenarios deliver the same amount of freight as the Reference case in 2030, using 7.1 and 6.2 quads, respectively. In the Climate Stabilization scenario, energy consumption is 22 percent and 40 percent below the Reference case by 2010 and 2030, respectively.

Of the reductions in freight-sector energy use, relative to the Reference case in the year 2030, about three-fourths are due to technology improvement, and one-fourth is due to mode shifting from truck to rail. This breakdown is very similar to the results for passenger travel.

Although technology-cost projections have large uncertainties, we estimate that all energy-use reductions in the non-Reference scenarios would be cost-effective. With changes in land-use

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[42] Sachs et al., "Fuel Economy Improvement for Heavy Trucks."

patterns, and urban-transportation policies oriented to increasing the efficiency of freight movement, there could be additional savings, but we did not analyze the impact of those factors for freight transportation. The following changes could significantly impact freight energy use, but were not analyzed: 1) changes in the average distance between production and consumption, and 2) land-use and traffic policies that affect freight movement in metropolitan areas.

As is the case for personal transport, petroleum greatly declines in importance as a source of energy for freight transport in our action-oriented cases. By 2030, petroleum represents 91 percent of freight energy use in the Reference case, 70 percent in the Market case, 58 percent in the Environmental case, and only 19 percent of freight energy use in the Climate Stabilization case. Natural gas is the principal alternative to petroleum in the Market and Environmental cases, while biofuels and natural gas supplant petroleum in the Climate Stabilization scenario.

Freight Transportation Energy Consumption (Quads)

	1988	2000	2010	2030
Reference Case	7.17	7.90	8.64	9.81
Market Case	7.17	7.20	7.28	7.06
Environmental Case	7.17	6.92	6.62	6.20
Climate Stabilization Case	7.17	6.72	6.76	5.89

Chapter 5: Energy supply

RENEWABLE ENERGY SOURCES

Our method of projecting the market penetration of renewable energy sources, described in detail in the Technical Appendixes, was similar to the procedure used for evaluating conservation measures. We compared the projected cost of renewable technologies to the projected cost of competing fossil-fuel technologies. Those renewable technologies with costs below the avoided cost for fossil-fuel options—including, where appropriate, environmental costs—were adopted progressively in order of ascending cost. Market penetration was not instantaneous, but gradual, reflecting constraints such as the rate of equipment turnover and institutional resistance to change. The main difference between scenarios was that higher-cost renewable options were introduced sooner in the Environmental and Climate Stabilization scenarios than in the Market scenario, reflecting the inclusion of environmental costs in energy prices.[1]

While this method varied in detail for each sector, several common features should be noted. First except for the transportation sector, the analysis was done explicitly on a regional basis, and the results were then aggregated for the country as a whole. This was necessary because the quality and quantity of renewable energy resources vary widely across the country. We used the four census regions: Northeast, South, Northcentral (or Midwest), and West.

Second, since many renewable technologies are neither fully mature nor commercially available, we relied on engineering analysis and expert opinion of their future costs and performance in evaluating their market potential. Naturally, this introduced an element of uncertainty in the results. Ideally, we would have liked to explore the sensitivity of the results to changes in cost assumptions, but this is outside the scope of our study. The cost assumptions were derived from a variety of government and industry sources, cited in the Technical Appendixes, and were generally consistent with a recent major DOE study.[2]

Third, where appropriate, environmental costs were assessed for renewable energy technologies as well as for fossil fuels. In general, the environmental costs of renewable energy technologies are very low, but they can be significant in the case of biomass, municipal solid waste incineration, and hydropower.[3] Since we assigned explicit monetary values to air emissions only, in effect we undervalued externalities associated with land use, water, and other impacts. (This applies to all

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[1] Estimates of renewable energy consumption in the Reference case were derived independently from NES data.

[2] *The Potential of Renewable Energy: An Interlaboratory White Paper*, Solar Energy Research Institute, Golden, Colorado, 1990.

[3] R. L. Ottinger et al., *Environmental Costs of Electricity*, Oceana Publications, New York, 1990.

energy sources, not just renewable sources.) Where possible, however, we took into account non-emissions-related environmental and siting constraints in quantifying renewable resources and costs. For example, we anticipated that public opposition to new hydropower development, among other factors, would limit the amount of new hydropower capacity to 16 GW (gigawatts), even though the total undeveloped resource is estimated to be 76 GW. Likewise, we assumed that no wind power development would occur on land deemed "environmentally sensitive," and that only 40 percent of municipal solid wastes would be available for conversion into energy because of policies to encourage source reduction, recycling, and reuse.[4] Furthermore, we assumed that the long-term cost of energy from dedicated energy crops would be $3 per MBtu, rather than DOE's goal of $2 per MBtu. This assumption accounts for the possible effects of environmental regulation, such as restricted use of high-yield annual crops on erodible land, and for the requirements of ecologically sound biomass-production practices.

Fourth, although renewable energy supply was modeled separately for each sector, all sectors shared a common set of renewable resource constraints (see the Technical Appendixes). We found solar, moderate-speed wind, and geothermal resources (including geopressured brines and hot dry rock) to be so large as to be essentially unconstrained—that is, their use is more likely to be determined by market factors than any practical resource limitations. Biomass resources—including energy crops, wood and wood wastes, agricultural residues, and other sources—are considerably more limited but still appear sufficient to satisfy expected market demand, even in our most ambitious scenarios. Other resources, including hydropower, municipal solid wastes, and high-speed wind, are significantly constrained. Variations in the geographic distribution of renewable resources are important to note. Biomass production, for example, is potentially far higher in the Midwest and South because of the availability of cropland, pastureland, and rangeland suitable for energy crops in those regions. High- and moderate-speed wind resources are less plentiful in the Northeast than in other regions, while hydropower resources are concentrated mainly in the West.

In evaluating our results, it is important to keep in mind that energy-efficiency measures tend to reduce demand for energy supply from all sources, including renewable sources. This is particularly true in the electricity sector, where power plants typically last 40 years or longer, resulting in only a limited demand for new electricity supply if overall electricity demand does not increase. Because our analysis integrated both efficiency and renewable options (one of its major strengths), the projected renewable contributions (in quads) are considerably lower than those of some other studies (notably the DOE *White Paper* cited above). This should not be taken to mean that these sources will play a less significant role, however. On the contrary, as a percentage of total energy supply, the projected renewable contributions of this study (exceeding 50 percent by 2030 in the Climate Stabilization scenario) are higher than those of most other studies, including the *White Paper*.

Electricity Supply

We considered 13 renewable electricity supply options, including three hydropower options (efficiency upgrades, expansions, and new construction), two wind options (high and moderate wind speed), two solar options (solar thermal electric and photovoltaic), three biomass options

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[4] It is a matter of debate whether municipal solid wastes should be regarded as a renewable resource, but here we follow DOE's convention of counting them as renewable.

(conventional wood-fired steam turbines, integrated gasifier/steam-injected gas turbines, and municipal solid waste incineration), and three geothermal options (liquid-dominated hydrothermal, geopressurized, and hot dry rock). In the first stage of the analysis, we compared the projected levelized cost of electricity from each technology with projected avoided costs of competing fossil sources. The avoided costs were based on an assumed fossil-fuel mix and capacity factor selected according to the duty cycle (baseload or cycle/peaking) of the renewable option being considered. A menu of qualifying technologies—those that passed the avoided cost screening—was then generated for each scenario and for each of three time periods: 1990 to 2000, 2000 to 2010, and 2010 to 2030.

In the second stage, we estimated the market share of electricity generation, in kilowatt-hours, captured by renewable energy sources in each time period and region, in a sequence of three steps. First, we estimated the overall demand for *new* electricity supply, basing the estimates on projections of growth in demand and retirements of existing capacity. Second, we assigned a fraction of this demand—called the "renewable market share"—to renewable energy technologies. That fraction was assumed to rise over time from a low of 30 to 50 percent in the first decade to a high of 70 to 90 percent in the last two decades, depending on the region and scenario. The rise was intended to reflect the expanding number and variety of cost-competitive renewable energy technologies expected to become available, as well as the growing acceptance of such technologies by electric utilities. The market shares in the first decade were based loosely on experience in California, where geothermal, biomass, wind, and solar plants provided roughly 50 percent of new electricity supply from 1980 to 1989. This was largely a result of California's aggressive implementation of PURPA (the Public Utility Regulatory Policies Act) and the establishment of federal and state renewable energy tax credits (now mostly expired). Third, we apportioned the renewable market share among the various technologies in rough proportion to relative cost, taking into account resource constraints.

We placed no explicit restrictions on the use of intermittent solar and wind power. Instead, we constructed a model to calculate the amount of storage capacity that would be required to maintain the reliability of electricity supply at any given penetration of intermittent sources. The cost of storage was included in the marginal costs of wind and solar power. We found that, at low intermittent penetrations of up to 10 to 15 percent of peak load, the additional cost was negligible; but at higher penetrations, it approached $0.015 per kWh. The additional cost was a significant, though not decisive, factor limiting the use of wind and solar power in the long term.

Residential and Commercial Buildings

For the analysis of residential and commercial buildings, we adopted, but extensively revised, a market-penetration model for dispersed solar technologies developed by a DOE consultant.[5] The model determines market penetrations based on the expected payback period of particular technologies. We eliminated some of the technology options included in the original model and added others we considered more promising. We also changed various parameters to reflect anticipated market conditions in the Market, Environmental, and Climate Stabilization scenarios.

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[5] *Market Penetration Model for Active and Passive Solar Technologies*, prepared by Science Applications International Corporation for the US Department of Energy, 1990.

r solar options and one geothermal option were considered: solar water heating, passive sola ing, active solar cooling, solar district heating with seasonal storage, and geothermal district ing. Passive solar cooling and daylighting measures were not considered here but were ıted as conservation measures in the buildings end-use analysis described previously.

carried out the market penetration calculation in several steps. First, we estimated a paybac od for each technology by dividing its cost by the 20-year levelized cost of the competing —either electricity or natural gas. A maximum payback period of 14 years was allowed as th : on cost-effectiveness, based on a 3-percent discount rate and 20-year measure life. Then, ending on the actual payback period, we calculated a "market penetration factor," which ed from 0 to 100 percent. Next, the market penetration factors were normalized so that the of renewable and nonrenewable market shares for each end-use would equal 100 percent. resulting renewable shares were then multiplied by a "technology acceptance factor," which esented the expected degree of consumer acceptance and commercial availability of renewa nologies. We assumed that this factor would rise linearly over time from zero to one, and th ise would occur faster in each successive scenario as a result of more aggressive policies and rams. Finally, the market shares were combined with anticipated rates of new building truction and existing building retrofits to determine the cumulative fuel and electricity savin pace heat, hot water, and space cooling.

ould be noted that this method probably understates the potential renewable energy ribution because it considers efficiency and solar measures independently. Ideally, the two s of measures should be fully integrated into building design from the beginning. If this were , the result would probably be to enhance the solar contribution, if not overall energy saving was, efficiency measures were assessed first, leaving more limited opportunities for cost- tive solar applications.

vood remains an important source of energy for residential buildings. We did not perform a pendent analysis of firewood consumption, but simply scaled the Reference case projections ct reductions in residential heating demand.

stry

nilar method was adopted in the industry analysis. Two renewable resources—solar thermal gy and geothermal energy—were considered as possible replacements for fossil fuels in nal applications (manufacturing sector only). Market penetration factors were calculated in ame way as in the buildings analysis, but the maximum allowed payback period was set at 2C rather than 14 years to reflect the longer lifetime of industrial energy sources. The market tration factors were further adjusted to reflect the fact that only about 30 to 50 percent of strial heating is carried out at temperatures low enough to be supplied by flat-plate or bolic-trough solar collectors and geothermal sources. Cumulative savings were determined c asis of assumed rates of industrial expansion and retirements of existing boilers and other oment.

d, paper, and pulp wastes are already extensively used in the forest-products industries for ess heat, steam, and generation of electricity. Since they come virtually free, there is a stron tive for industry to continue consuming these resources even if overall energy demand nes. Consequently, we assumed that waste consumption would decline only slightly in our efficiency scenarios. At the same time, we assumed that cogeneration from wood wastes would grow through the use of new, efficient technologies, such as biomass gasification in combination with gas turbines.

Transportation

For the transportation sector, we identified prospective renewable fuels, such as methanol, ethanol, and hydrogen, all of which could be derived from biomass at varying efficiencies and production costs. We made no attempt to choose winners and losers among those fuels, but instead substituted a generic biofuel with a single set of cost and emissions parameters. We then projected how much of this fuel could be made available within assumed biomass resource constraints. It was left to the transportation sector end-use analysis to determine how much biofuel would actually be consumed in the alternative scenarios. We did not include the option of producing hydrogen from water using solar- or wind-generated electricity because current data suggest that biomass-derived hydrogen will be considerably less expensive for the foreseeable future.

Results

The tables on the following pages summarize the contributions of renewable energy sources in each scenario and energy sector. Additional details, including breakdowns by region, are provided in the Technical Appendixes. Electricity production is expressed in terms of primary fossil-energy equivalent, with an assumed conversion factor of 10,340 Btu per kWh for sources other than biomass and municipal solid wastes; for the latter, actual heat rates are used. Biomass and biofuel contributions also include losses in production and conversion.

In the Reference case, the amount of primary energy supplied by renewable sources approximately doubles from 7.4 quads in 1988 to 15.5 quads in 2030. Because of the large increase in total energy demand anticipated in this case, however, the share of primary-energy consumption supplied by renewables increases only moderately, from 9 percent to 13 percent. The largest additions come from biomass, primarily in industry and electricity. The generation of renewable electricity increases by about 145 percent to eight quads in 2030. Hydropower's output grows by about 43 percent, but its share of renewable-electricity production drops from 76 percent to about 44 percent, as significant contributions are made by biomass, geothermal, wind, and solar power.

The Market, Environmental, and Climate Stabilization scenarios show substantially greater utilization of renewable energy sources than the Reference scenario. In the Market case, renewable energy supply reaches 29.7 quads in 2030, almost a doubling of the Reference level. Major increases come from wind, solar, geothermal, and biofuels in the transportation sector. Moderate additional increases in renewable energy supply are projected in the Environmental and Climate Stabilization cases. Because of declining energy demand, however, the renewable share of primary energy supply reaches 53 percent in the Climate Stabilization scenario and 41 percent in the Environmental scenario, compared to 36 percent in the Market scenario and just 13 percent in the Reference scenario.

PRIMARY RENEWABLE ENERGY SUPPLY - REFERENCE CASE

Sector/Fuel	1988	2000	2010	2030
Electricity*	**3.22**	**4.76**	**5.68**	**7.95**
Hydro	2.45	3.37	3.37	3.51
Wind	0.03	0.05	0.18	0.86
Solar	0.01	0.02	0.13	0.82
Biomass	0.42	0.97	1.45	1.62
MSW***	0.00	0.00	0.00	0.00
Geothermal	0.31	0.34	0.55	1.16
Buildings	**1.05**	**1.21**	**1.43**	**1.86**
Biomass	0.97	1.06	1.14	1.29
Solar	0.08	0.15	0.29	0.57
Geothermal	0.00	0.00	0.00	0.00
Industry	**3.11**	**3.82**	**4.09**	**5.00**
Biomass	3.06	3.75	4.01	4.91
Solar	0.00	0.00	0.00	0.00
Geothermal	0.00	0.00	0.00	0.00
Other**	0.05	0.06	0.08	0.09
Transportation	**0.00**	**0.00**	**0.02**	**0.65**
Biofuels****	0.00	0.00	0.02	0.65
TOTAL	**7.39**	**9.79**	**11.22**	**15.47**

* Primary fossil energy equivalent.
** Includes hydro and MSW.
*** MSW included in biomass.
**** Includes losses in production and conversion.

PRIMARY RENEWABLE ENERGY SUPPLY - MARKET CASE

Sector/Fuel	1988	2000	2010	2030
Electricity*	**3.22**	**4.64**	**6.13**	**14.01**
Hydro	2.45	3.33	3.52	3.67
Wind	0.03	0.27	0.66	2.72
Solar	0.01	0.03	0.21	1.53
Biomass	0.42	0.66	1.05	2.91
MSW	0.00	0.07	0.23	0.83
Geothermal	0.31	0.28	0.47	2.35
Buildings	**1.05**	**1.28**	**1.70**	**3.12**
Biomass	0.97	1.01	0.97	0.99
Solar	0.08	0.26	0.69	1.93
Geothermal	0.00	0.01	0.04	0.20
Industry	**3.11**	**3.90**	**4.37**	**5.68**
Biomass	3.06	3.75	4.01	4.91
Solar	0.00	0.02	0.07	0.19
Geothermal	0.00	0.07	0.20	0.49
Other**	0.05	0.06	0.08	0.09
Transportation	**0.00**	**0.36**	**2.56**	**6.20**
Biofuels***	0.00	0.36	2.56	6.20
TOTAL	**7.39**	**10.18**	**14.76**	**29.02**

* Primary fossil energy equivalent.
** Includes hydro and MSW.
*** Includes losses in production and conversion.

PRIMARY RENEWABLE ENERGY SUPPLY - ENVIRONMENTAL CASE

Sector/Fuel	1988	2000	2010	2030
Electricity*	**3.22**	**4.96**	**6.27**	**14.50**
Hydro	2.45	3.33	3.45	3.71
Wind	0.03	0.42	0.79	3.00
Solar	0.01	0.07	0.26	1.83
Biomass	0.42	0.76	1.08	2.58
MSW	0.00	0.08	0.21	0.83
Geothermal	0.31	0.30	0.49	2.55
Buildings	**1.05**	**1.24**	**1.84**	**3.38**
Biomass	0.97	0.90	0.91	0.97
Solar	0.08	0.33	0.87	2.18
Geothermal	0.00	0.01	0.06	0.23
Industry	**3.11**	**4.08**	**4.67**	**6.03**
Biomass	3.06	3.86	4.20	5.21
Solar	0.00	0.04	0.10	0.25
Geothermal	0.00	0.12	0.28	0.49
Other**	0.05	0.07	0.10	0.09
Transportation	**0.00**	**0.31**	**2.79**	**5.36**
Biofuels***	0.00	0.31	2.79	5.36
TOTAL	**7.39**	**10.60**	**15.57**	**29.28**

* Primary fossil energy equivalent.
** Includes hydro and MSW.
*** Includes losses in production and conversion.

PRIMARY RENEWABLE ENERGY SUPPLY-CLIMATE STABILIZATION CASE

Sector/Fuel	1988	2000	2010	2030
Electricity*	**3.22**	**5.65**	**7.59**	**15.94**
Hydro	2.45	3.39	3.55	3.54
Wind	0.03	0.64	1.21	3.44
Solar	0.01	0.11	0.40	2.19
Biomass	0.42	1.03	1.50	3.13
MSW	0.00	0.14	0.31	0.80
Geothermal	0.31	0.33	0.62	2.84
Buildings	**1.05**	**1.30**	**1.99**	**3.06**
Biomass	0.97	0.89	0.89	0.93
Solar	0.08	0.39	1.01	1.90
Geothermal	0.00	0.02	0.09	0.22
Industry	**3.11**	**4.18**	**4.87**	**6.06**
Biomass	3.06	3.86	4.20	5.21
Solar	0.00	0.07	0.17	0.24
Geothermal	0.00	0.18	0.41	0.53
Other**	0.05	0.06	0.08	0.09
Transportation	**0.00**	**1.30**	**3.60**	**7.66**
Biofuels***	0.00	1.30	3.60	7.66
Total	**7.39**	**12.43**	**18.05**	**32.72**

* Primary fossil energy equivalent.
** Includes hydro and MSW.
*** Includes losses in production and conversion.

ELECTRICITY SUPPLY

Each successive scenario in the electricity supply analysis reflects greater levels of end-use efficiency, and hence lower electricity demand; increased power supplied by renewable resources; and a shift from old fossil-fuel technology to new fossil-fuel technology with lower emission rates. Assumptions concerning life extensions (renovations) and retirements of existing power plants varied between scenarios, with fewer life extensions and more retirements of coal-fired plants assumed in the Environmental and Climate Stabilization scenarios than in the Reference and Market scenarios. Besides renewable resources, the predominant alternative to coal was natural-gas-fired combined-cycle, a technology with very low CO_2 and other pollutant emissions.

The performance and costs of fossil-fired technologies considered in this analysis are listed in the table on the next page. (Corresponding costs of renewable energy technologies are listed in the Technical Appendixes.) All of these options except natural-gas fuel cells were included in each scenario; the latter were included only in the Climate Stabilization scenario. As in the Reference case, the alternative scenarios do not include the construction of new nuclear reactors or the relicensing of existing reactors, so these options are not listed in the table.

The assumption of no new construction and no relicensing accords with the NES "Current Policy" case. Nuclear power plant construction and operating costs have risen dramatically since the 1970s, suggesting that existing technology is no longer economically viable. On the other hand, insufficient information is available on the engineering design of new, advanced reactors to project their costs with any confidence. Even if the new reactors meet their cost targets, public opposition to new nuclear construction remains high, and the industry as a whole is vulnerable to a forced shutdown if a catastrophic accident occurs at any one plant. The Bush administration assumes that these hurdles can be overcome, leading to a doubling of nuclear capacity by 2030. But we are skeptical that this will be possible.

The data require some explanation, as they are not directly comparable to busbar costs developed in other studies. The most important differences derive from two factors: the assumption of a "societal discount rate" of 3 percent (inflation-adjusted), and the assumption of an in-service date of 2010 in the derivation of levelized costs. The societal discount rate was adopted to reflect society's interest in reducing costs to future generations, consistent with our societal perspective, and in increasing long-term investment. Combined with the assumption of no taxes in capital recovery thus leads to a 5 percent levelized fixed charge rate for a 30-year investment rather than the more typical value of 10-12 percent. Together, these factors tend to increase the importance of fuel costs relative to capital costs, particularly in the case of relatively high gas prices projected by the DOE. Thus, for example, a Pressurized Fluidized Bed Coal (PFBC) plant appears to be a more attractive investment than the Natural Gas Combined Cycle (NGCC) plant for the post-2010 period, whereas the reverse is true if a 1990 in-service date and a private perspective is assumed. The supply options listed in the table should be viewed as indicative, but not exhaustive, of the full range of options that might in fact be developed.[6]

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[6] For example, advanced gas-turbine cycles, including intercooled and reheat steam-injected gas turbines, promise efficiencies of 50 percent or more (i.e., heat rates of 6,800 Btu per kWh or less). See "Fuels Report," Report # P300-89-018, California Energy Commission, Sacramento, 1989.

Avoided Power Plant Costs at the Busbar
1990$ Levelized 2010-2040
(cents/kWh)

	Heat Rate (MMBtu per MWh)	Capital Cost	Additional Control Cost	Fuel Cost	O&M Cost	Total Direct Cost	Air Emissions Costs	Total Social Cost
New Coal								
AFBC	10.06	1.36	0.57	2.43	1.29	**5.65**	0.59	**6.24**
PBC	9.70	1.33	0.57	2.35	1.16	**5.41**	0.59	**6.00**
IGCC	9.22	1.32	0.27	2.23	0.91	**4.73**	0.22	**4.95**
MHD/ Fuel Cell	6.40	1.13	-.--	1.55	1.14	**3.82**	0.04	**3.86**
New Natural Gas								
NGCC	7.74	0.43	0.27	5.60	0.46	**6.76**	0.22	**6.98**
Fuel Cell	5.75	0.66	-.--	4.14	0.84	**5.64**	0.02	**5.66**
CTNG	9.43	1.53	2.24	6.82	0.86	**11.45**	0.39	**11.84**
Life Extension								
Coal ST	10.00	0.19	-.--	2.44	0.80	**3.43**	1.19-2.10	**4.62-5.53**
Gas ST	10.00	0.10	-.--	7.23	0.40	**7.73**	0.75-1.51	**8.48-9.24**
Oil ST	10.00	0.13	-.--	7.32	0.40	**7.85**	0.69-2.41	**8.54-10.26**

Notes: AFBC-Atmospheric Fluidized Bed Combustion; PBC-Pressurized Fluidized Bed Combustion; IGCC-Integrated Gasification/Combined Cycle; MHD-Magnetohydrodynamic; NGCC-Natural Gas Combined Cycle; CTNG-Combustion Turbine using natural gas fuel; Coal, Gas and Oil ST-Existing steam turbine facilities.
These values assume a 75-percent capacity factor for baseload plants and a 15-percent capacity factor for peaking plants (CTNG). Costs and heat rates of new facilities were adapted from *Technical Assessment Guide Volume 1: Electricity Supply - 1989,* EPRI P-6587-L, Volume 1, Revision 6, Electric Power Research Institute, Palo Alto, California, November 1989, except fuel cells, which were adapted from *Electricity Supply: Supporting Analysis for the National Energy Strategy,* SR/NES/90-03, Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, Electric Power Division, US Department of Energy, Washington, D.C., January 1991. Costs of life extension were from *Electricty Supply.* Life extension assumes that Clean Air Act modifications are already made. Control costs: AFBC and PBC-scrubber, *Electricity Supply*; IGCC, NGCC and CTNGs-steam injection, *Technical Assessment Guide.* Emissions costs reflect regional differences in emissions, and air emissions externalities values were given earlier and in the Technical Appendixes. Coal life-extension cost includes additional 0.3 cents/kWh for O&M for meeting the Clean Air Act sulphur dioxide targets. Oil security externality costs (at $2.50/barrel) would add about 0.4 cents per kWh to the oil-fueled plants.

Electricity generation by fuel type in each scenario is presented in the tables on the next pages. Corresponding tables for electricity generation and capacity by facility type are provided in the Technical Appendixes. It can be seen that overall electricity requirements are progressively reduced as we move from the Reference case, in which demand almost doubles by 2030, through the Climate Stabilization case, in which demand decreases by almost 18 percent. The corresponding decline in electricity capacity is not quite as large, as renewables with relatively low capacity factors account for an increasing share of generation in the Environmental and Climate Stabilization scenarios.

Reference Scenario

Our Reference case projections for electricity supply begin with the facilities that currently exist, and evolve to encompass load growth, plant retirements, and changes and additions in the mix of energy resources. The bulk of new baseload capacity added before 2010 uses coal (150 GW), whereas new natural-gas combined-cycle facilities supply 55 GW, and new wind, solar, wood, and geothermal plants account for 27 GW.

Existing nuclear power plants are assumed to be retired at the end of their normal lifetimes, resulting in a decline of their total from about 100 GW today to about six GW by 2030. In addition, all existing gas- and oil-fired steam-turbine units are assumed retired by 2030. Coal plants existing in 1988 are retrofitted to conform to recent amendments of the Clean Air Act; two thirds of them are assumed to continue operation (with life extensions) through 2030, while the rest are retired between 2010 and 2030.

Market Scenario

With the implementation of end-use efficiency measures, the need for capacity additions is greatly reduced. Further, a greater portion of the new capacity is provided by renewable sources. The remaining baseload and peaking needs are met by essentially the same mix of resources as in the Reference scenario. However, 10 percent of the baseload coal additions after 2010 are assumed to be advanced magnetohydrodynamic (MHD) or advanced fuel cells.

Environmental Scenario

The need for capacity additions is further reduced in the Environmental scenario. Because of the inclusion of environmental costs in the price of coal, however, life extensions of coal plants are economically much less attractive, and consequently a larger fraction—two-thirds—of existing coal capacity are assumed to be retired by 2030. Twenty-five percent of new baseload coal additions after 2010 (about 16 GW) are assumed to be MHD or advanced fuel cells. Finally, renewable energy sources achieve much greater penetration, led by wind, solar, and geothermal.

Climate Stabilization Scenario

To meet the CO_2 reduction targets of this scenario, all existing coal-fired power plants are assumed to be retired between 1995 and 2030. About 25 GW of electricity from MHD or advanced fuel cells come on line after 2010. Almost all of the new baseload fossil units added before 2010, and all of the new units added thereafter, are natural-gas combined-cycle, natural-gas steam-injected gas turbines (STIG), or natural-gas fuel-cell, resulting in a major shift in fossil-fuel use and

REFERENCE CASE ELECTRIC SUPPLY: GENERATION BY FACILITY TYPE

(1000 GWH)

PLANT TYPE	1988	2000	2010	2030
COAL	1598	1897	2632	3970
NATURAL GAS	276	565	598	648
OIL	142	224	142	27
NUCLEAR	531	563	536	32
HYDRO	237	326	326	339
SOLAR	1	2	13	79
BIOMASS	33	76	113	126
WIND	3	5	17	83
GEOTHERMAL	30	33	53	112
TOTAL ELECTRIC	2851	3691	4430	5416

MARKET CASE ELECTRIC SUPPLY: GENERATION BY FACILITY TYPE

(1000 GWH)

PLANT TYPE	1988	2000	2010	2030
COAL	1598	1775	1754	1682
NATURAL GAS	276	335	274	183
OIL	142	219	164	11
NUCLEAR	531	508	481	32
HYDRO	237	322	340	355
SOLAR	1	3	20	148
STORAGE	0	0	5	20
BIOMASS	33	56	96	278
WIND	3	26	64	263
GEOTHERMAL	30	27	45	227
TOTAL ELECTRIC	2851	3271	3243	3199

ENVIRONMENTAL CASE ELECTRIC SUPPLY: GENERATION BY FACILITY TYPE

(1000 GWH)

PLANT TYPE	1988	2000	2010	2030
COAL	1598	1688	1334	1062
NATURAL GAS	276	195	180	164
OIL	142	163	138	11
NUCLEAR	531	496	474	32
HYDRO	237	322	334	359
SOLAR	1	7	25	177
STORAGE	0	1	2	27
BIOMASS	33	64	97	252
WIND	3	40	76	290
GEOTHERMAL	30	29	47	247
TOTAL ELECTRIC	2851	3005	2707	2621

CLIMATE STABILIZATION CASE ELECTRIC SUPPLY: GENERATION BY FACILITY TYPE

(1000 GWH)

PLANT TYPE	1988	2000	2010	2030
COAL	1598	1503	1021	158
NATURAL GAS	276	204	215	199
ADVANCED FUEL CELL	0	0	0	454
OIL	142	140	158	119
NUCLEAR	531	502	482	30
HYDRO	237	328	343	342
SOLAR	1	11	39	212
STORAGE	0	1	5	38
BIOMASS	33	89	136	293
WIND	3	62	117	333
GEOTHERMAL	30	32	60	275
TOTAL ELECTRIC	2851	2872	2576	2453

improved electricity-conversion efficiency. Finally, the contributions of renewable energy sources increase even further than in the Environmental case, reaching 64 percent of total electricity generation and 73 percent of total electric capacity by 2030.

Chapter 6: Policies for a clean and prosperous America

INTRODUCTION

In this chapter, we outline policies that should be implemented to move the United States toward cleaner and more prosperous future. Some of these policies apply only to one of our scenarios, while others, implemented at different rates or to different degrees, apply to all of them. Many of the policies—such as automobile fuel-economy standards and building codes—are quantitatively linked to the scenarios, but others—such as integrated land-use and transportation planning and increased research and development funding—are not amenable to modeling, and thus their effect could only be estimated. All authors do not necessarily endorse every policy described below. The analysis presented in the preceding chapters, however, clearly demonstrates the economic and environmental benefits of pursuing the set of policies described here.

Our policies reflect three guiding principles that the United States should follow to enhance its environmental and economic well-being. The nation must:

- Harness market forces.
- Make efficiency the standard.
- Invest in the future.

Policies following these guidelines will correct or compensate for widespread and well-documented market barriers that discourage or prevent consumers from making least-cost energy choices.[1] The barriers include subsidies for conventional energy production, lack of information on cost-effective efficiency measures and renewable energy sources, and imperfections in capital markets. They have the effect of creating a "payback gap," which puts consumers in the position of apparently requiring disproportionately high rates of return—as much as 100 percent annually—on their energy-saving investments.[2]

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[1] E. Hirst and M. Brown, "Closing the Efficiency Gap: Barriers to the Efficient Use of Energy," *Resource Conservation and Recycling 3*, 1990, pp. 267-81.

[2] R. Cavanagh, "Least-Cost Planning Imperatives for Electric Utilities and Their Regulators," *Harvard Environmental Law Review 10*, 1986, pp. 299-344; F. Krause and J. Eto, *Least-Cost Utility Planning Handbook for Public Utility Commissioners 2*, 1988; H. Ruderman, M. D. Levine, and J. E. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *The Energy Journal 8*, 1987, pp. 101-24. It is unlikely that consumers actually require paybacks at such high rates; they do, after all, often invest in savings plans that have a real return of less than 5 percent. Instead, observed paybacks are one way to measure the size of the hurdle that market barriers create; that is, they are the discount rates *implicit* in the marketplace. The policies described here would help overcome this gap by incorporating the social discount rate of 3 percent real, discussed in chapter 3. For example,

To overcome the current barriers in energy markets, government must establish correct market incentives, set efficiency standards, and invest in research and development. To be most effective, these approaches must work together. For example, efficiency standards for appliances such as refrigerators, though helpful and easy to administer, should be complemented by incentives that encourage consumers to purchase equipment that is even more efficient than the minimum level set by the standards. Utilities will enthusiastically provide such incentives if regulations are reformed to give the utilities a share in the profits from the energy savings. Likewise, federal and state funding for research and development of generic technologies, such as vacuum-panel insulation, solar-collector elements, and efficient CFC-free refrigerants, can compensate for industry's tendency to underinvestment in these technologies and thus lead to the marketing of even more efficient equipment.[3]

The policies we describe include ones that should be implemented by federal, state, and local governments, as well as by businesses and private citizens. In fact, a number of state and local governments have already implemented, or have begun to consider, policies similar to some of those we describe below. While the state initiatives are laudable, the United States still lacks a coherent national plan for ensuring the implementation of effective policies at every level. Our policy recommendations recognize and address this shortfall. At the end of this chapter, we summarize the policy recommendations for each implementing institution, including the Congress, DOE, EPA, state and local governments, and private business. Interested readers can find more detailed discussions of the policies in the Technical Appendixes.

In general, the policies described below apply to all of our scenarios. The details of their implementation are different for each scenario, however. In the Market scenario, policies are designed to enable energy markets to work better, mainly through more rapid introduction of cost-effective technologies, without explicitly seeking to enhance energy security and reduce environmental damage. The Market scenario policies are therefore appropriate on economic grounds alone, even in the absence of concern about smog, acid rain, global warming, and energy security.

The Environmental scenario seeks to eliminate market imperfections stemming from the fact that energy use entails costs that are not reflected in energy prices and are therefore "external" to the

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building codes that minimize life-cycle costs would be analyzed using a 3-percent discount rate, as would utility least-cost plans (even though revenue requirements would be calculated using the actual cost of capital to utilities, which may be higher).

[3] It is widely recognized that private investments in research and development are discouraged because the benefits are only partially captured by the firms that make them. Technological developments tend to provide benefits to the industry or economy as a whole. Private firms also limit their research and development investments because of the risk of failure and because of the pressure to show near-term profits. M. N. Baily and N. Chakrabarti, "Innovation and US Competitiveness," *The Brookings Review 4* (1), Fall 1985.

market.[4] Raising taxes on gasoline and introducing taxes on pollution (while reducing income or other taxes by a comparable amount) would be the most direct method of incorporating at least some of these externalities into market prices.

Including externalities in energy prices would enhance the economic benefits of other measures embodied in the Environmental scenario, such as efficiency standards, which are based on equating the cost of conserved energy with avoided fuel costs (including, in this case, environmental costs). In fact, most available efficient technologies are cost-effective without considering environmental costs. However, the rate at which these technologies are phased in will most likely depend on the difference between their cost and the avoided cost. Since this difference will appear larger when environmental costs are considered, we assume that efficient technologies are adopted more quickly in the Environmental scenario than in the Market scenario.

Because external costs are not reflected in market transactions, it can be difficult to assign an accurate value to them. However, entirely ignoring such costs, as is now the practice, creates a strong market bias in favor of greater use of polluting fossil fuels. In the Environmental scenario, we chose to quantify those external costs (other than global warming) that appear most significant on a national basis. In particular, we incorporated costs for emissions of air pollutants targeted by the Clean Air Act, that is, volatile organic compounds (VOC), total suspended particulates (TSP), carbon monoxide (CO), nitrogen oxides (NO_X), and sulfur oxides (primarily SO_2). We also included estimated costs associated with oil security and traffic congestion. We did not assign a cost to land and water impacts, although they can be significant on a local and regional scale, particularly for some renewable energy sources such as hydropower, and also for some fossil-fuel activities such as coal mining.[5] Where possible, however, we took into account constraints on land use and siting in our assessments of renewable resources and costs.

In the Climate Stabilization scenario, we did not seek explicitly to minimize societal costs, but rather to meet predetermined CO_2 reduction targets (25-percent reduction by 2005 and at least 50-percent reduction by 2030 from 1988 levels). As it turns out, however, the additional investments required to move from the Environmental scenario to the Climate Stabilization scenario are more than offset by additional savings in fuel costs. The CO_2 reduction goals might be achieved either through an energy tax based on the carbon content of each fuel (in addition to other pollution taxes) or by auctioning tradeable CO_2 emissions permits, as discussed below.

Unfortunately, DOE did not analyze policies needed to achieve similar CO_2 emissions targets when the NES was developed. At a minimum, DOE should analyze scenarios equivalent to the four we

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[4] Externalities can include benefits, often called "public goods," as well as costs. Neighbors enjoy a beneficial externality when someone improves the outdoor appearance of their house, for example. Although there may be a local economic-development benefit from investments in *any* energy activity, these economic changes are not externalities per se, but part of the market effects that any change in economic activity implies. Because these benefits are not external to market operations, there is no misallocation of resources if the particular energy or efficiency investment is not made. See Baumol and Oates, *The Theory of Environmental Policy*, Press Syndicate of the University of Cambridge, UK, 1988.

[5] New York State does consider these additional impacts in its least-cost energy planning process.

have examined and develop policy options to achieve each scenario. The Congress should require DOE to publish this analysis and allow at least 90 days for public comment. Before issuing final policy recommendations, DOE should be required to consider and respond to the comments received.[6]

Although the policies discussed here are comprehensive, they do not encompass all of the avenues that might lead to enhanced efficiency and use of renewable energy sources. In choosing among the options, policymakers must consider factors we have not discussed, such as effects on the distribution of income by class and region. Whatever policies are ultimately selected, however, the goal should be to stimulate maximum use of cost-effective and desirable energy-efficiency and renewable energy measures. Achieving this goal will lead to improvements in productivity, enhance US competitiveness in the international marketplace, improve the country's balance of trade, make homes more affordable, and dramatically reduce the impact of air pollution on all living things.

HARNESSING MARKET FORCES

Two key requirements for achieving our policy objectives are to ensure effective and fair competition between energy supply and efficiency, and to reflect environmental costs in energy prices. Policymakers can meet these requirements in three ways:

- Ensure that investments in efficiency are at least as profitable for utilities as investments in supply.
- Use tax credits, fees, and rebates to provide a market pull for energy efficiency and renewable energy.
- Shift some of the tax burden from income to pollution.

These three approaches are described below.

Ensure That Utility Investments in Efficiency Are as Profitable as Those in Supply

Almost half of the energy used in the United States flows through electric and gas utilities, which are regulated principally by state utility commissions. In most states, the regulatory framework now in place inadvertently rewards utilities when more electricity or gas is sold, thus encouraging utilities to expand energy supplies while discouraging more efficient energy use.[7]

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[6] This process could be modeled on the highly successful program of the Oregon-based Bonneville Power Administration. This program is coordinated through the Northwest Power Planning Council, which prepares regional least-cost power plans every three years in response to federal legislation (the Northwest Power Act of 1980).

[7] D. H. Moskovitz, *Profits and Progress through Least-Cost Planning*, NARUC, Washington, D.C., November, 1989.

All of our policy scenarios depend on eliminating regulatory incentives for increased energy sales. Utility commissions should allow investments in increased supply to compete on an equal footing with investments in increased efficiency. In addition, the commissions should require utilities to develop least-cost plans that reflect the equal standing of those investments, and provide adequate opportunities for public review and comment on the plans before they are adopted.

Finally, utility commissions should ensure that least-cost investments are the most profitable ones for the utilities. They can do this by linking net revenues, or profits, in part to the utilities' verified success in delivering cost-effective efficiency improvements. As with any question about the prudence of an investment by a utility, evidence that the utility is not in reasonable compliance with an approved least-cost plan would be grounds for reducing that utility's allowed rate of return. Regulatory changes such as these are critical to making utilities active partners in building a least-cost energy future.[8]

The federal government also can play an important role in ensuring that utilities invest in efficiency. The Federal Energy Regulatory Commission (FERC), which regulates approvals for long-term power purchases by utilities, should grant approvals only to projects that have been certified as being consistent with a state least-cost plan. If no such plan exists in the utility's home state, the federal commission could require the utility to demonstrate that a lower-cost option does not exist for providing the same energy services. In addition, conservation can be included as a qualifying energy source under the Public Utility Regulatory Policy Act.[9]

Further, Congress should require federal power-marketing authorities, such as the Western Area Power Administration, to give preference in power sales to those utilities implementing least-cost plans. This would ensure that utilities would not squander energy resources that have been developed by taxpayers if less-expensive alternatives are available. If necessary, the federal power authorities should capture such resources through direct demand-side purchases in states that do not require investor-owned utilities to practice least-cost investments. Moreover, the Tennessee Valley Authority should base its energy plans on least-cost principles and implement cost-effective measures in energy efficiency.

Establish Tax Credits for Renewable Energy

Financial incentives are needed to encourage the growth of nascent renewable energy industries, many of which face severe market barriers, including short consumer payback periods and

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[8] The success of this approach is becoming evident in New England. In 1990, the New England Electric System doubled its expenditures on conservation and load-management programs following changes in regulation that gave the utility a profit for efficiency investments that are proven effective. The utility is allowed to recover its costs plus about 10 percent of the net economic savings resulting from these investments. In 1990 this program reduced peak demand by about 116 MW at an average cost of about $600 per kilowatt saved. See A. F. Destribats et al., "Demand-Side Management at New England Electric: Implementation, Evaluation, and Incentives," paper presented at the 3rd National NARUC Conference on Integrated Resource Planning, Santa Fe, April 1991.

[9] Although this law requires utilities to buy cogenerated electricity and other energy sources from small power producers, it does not now define conservation as a qualified energy source.

overpowering competition from established energy industries. From the late 1970s to the mid-1980s, substantial federal and state tax credits for renewable energy investments were available, but most of these have been eliminated, and those that remain must be renewed on an annual basis.[10] New credits are needed to correct for inequities in the tax treatment of renewable energy sources. Other incentives, such as loan banks and loan guarantees, are also needed to make more capital available for renewable energy investments. Concerns about the possibility that these incentives might be abused or misapplied can be met by basing the incentives on performance rather than up-front cost and by relying on federal and state certification of renewable energy systems.

In particular, the federal government should establish a performance-based tax credit of 2.5 cents per kilowatt-hour for electricity produced from renewable sources,[11] and it should establish a similar tax credit of $2 per million Btu for heat supplied from renewable sources to large industrial and commercial users. These credits should be available for a limited time beginning with the start of a project and should gradually be phased out for the industry as a whole as renewable industries mature. The existing 10-percent tax credit for commercial solar investments should be continued as an alternative to the above credits, and a 10-percent residential tax credit should also be established.

Use Market Incentives to Encourage Efficient Technologies

Fees or rebates that reflect the long-term energy costs of equipment are an effective tool for overcoming the payback gap between energy consumers and energy producers. In many states, utilities use this approach to encourage their customers to purchase high-efficiency appliances, lighting, solar water heaters, and other equipment. However, the IRS has unfortunately decided to treat such rebates as taxable income of the rebate recipients. Rather than have the federal government discourage efficiency rebates by taxing them, Congress should prevent the IRS from imposing this efficiency tax.

Utilities, equipment manufacturers, and the federal government should work together to create programs that encourage the development of solar and other innovative or high-efficiency appliances—those that are too advanced to be the basis of standards and too risky to be commercialized without substantial incentives. A number of utilities could jointly establish a large pool of funds that would be the source of awards, sometimes called "golden carrots," to

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[10] The critical importance of tax credits to the success of renewable energy industries was dramatically illustrated by the recent failure of Luz International Corporation, the only company that has successfully developed and sold large-scale solar-thermal power plants. Because the Luz investors were required to pay much higher taxes than investors in conventional power plants of a similar size, they demanded assurance of the continued availability of the existing 10-percent federal solar investment tax credit. When the Congress extended this tax credit for only seven months this year, and when California's governor failed to sign into law a property-tax exemption that would have reduced Luz's tax burden, Luz investors were forced to withdraw funding for the 10th Solar-Electric Generating System, and the company went bankrupt.

[11] This proposal was originally included in a draft of the NES but was later dropped. The amount of the tax credit was chosen to reflect the unequal tax treatment of capital investments and fuel expenditures under existing tax laws.

manufacturers of qualifying products; the funds could also be the source of rebates to purchasers of any such product sold during a specified period. For example, a rebate of several hundred dollars might be offered for each refrigerator sold from 1993 through 1997, if the refrigerator is both CFC-free and 30-percent more efficient than the applicable federal standard.

This proposal involves little risk for the utilities, because their investment will be small unless many units meeting the criteria are actually sold (in which case, they will have reduced costs of new plants). At the same time, the risk to manufacturers is low because the golden carrot program fosters an initial market if the product is successfully developed. In fact, organizations such as the American Council for an Energy-Efficient Economy, the Bonneville Power Administration, EPA, the Natural Resources Defense Council, and the Pacific Gas & Electric Company have joined together to promote this concept for refrigerators. DOE should also support the development and promotion of such programs in a variety of areas, including residential appliances, heating and cooling systems, lighting products, and building components.

Automobile efficiency can also be effectively promoted through point-of-sale price incentives designed to stimulate consumer demand for cleaner and more efficient vehicles. The gas-guzzler tax is an established mechanism that has been constructive in raising the fuel economy of low-mpg cars, particularly since 1983.[12] Vehicle purchase incentives could be expanded from a fee on the least-efficient vehicles to a fee-and-rebate, or "feebate," system that is linked to the efficiency of a model relative to the average fuel economy of the new vehicle fleet.

A national feebate program would complement increases in Corporate Average Fuel Economy (CAFE) standards, because it would increase the market demand for efficient cars, and because it would immediately reward the adoption of new efficiency technologies through a larger rebate. Variations on the feebate concept include incentives linked only to fuel economy, vehicle size, or CO_2 emissions, as well as systems that would combine indices of fuel economy, emissions of traditional pollutants, and safety. In addition, the federal government should institute a golden carrot program designed to encourage the introduction of super-efficient vehicles meeting specified size, safety, and performance criteria.[13]

The California legislature has examined such a mechanism, known as "Demand-based Reductions in Vehicle Emissions, Plus improvements in fuel economy," or DRIVE+, that is designed to encourage the purchase of cars that are not only more efficient but also less polluting.[14] DRIVE+ would increase the sales tax on vehicles having higher-than-average emissions and fuel use, and would decrease the sales tax on vehicles below those averages. DRIVE+ would not affect tax

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[12] M. Ledbetter and M. Ross, "Light Vehicles: Policies for Reducing Their Energy Use and Environmental Impacts," in J. Byrne and D. Rich, eds., *Energy and Environment 6*, Transaction Books, 1991.

[13] J. DeCicco, *The Advanced Automotive Development Challenge*, ACEEE, Washington, D.C., March 1991.

[14] L. Levenson and D. Gordon, "DRIVE+: Promoting Clean and Fuel-Efficient Motor Vehicles Through a Self-Financing System of Sales Tax Incentives," *Journal of Political Analysis and Management 9* (3), Summer 1990, pp. 409-15.

revenues, because the fees would fund the rebates, and both fees and rebates would be adjusted over time as more-efficient and less-polluting vehicles are sold.

The costs incurred by automobile drivers should more accurately reflect the full cost of automobile use. In particular, insurance rates do not incorporate the distance a vehicle is driven, even though accident rates do.[15] Thus for the sake of fairness, as well as to discourage unnecessary driving, insurance companies could institute "pay-as-you-drive" (PAYD) insurance, in which part of the premium would be a function of the distance driven. The distance-variable portion of a car-owner's premiums could be either collected at the gas pump or through insurance payments based on odometer readings; analysis of the variable costs (based on California insurance rates) suggest that an appropriate premium might be about $1 per gallon. Although the overall cost of insurance should stay the same or go down, PAYD premiums would cause a significant decrease in the total miles driven because they would increase the marginal cost of driving.

Drivers usually do not pay the full cost of road use either—an additional imperfection in the market that results in unnecessary driving. Governments could correct the problem by eliminating tax exemptions for employer-subsidized spaces at commercial parking lots and increasing the use of highway tolls.[16] In addition, governments should increase the limit on the tax-exempt value of transit passes that employers provide. Employers should provide additional incentives to discourage single-occupant commuting, such as organizing car and van pools and providing good parking facilities for vehicles used in such pools.

Shift Some of the Tax Burden from Income to Pollution

To move the United States beyond the Market scenario and toward an energy policy that reflects the total cost of providing energy services to society, we could attempt to quantify all of the environmental and national security costs of each fuel, and then reflect them in investment choices. If the federal government assigned new fees to fossil-fuel consumption, and based the fees on the quantity of pollution emitted or energy used, consumers would begin paying more of the environmental and national security costs of fossil-fuel use, and thus would have less incentive to waste. At the same time, some of the federal tax burden could be shifted from productive activities—now taxed in the form of payroll-deduction and capital-gains taxes—to polluting activities, thus benefiting both the economy and the environment.

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[15] M. El-Gasseir, "The Potential Benefits of Pay-As-You-Drive Automobile Insurance." Testimony before the California Energy Commission, Docket 89-CR-90, 1990.

[16] A newer type of highway toll is known as "highway metering."

Currently, the US tax burden is borne principally by personal income taxes and payroll taxes.[17] Those taxes have the effect of making labor relatively more expensive than energy and other natural resources, resulting in a distortion of economic choices that discourages employment and investment. It is estimated that those distortions reduce gross national product by several percent, or a few hundred billion dollars per year.[18]

A shift in the tax burden towards pollution is embodied in our Environmental and Climate Stabilization scenarios. The national security risks of burning oil could be incorporated with a fee on imported and domestic oil of $2.50 per barrel (6 cents per gallon). A tax of 44 cents per gallon of gasoline would reflect both the environmental cost of driving and the other costs that come with having an increasing number of cars on our roads.[19] Even with a tax increase of 50 cents per gallon, US gasoline taxes would remain very modest compared to those of other OECD countries, most of which have gasoline taxes of at least $2 per gallon. Revenues from the proposed taxes on oil and gasoline would total about $70 billion per year.

Large stationary sources of air emissions from the burning of fossil fuels, such as industrial and utility plants, could be taxed for the pollution they emit as determined by monitoring actual emissions of CO, HC, TSP, NO_X, and SO_2 from sources over a given size (see table on next page).[20] The taxes (in dollars per ton emitted) could be determined by a number of different methods; our values are based on marginal emissions control costs and were derived through independent analysis by the Tellus Institute. Total revenues from such taxes would be almost $150 billion per year at current levels of consumption and emissions. (The effects on fossil-fuel demand and emissions resulting from the 1990 amendments to the Clean Air Act, as well as from the

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[17] This share has increased dramatically over the last 50 years:

	Percentage of total tax	
	1941	1991
Federal revenue source		
Individual income tax	15.1	45.1
Corporate income tax	24.4	8.8
Social insurance taxes	22.3	36.8
Excise taxes	29.3	4.1
Other taxes	9.0	5.1

Source: *Washington Post*, April 7, 1991, based on the president's proposed FY 1992 budget.

[18] R. Dower and R. Repetto, "Use of the Federal Tax System to Improve the Environment," Testimony before the Committee on Ways and Means, US House of Representatives, March 6, 1990.

[19] This figure is based on emission levels for cars meeting the future standards established by the 1990 Clean Air Act Amendments plus national security costs. A much higher tax could be justified based on the pollutant emissions from the current fleet.

[20] Many of the pollutants are already subject to controls, but some sources are exempt. In general, taxes on controlled emissions are appropriate if the remaining emissions following pollution controls still have significant environmental impacts.

recommended taxes, did not figure into this calculation.) This amount could displace more than half of the current revenue from payroll (social security plus unemployment insurance) taxes.

To help achieve the targets for CO_2 reduction set in the Climate Stabilization scenario, coal, oil, and gas could be taxed in proportion to the carbon content of each fuel. The taxes would be collected most easily at the point where a fuel first enters the economy—at the mine mouth, wellhead, or shipping port. A tax of $25 per ton of CO_2, equivalent to $92 per ton of carbon, in conjunction with the other policies recommended here, appears to be of the right magnitude for achieving the targets specified in this scenario.[21] This value would translate into a tax ranging from about $1.50 per million Btu for gas to about $2.60 per million Btu for coal (nonfossil fuels would pay no tax). It would raise approximately an additional $140 billion per year, assuming continuation of current levels of fossil-fuel use. Combined with other pollution taxes, total revenues would be about equal to current payroll tax revenues.

Stationary Source Emissions and Taxes

	Emissions (1988) (million tons)		Tax (1990$/ton)	Revenue (billion 1990$)		
	Industry	Utility		Industry	Utility	Total
CO	0.48		900	0.4		0.4
HC	0.14		3000	0.4		0.4
NO_X	2.4	7.1	6400	15.2	45.5	60.7
SO_2	2.2	17.6	880	1.9	15.5	17.4
TSP	0.30		2300	0.7		0.7
Total				**18.6**	**61.0**	**79.6**

Source: Tellus Institute; see the Technical Appendixes.

The competitive position of most industries would not be significantly affected by this tax shift, because energy is a relatively small fraction of the cost of production for most firms, and because increased energy costs would be at least partially offset by lower taxes. The international competitiveness of energy-intensive industries in the United States can be protected if the federal government provides rebates on exports, and taxes imports, of fuels and energy-intensive goods. This practice is permissible under both the General Agreement on Tariffs and Trade, and the Canadian Free Trade Agreement, as long as the import duty accurately reflects the domestic tax. The federal tax recently enacted on CFCs provides a precedent for this approach. The commodities subject to the rebates and taxes might include electricity, steel, iron, copper, aluminum, cement, fertilizer, plastics, bulk chemicals, and perhaps automobiles. The IRS could add additional commodities as necessary.

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[21] Nevada and Massachusetts have adopted a value of $22 per ton of CO_2 for least-cost utility planning.

An alternative to the CO_2 tax mentioned above is for the federal government to auction CO_2 emissions permits. The number of permits offered for sale each year would be equivalent to the target emissions levels for that year. Permits could be valid for a limited time, such as five years, and once they were auctioned, a secondary market would allow free trading. Permits could be required at the same point that CO_2 taxes would be collected. The CO_2 tax and marketable permi approaches are in theory equally efficient at reducing emissions. If the federal government specifies a fixed CO_2 tax, however, there is uncertainty about the quantity of CO_2 that will actually be emitted, whereas if the federal government fixes the number of permits to be offered, the CO_2 targets can be enforced but uncertainty remains about the price of the permits and resultant revenues. In addition, the permit approach does not necessarily encourage overall reductions in emissions below the target levels.

In some cases, the cost of pollution can be reflected in investment choices without a direct tax. Because electric utilities are regulated, regulators can require the utilities to employ least-cost planning methods that reflect the environmental costs of each power source. Regulatory commissions in California, Massachusetts, Nevada, New York, and elsewhere already use this approach. In those cases, however, the approach applies only to decisions affecting new generatin capacity, not the order in which generating units are deployed ("dispatch"). Environmentally sound dispatch could be required to influence these choices, but simply imposing the tax on all emissions would probably be more straightforward. With appropriate incentives, then, the decisions of utilities and industrial firms would tend to support an Environmental or Climate Stabilization energy strategy. The federal government should encourage the gradual extension of the exemplary practices currently used by a number of states in order to achieve a more uniform treatment of all emissions.

For market forces to be most effective, utility customers should also receive appropriate price signals through electricity and gas rates that reflect the marginal cost of new supplies, including environmental costs. This goal can be accomplished without affecting total utility revenues by replacing declining block rates with rates that reflect the marginal costs to society for the highest usage block.

MAKING EFFICIENCY THE STANDARD

An enormous reservoir of energy savings exists in the United States, according to our analysis and numerous other studies, including ones by DOE's national laboratories, the National Academy of Sciences, the Congressional Office of Technology Assessment, and other public and private institutions.[22] Efficiency standards can be extremely effective in exploiting this potential by compensating for information costs and other market barriers that inhibit investments that

[22] R. Carlsmith, W. Chandler, J. McMahon, and D. Santini, *Energy Efficiency: How Far Can We Go?* Oak Ridge National Laboratory, Oak Ridge, TN, 1990; National Academy of Sciences, *Policy Implications of Greenhouse Warming*, National Academy Press, Washington, D.C., 1991; Office of Technology Assessment, US Congress, "Changing by Degrees: Steps to Reduce Greenhouse Gases," US Government Printing Office, Washington, D.C., 1991; A. Lovins and H. Lovins, "Least Cost Climate Stabilization," in *Annual Review of Energy*, 1991; EPRI, "Efficient Electricity Use"; New York State Energy Research and Development Authority, *The Potential for Electricity Conservation in New York State*, Energy Authority Report 89-12, Albany, NY, 1989.

minimize life-cycle costs.[23] State, federal, and local governments also can dramatically improve their own energy management and procurement activities, which would save billions of taxpayer dollars and accelerate the introduction of more efficient technologies.

Increase Automobile Fuel-Economy Standards

First enacted by Congress in 1975, the CAFE standards have been the principal force behind a 75-percent increase in on-road automobile efficiency since 1973.[24] Although the energy crises of 1973 and 1979 provided temporary spurs to greater fuel efficiency, CAFE standards have provided the steady pressure that US automakers needed to consistently bring existing efficiency technologies into the market and to develop innovative technologies for the future. Today's car gets twice the mileage and produces one-tenth the pollution as did a car of the same size in 1973. In addition, today's car is safer.

An increase in CAFE standards is now long overdue. The existing standards reached their maximum required level—27.5 miles per gallon—in 1985, and the average efficiency of new cars sold in the United States has been falling since 1988.[25] Large improvements in efficiency are still possible (see chapter 3). Nevertheless, without increased CAFE standards, the low cost of today's oil and the relatively small share that fuel plays in the total cost of owning and operating a vehicle will drive automakers to continue to market power, performance, and other features, rather than promote more-efficient vehicles. More stringent standards must also be applied to light trucks and minivans, which now capture a large share of the automobile market and which have significant potential for improved fuel economy.

In the Market scenario, we assumed CAFE standards of 40 mpg in 2000 and 50 mpg in 2010. Standards at this level would save 2.5 million barrels of oil per day (mbd) in 2005 compared to today's level of fuel efficiency. In the Environmental scenario, we assumed CAFE standards of 43 mpg in 2000 and 54 mpg in 2010. Those standards would lead to oil savings in 2005 of 2.8 mbd compared to today's level of efficiency.

The EPA should complement higher CAFE standards by updating the system it uses to rate fuel economy. Because of increased congestion, vehicle speeds, and urban travel, the actual on-road

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[23] There are two reasons why performance standards can make good economic sense. The "transaction costs" associated with acquiring information on efficiency opportunities can be sufficiently high that it is not worthwhile for an *individual* consumer to collect and digest this information on his or her own. In this case, performance standards can be in the consumer's best *economic* interest. While such standards may result in a small number of consumers buying somewhat more efficiency than is optimal, most consumers will come out ahead. In other cases, standards may overcome regulatory or institutional constraints on the availability of efficient products.

[24] D. L. Greene, "Energy Efficiency Improvement Potential of Commercial Aircraft to 2010."

[25] Although some manufacturers did not achieve the standard in 1985, penalties were essentially eliminated when the Reagan administration lowered the standard between 1986 and 1989. By exceeding this reduced standard, manufacturers earned credits that they could use against previous violations.

fuel economy of vehicles has dropped markedly below their EPA-rated fuel economy (the combined 55-percent urban, 45-percent highway mpg index). DOE researchers have estimated that the gap between ratings and on-road performance was 15 percent in 1987 and have projected that it will grow to 30 percent by 2010 if present trends continue.[26] A rating system that more accurately reflects actual driving conditions is needed to encourage manufacturers to optimize their designs for those conditions.

The EPA ought to craft CAFE standards in such a way that they encourage the use of more environmentally benign fuels. This is best accomplished by considering not only the pollution caused by driving the vehicle, but the pollution caused by the extraction, production, and distribution of each fuel as well. This accounting for pollution on the basis of the entire fuel cycle is vital; without it, an electric or alternative-fueled vehicle could receive unjustifiably high fuel-economy ratings, even if the total pollution it was responsible for was greater than that caused by a conventionally powered vehicle. We recommend that fuel-economy ratings take into account the complete fuel cycle of each car and be determined on the basis of CO_2 emissions per mile.[27]

Set Building and Equipment Efficiency Standards to Minimize Life-Cycle Costs

The introduction of new, minimum-performance standards for buildings (both for new construction and for retrofits of existing structures), appliances, lighting products, and other energy-using equipment could realize large gains in efficiency with modest administrative costs. The Department of Energy and state agencies should set such standards, and once set, they should be updated regularly.

By requiring building codes to embody the highest levels of energy efficiency that are cost-effective, governments can assure that new buildings will use energy substantially more efficiently than is typically the case now. Promulgating such codes can lead to marked economic benefits, because new buildings may last for 50 to 100 years, and the cost of retrofitting buildings is much higher than the cost of building to proper standards. Although building codes are adopted and enforced by state and local governments, current law requires DOE to adopt a model energy code for the entire country. The code is mandatory for federally owned buildings but voluntary for the private sector. The federal government should update and strengthen the model code, and require states and localities to adopt codes that meet or exceed the efficiency of the national model. In addition, Congress should require that federally financed or subsidized buildings meet the standards of the model code.

Approximately 200,000 mobile homes are built each year, and they are not subject to state or local building codes. They are under the exclusive authority of the federal government, whose current standards for energy efficiency fall woefully short of the cost-effective potential in this segment of the buildings sector. The federal government should move swiftly to tighten standards for mobile homes because these homes tend to be occupied by low-income residents who can least afford the

[26] F. Westbrook and P. Patterson, "Changing Driving Patterns and Their Effect on Fuel Economy," presented at the 1989 SAE government/industry meeting, May 1989.

[27] The California Energy Commission has developed a straightforward methodology for estimating fuel-cycle emissions. See California Energy Commission (CEC), *1988 Inventory of California Greenhouse Gas Emissions*, CEC, Sacramento, Calif., 1990.

painful impact of high energy bills, and because the construction of most mobile homes limits retrofit opportunities.

Federal and state governments should also enact standards that will upgrade the efficiency of the existing stock of almost 100 million buildings, most of which offer substantial opportunities to save energy more cheaply than local utilities can produce it. Although state and federal weatherization programs have set standards for individual retrofit products, such as caulking and weatherstripping, those standards are not widely disseminated and do not apply to retrofits undertaken privately. Beyond the energy savings for individual products, however, are the benefits stemming from the use of retrofit products in cost-effective combinations. Only recently have weatherization programs begun to move from check-list type retrofits to analyses of the cost-effectiveness of weatherization packages. One field study demonstrated that an optimized combination of retrofit options resulted in an increase of more than 50 percent in energy savings per dollar spent.[28] Federal and state agencies should ensure that all weatherization programs use the most cost-effective combination of measures.

The federal government should also develop model retrofit standards that must be met as a condition of building sale, lease, and renovation. States and municipalities should adopt those retrofit standards, sometimes called energy-conservation ordinances. Such standards are required already as a condition of sale in several counties and cities (e.g., San Francisco, California, and Ithaca, New York). The cost of the retrofit, if one is needed, is then included in the sales price. This will not disqualify potential buyers if the purchase is financed according to the terms of an energy-efficient mortgage.[29]

In addition to promoting energy efficiency, building codes and retrofit standards should be flexible enough to allow the use of solar measures, such as daylighting, active and passive space heating and cooling, and water heating, to meet efficiency targets. Too often, states require builders to follow a set of "cookbook" conservation measures, with the result that many cost-effective and esthetically pleasing solar measures may be overlooked.

Already-adopted federal appliance standards will reduce the demand for electricity by tens of thousands of megawatts and save billions of dollars.[30] Those savings are being reaped with minimal administrative and enforcement costs[31] and with minimal disruption to industry. DOE is required

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[28] M. Hopkins, *Energy Use in Federal Facilities*, Alliance to Save Energy, Washington, D.C., 1991.

[29] Energy-efficient mortgages allow home buyers to obtain a larger loan than they would otherwise qualify for, by taking into account the lower energy expenses of an efficient home. Mortgage companies are required by federal law to provide energy-efficient mortgages, but currently procedures differ among underwriters, and most home buyers are not made aware of this option.

[30] J. McMahon et al., "Impacts of US Appliance Energy Performance Standards on Consumers, Manufacturers, Electric Utilities, and the Environment," *Proc. of ACEEE 1990 Summer Study on Energy*, ACEEE, Washington, D.C., 1990.

[31] DOE's appliance standards budget is less than $3 million per year, compared to program benefits of several billion dollars a year.

to set efficiency standards at the maximum level that is technologically feasible and economically justified. Future revisions promise substantially more savings if DOE fully implements the directives of existing laws. Furthermore, while current appliance standards apply to 13 products used in the residential sector, creating standards for other household products and many commercial and industrial products could provide enormous additional savings.

Federal efficiency standards should be extended to additional products, including lamps, motors, light fixtures, showerheads, commercial cooling and heating equipment, distribution transformers, and office equipment. For products such as lamps, motors, and showerheads, information is already available to set initial standard levels. Products such as light fixtures and office equipment, however, will first require the development of both the necessary database and the test procedures for setting standards. If the federal government fails to adopt standards for these products in a timely manner, states can and should adopt standards, both for their own benefit and to prompt federal action.[32] Governments should also adopt recycling requirements, both to reduce waste-disposal costs and to save the energy required to manufacture products from virgin materials.

Require Effective Energy Management at the Federal Level

Government agencies are major consumers of building and transportation services. In fact, the federal government is the nation's largest energy consumer, each year spending $8.7 billion in its own facilities, and another $3.9 billion in subsidies of the energy expenses of low-income households.[33] Conservative estimates show that the federal government could reduce fuel costs by more than $850 million a year in its own buildings by making cost-effective efficiency improvements.[34] Federal and state governments should invest in cost-effective efficiency and renewable energy measures, not only to save taxpayers' money but also to stimulate the market for state-of-the-art products.

Procurement practices and year-to-year budgeting tend to discourage investments in efficiency and renewable energy. Although an executive order of April 1991 called for a 20-percent reduction in energy use per square foot of floor area in federal buildings by 2000, no funds have been provided to help agencies achieve this goal. Congress should establish a revolving fund of at least $500 million, to be administered by DOE, to provide federal agencies with the means of financing cost-effective efficiency and renewable energy investments. Alternatively, each agency should contribute to the fund in proportion to its energy expenditures. The Department of Energy could provide technical support and screen projects. Procurement practices should also encourage use of utility rebates and shared-savings programs of energy service companies. Finally, government employees must be better trained in energy management and motivated to seek out maximum

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[32] S. Nadel and H. Geller, *Efficiency Standards for Lamps, Motors, Commercial HVAC Equipment, and Showerheads: Recommendations for State Action*, ACEEE, Washington, D.C., 1991.

[33] Office of Technology Assessment (OTA), US Congress, *Energy Efficiency in the Federal Government: Government by Good Example?* US Government Printing Office, Washington, D.C., 1991.

[34] OTA, *Energy Efficiency in the Federal Government: Government by Good Example?*; Hopkins, *Energy Use in Federal Facilities*.

energy-savings opportunities. High-quality training programs, design contests, and performance awards can create the needed momentum.

Government demand for solar products, such as hot water and active cooling systems, could stimulate growth of the solar industry and lead directly to cost reductions and performance improvements. The use of solar design principles in new government buildings could likewise serve as a training ground for a new generation of architects and construction engineers.

INVESTING IN THE FUTURE

Investments in research and development, infrastructure, and education are essential to prepare the United States for the 21st century. Existing allocations of funds must be reoriented, an efficient transportation network must be developed, and expertise in energy efficiency and renewable energy technology must be expanded. In addition, workers displaced by declining employment in the fossil-fuel industries must also be retrained.[35]

Provide Adequate Support for Energy-Efficiency and Renewable Energy Research and Development

Scarce research and development (R&D) funds should be allocated to various technologies according to their potential to provide least-cost energy services. Although the logic of that priority would seem to be self-evident, the focus of present and past funding for energy R&D has been nuclear and fossil energy supplies. Although DOE requested an R&D budget for civilian energy in FY 1992 of about $3 billion, only 8 percent of that amount was allocated to energy efficiency, and only 7 percent of it to renewable energy. The difference between the R&D funds that go to energy-supply projects and those that go to energy-efficiency projects is startling—nearly 20 times more for energy supply between 1973 and 1987.[36] This inequity is particularly perverse since the conventional "supply" industries (fossil-fuel and nuclear) are large, mature, and well-financed, while the renewable and efficiency industries are much younger and have far fewer resources with which to develop their potential.

Implementing a least-cost energy strategy requires a reversal of current R&D priorities. Energy efficiency is by far our largest and least expensive energy resource. In addition, the fragmented nature of the energy-efficiency industry means that private investment is unlikely to make up for lack of federal support. Renewable energy sources already provide more energy than nuclear power and, with increased and sustained support, could become the dominant source of new energy production in the 21st century.

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[35] Employment in these industries is already declining, mainly because of automation. This trend would be accelerated in our Environmental and Climate Stabilization scenarios, as fossil-fuel consumption would decline substantially in those cases. Worker retraining would be needed to offset these employment losses.

[36] F. Sissine, *DOE Energy Conservation Budget Trends: A Review with Comparisons to other DOE Programs*, Congressional Research Service, Washington, D.C., 1987, p. 15.

We suggest that the share of DOE's budget for research and development in civilian energy that is devoted to energy efficiency and renewable energy be increased from its current level of 15 percent to 67 percent during the next decade. This implies annual increases of about $150 million to an eventual level of about $2 billion per year in 1990 dollars, assuming a constant R&D budget. The technological gains from this level of R&D investment can make the United States a world leader in supplying energy-efficient vehicles, appliances, and production processes, as well as renewable energy technologies such as wind turbines, advanced biofuels, and solar collectors.

The results of R&D efforts will blossom into economic benefits only if they are commercialized. To that end, DOE should engage in more cost-shared joint ventures with private companies that develop advanced energy-efficiency and renewable energy technologies. In particular, DOE should establish joint R&D centers with industrial consortia, and conduct basic and applied research on energy-intensive industrial processes, such as membrane separation techniques, chemical processing in a molten bath, metal casting and forging, fuel refining, and paper making.

Develop an Integrated and Diversified Transportation Network

In contrast to the rapidly increasing reliance on personal vehicles and trucks in the Reference case our alternative scenarios are based on infrastructure investments that provide a wider range of transportation choices and that encourage the use of the most cost-effective combination of transportation modes.

In order to reduce vehicle miles traveled and increase transit ridership to the levels called for in the Market, Environmental, and Climate Stabilization scenarios, policymakers must implement zoning reforms and programs that increase vehicle occupancy, and invest in improved transit systems. Those measures will be most effective if they are instituted in combination with the market-based measures discussed above, in which automobile users pay the full cost of driving. Zoning changes can increase the effectiveness of transit service and reduce the need to drive, by discouraging sprawl and encouraging in-fill development in cities and other developed areas. High-occupancy vehicle lanes and ridesharing programs increase both the number of passengers in personal vehicles and the peak passenger-carrying capacity of existing highways. In most cases where new transportation infrastructure is needed, mass transit has a lower cost per peak passenger-mile than highways,[37] and so should be more actively pursued as a transportation option. If federal and state governments allocated transportation funds according to a least-cost approach, rail and bus transit projects would receive substantial increases in support, while overall spending for new transportation infrastructure could actually decrease.

These investments in infrastructure and changes in land use would increase the use of high-quality mass transit, while reducing the distance required for typical activities. Experience with urban transportation systems shows that increasing the density of development leads to marked reductions in vehicle miles traveled. In Toronto, for example, zoning changes favoring denser,

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[37] D. Goldstein, "Energy and Capital Cost Savings from New Rail Transit Systems: An Illustration of Least Cost Methods for the Transportation Sector," Natural Resources Defense Council, San Francisco, Calif., 1988; D. Goldstein, J. Holtzclaw, and W. Davis, "Efficient Cars in Efficient Cities," NRDC/Sierra Club Testimony for Conservation Report Hearing on Transportation Issues, Docket No. 89-CR-90, California Energy Commission, Sacramento, Calif., April 23, 1990, revised April 2, 1991; Technical Appendixes.

mixed-use development in transit corridors have reduced the city's vehicle miles traveled per capita to a value 50 percent less than that of comparable US cities; Toronto achieved that reduction even as it preserved open public space in the city. Similarly, urban-development policies in Oregon are saving energy and protecting parks and farmlands while reducing the costs of building utility lines and roads.

Federal and state governments should facilitate the standardization of computer tracking systems and terminals, or hubs, where people and freight can transfer from one transportation mode to another. Such action holds great promise not only for reducing energy consumption but also for improving the quality of passenger and freight transportation. Freight transport by integrated rail-and-truck systems allows hauls of more than several hundred miles to be accomplished by rail, and shorter journeys by truck, thus reducing the energy needed for shipment. Air to high-speed-rail links could greatly reduce short-haul air traffic for passengers during peak hours and for freight at other times.

Making our transportation systems less hostile to pedestrians and bicyclists, as well as improving their access to mass transit systems, can reduce automobile traffic in city centers and in the vicinity of suburban train stations. The federal government should support the development of advanced telecommunications to allow substitution of the electronic transmission of information for the physical transportation of people and paper. For example, federal standards for electronic-mail and computer-system interconnections would make computer communication as straightforward as phone calls. The federal government should also lead the way in educating businesspeople about the possibilities of telecommuting programs.

Federal and state governments must also take steps to ensure a diversity of fuel supply for the future transportation system. In our analysis we found no clear "winners" or "losers" among the potential alternatives to conventional transportation fuels. Rather, it appears that several alternatives, including natural gas, electricity, biomass-derived alcohol fuels, and hydrogen, could play a significant role. To encourage the wider use of alternative fuels, federal and state government fleet vehicles should be required to use them where justified on the basis of life-cycle costs (including environmental and security costs). In addition, research, development, and demonstration programs should be instituted or expanded to make such fuels more widely available and bring down their cost.

Expand Education, Training, and Certification Programs in Energy Efficiency and Renewable Energy

The goals of our policy scenarios will be very difficult, if not impossible, to attain, unless qualified people are available for such tasks as designing national programs and inspecting construction projects for compliance with energy-efficient building codes. A commitment to any one of our scenarios requires that federal and state governments, in conjunction with the private sector, expand their support for educational and training programs (including degree-granting graduate programs) in industrial efficiency, energy-efficient architecture and design, demand-side utility management, and renewable energy utilization.

Businesses and private consumers would benefit from information and technical assistance on renewable energy technologies, which are unfamiliar to most people. Among the programs needed are improved design manuals and computer tools for architects and builders dealing with solar building design; new analytical and conceptual tools to help utilities better assess the value of dispersed renewable energy sources in a traditional, highly centralized utility setting; and a comprehensive system of performance standards and certification procedures to give potential users of renewable energy confidence that the products they buy will indeed work as advertised.

Public information and technology-transfer programs are also essential if our Market, Environmental, or Climate Stabilization scenarios are to be realized. DOE already provides an example of this sort of program in its industrial audit and diagnostic centers, which provide energy audits and efficiency information on request. University engineering departments operate these centers, which have proved enormously successful at getting cost-effective efficiency measures installed in small firms and businesses, where in-house energy expertise is often in short supply. Unfortunately, only a few such centers are in operation. To better reach the firms that need this information, state and federal governments should expand these programs. If the work of the centers were to be coordinated with training and certification programs for industrial energy officials, the efficiency innovations of individual companies could become widely available to firms around the country.

POLICIES ACCORDING TO IMPLEMENTING AGENCY

This section provides a list of the individual measures discussed in the Technical Appendixes and organizes the measures by the most significant actor. In many cases, more than one actor is involved—for example, Congress passes legislation and DOE implements it. Generally, initiatives requiring congressional authorization or for which a congressional mandate appears to be necessary are listed under the Congress heading; actions that agencies can take under existing authority are listed under the relevant heading.

US Congress

Harnessing Market Forces

- Mandate that the federal power supply and distribution agencies, such as the Tennessee Valley Authority and the Western Area Power Administration, conduct least-cost planning and give a preference in power sales to those purchasing utilities that do the same.
- Establish regional planning councils following the example of the Northwest Power Planning Council.
- Prevent the IRS from taxing utility rebates and other incentives as income to customers.
- Shift the tax burden from payroll, income, or corporate taxes to pollution by raising energy taxes and emission fees, including a phased-in tax of $25 per ton of CO_2 emitted and a gasoline tax of 50 cents per gallon.
- Establish a revenue-neutral system of gas-guzzler fees and gas-sipper rebates.
- Raise the tax-exempt limit on employer-provided transit passes and restrict tax-free employer-provided parking.

- Lift the size cap under the Public Utilities Regulatory Policy Act for qualifying facilities using renewable resources.

- Establish tax credits of 2.5 cents per kWh and $2 per MMBtu for utility, industry, and large-scale commercial investments in renewable energy, to be available for a limited period and phased out as industries mature. Companies able to take advantage of the existing 10-percent tax credit for solar business investments should be allowed to continue to do so for a limited time.

- Establish a 10-percent tax credit for residential solar investments; credits should be conditioned on projects' meeting minimum federal standards of performance and cost.

- Establish federal loan guarantee programs and other similar mechanisms to help finance renewable energy investments by businesses and homeowners.

Making Efficiency the Standard

- Establish new CAFE standards to increase car and light-truck efficiency by at least 40 percent by the year 2000.

- Set minimum efficiency standards for lamps, motors, HVAC equipment, and distribution transformers, and expand DOE's mandate to set efficiency standards for other end-use equipment.

- Require that states adopt the Model Energy Code or an equally stringent alternative as part of state building codes.

- Require energy-efficiency labeling for all new and existing buildings.

- Prohibit the use of federally subsidized or guaranteed mortgages for homes that fail to meet energy-efficiency standards.

- Expand the federal weatherization program to provide additional funding for appliances, lighting, and air-conditioning systems.

- Establish content standards for recycled materials, including 60-percent for newsprint and aluminum by 1997, in the Resource Conservation and Recovery Act.

- Establish a revolving fund of at least $500 million to finance energy-efficiency projects in federal buildings.

Investing in the Future

- Reorient DOE's research and development priorities by devoting two-thirds of energy research and development funds to efficiency and renewable energy technology.

- Redirect funding for the Surface Transportation Act from highways to mass transit, intercity rail, and intermodal infrastructure.

- Require that DOE develop a least-cost plan for meeting CO_2 emissions reduction targets and guarantee public participation in the process.

Department of Energy

Harnessing Market Forces

- Adopt FERC regulations to require least-cost plans as a condition for regulatory approval of wholesale electricity purchases.

- Assist in the development and promotion of national incentive, or golden carrot, programs for utility companies, appliance manufacturers, and auto makers.

- Conduct design competitions with substantial cash awards for vehicles and buildings that meet specified efficiency and performance criteria.

Making Efficiency the Standard

- Develop model building codes for residential and commercial buildings; base the codes on minimum life-cycle cost; encourage states to adopt and enforce the codes through financial and technical assistance; and update and revise the codes every three to five years.

- Develop and disseminate model standards for retrofit programs that are aimed at residential and commercial buildings; base the standards on minimum life-cycle cost; and update and revise the standards every three to five years.

- Set minimum efficiency standards for energy-hungry equipment as mandated by Congress; update the standards every three to five years.

- Ensure that all federal agencies rapidly improve their energy efficiency by providing technical assistance, developing model shared-savings contracts with energy service companies, and awarding performance incentives to building managers based on energy savings achieved.

- Establish energy-use reporting requirements and voluntary energy-efficiency targets for industry.

Investing in the Future

- Establish energy-efficiency training and certification programs for contractors, building-code officials, and industrial energy managers; require certification for contractors working on federally supported projects.

- Establish public-private industrial R&D centers.

- Greatly expand consumer education and technical assistance programs in renewable energy, and establish a comprehensive testing and certification program.

- Reorient the renewable energy R&D programs to place greater emphasis on technology transfer and cost-shared development and demonstration projects.

Department of Housing and Urban Development

Harnessing Market Forces

- Permit certified solar investments to be financed through Federal Housing Administration-approved mortgages.

Making Efficiency the Standard

- Adopt and enforce national building codes for all publicly owned residential housing; base the codes on minimum life-cycle cost; and update the codes every three to five years.

- Adopt and enforce national building codes for mobile homes; base the codes on minimum life-cycle cost; and update the codes every three to five years.

General Services Administration

Making Efficiency the Standard

- Require all buildings owned or occupied by federal agencies to comply with efficiency provisions in model building codes.

- Require that light vehicles purchased for the federal fleet exceed the applicable CAFE standard and that other purchases be selected from among the two or three models having the lowest life-cycle cost for each type of equipment.

- Use federal purchasing power to establish a market in superefficient equipment and renewable energy systems, by guaranteeing the purchase of a specified number of units that meet certain cost and performance characteristics.

Investing in the Future

- Require the use of alternative fuels in fleet vehicles where justified by life-cycle costs.

Environmental Protection Agency

Harnessing Market Forces

- Quantify external costs of energy consumption; use those costs in establishing standards for least-cost efficiency, fuel mix, and pollution controls; and assist states in incorporating environmental externalities into utility regulations.

- Fully incorporate energy efficiency and vehicle miles traveled reductions as pollution control measures in implementing the Clean Air Act.

Making Efficiency the Standard

- Develop standards and guidelines for the release of toxic and hazardous gases from construction materials, thus minimizing the need for building ventilation.

Investing in the Future

- Establish environmental regulations governing various aspects of renewable fuels and technology, including energy crop cultivation practices, requirements for recycling and reuse of hazardous materials in photovoltaic modules, and siting of wind turbines.

States and Localities

Harnessing Market Forces

- Reform utility regulations to make least-cost efficiency investments the most profitable ones for utilities.

- Incorporate environmental costs into least-cost planning criteria.

- Base avoided-cost payments under the Public Utility Regulatory Policies Act on long-term costs to society.

- Ensure that small power producers (including individual homeowners) using renewable resources have fair access to utility grids.

- Establish marginal-cost block rates that include environmental costs.

- Prohibit "economic development" and other tax incentives where proposed efficiency levels do not meet minimum standards.

- Establish purchase incentives for motor vehicles with fees and rebates to favor improved efficiency and lower emissions.

- Establish car- and vanpool programs, high-occupancy vehicle lanes, and parking fee structures that discourage single-occupancy commuting.

- Adopt pay-as-you-drive automobile insurance.

- Use truck weight-length regulations and tire taxes to encourage adoption of efficiency improvements.

- Establish tax credits for renewable energy investments to supplement federal credits as needed to foster growth of renewable energy industries; credits should be conditioned on projects' meeting minimum state and federal performance and cost criteria, and should be phased out as industries mature.

Making Efficiency the Standard

- Adopt and enforce model building codes for residential and commercial buildings.

- Provide guidelines and flexibility for incorporating solar and efficiency measures in meeting the performance criteria specified in building codes.

- Adopt point-of-sale and point-of-lease retrofit standards.

- Adopt cost-effective efficiency standards on products not regulated by the federal government.

- Provide incentives to building managers and/or state agencies that substantially exceed minimum standards.

- Adopt a comprehensive approach to weatherization efforts, including as many technologies as possible and combining the technologies in the most cost-effective way.

- Enforce highway speed limits.

- Adopt power-generation efficiency standards to speed up the commercialization of advanced technology.

Investing in the Future

- Provide transit systems and establish land-use plans that avoid automobile dependence.

- Adopt certification standards and require certification for energy-efficiency contractors; provide certification in energy-efficiency techniques for general-retrofit contractors.

- Require state and city fleet vehicles to use alternative fuels where justified by life-cycle costs.

- Require utilities to devote a portion of revenues to investments in research and development on renewable energy sources.

- Create or expand regional R&D efforts in renewable energy, with particular emphasis on cost-shared demonstration projects.

Utilities

Harnessing Market Forces

- Conduct least-cost planning and investment; promote all cost-effective energy-efficiency measures in both energy supply and end-use.

- Participate in golden-carrot programs to stimulate development of new energy-efficient technologies.

Making Efficiency the Standard

- Support the adoption of efficiency standards for equipment and strong building codes at the federal and state level.

Investing in the Future

- Demonstrate and test renewable energy technologies; seek economical renewable energy applications.

Businesses

Harnessing Market Forces

- Take advantage of utilities' rebate programs, tax credits, and other efficiency and renewable energy incentives.

Making Efficiency the Standard

- Purchase the most efficient vehicle in each class for fleet use.

Investing in the Future

- Have an efficiency expert conduct an audit every three to five years to review the efficiency of overall processes and individual pieces of equipment; check with the local utility, DOE Energy Diagnostic Centers and Energy Extension Service, and the state energy office about available programs.

- Employ a professional energy manager in larger facilities to track energy use, maintain equipment for efficient operation, and identify efficiency investment opportunities.

- Adopt an explicit investment rule for energy efficiency and cogeneration projects; base the rule on a relatively low internal rate of return, such as the company's cost of capital.

Individuals

Harnessing Market Forces

- Take advantage of utility rebate programs and other efficiency and renewable energy incentives.

Making Efficiency the Standard

- Retrofit existing homes and buildings to reflect the gamut of cost-effective opportunities; include shell measures, such as insulation and weatherstripping, and heating and cooling system measures; and obtain information for retrofits through utility- or government-sponsored audit programs such as the Energy Extension Service.

- Request an energy rating and an energy-efficient mortgage when looking for a new or existing building to purchase.

- Low-income families should contact their state energy office or their local community-action program to sign up for energy-efficiency improvements through the weatherization program.

- Purchase new appliances, automobiles, and other energy-using equipment with the most cost-effective energy-efficiency rating; be certain that salesmen, distributors, and contractors are aware of the fact that you wish to purchase an energy-efficient model.

- Demand that elected officials support policies promoting energy efficiency and renewable energy sources.

List of Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AEEI	autonomous energy-efficiency index
ASE	Alliance to Save Energy
Btu	British thermal unit
CAFE	corporate average fuel economy
CEC	California Energy Commission
CFC	chlorofluorocarbon
CO	carbon monoxide
CO_2	carbon dioxide
CSE	cost of saved energy
DOE	Department of Energy
DRIVE+	Demand-based Reductions in Vehicle Emissions, Plus improvements in fuel economy
EDB	Environmental Database
EEC	European Economic Community
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FY	fiscal year
GNP	gross national product
HC	hydrocarbons
HVAC	heating, ventilation, and air conditioning
IRS	Internal Revenue Service
kWh	kilowatt hour
LEAP	Long-range Energy Alternative Planning
MBtu MMBtu	million Btu
mpg	miles per gallon

NARUC	National Association of Regulatory Utility Commissions
NES	National Energy Strategy
NO_X	nitrogen oxides
NRDC	Natural Resources Defense Council
NYSERDA	New York State Energy, Research, and Development Authority
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
OTA	Office of Technology Assessment
PAYD	pay-as-you-drive
PG&E	Pacific Gas & Electric Company
PMT	passenger miles traveled
PURPA	Public Utility Regulatory Policies Act
R&D	research and development
SAE	Society of Automotive Engineers
SEI-B	Stockholm Environmental Institute-Boston Center
SERI	Solar Energy Research Institute
SIC	Standard Industrial Classification
STIG	steam-injected gas turbines
SO_2	sulphur dioxide
SO_X	sulfur oxides
TDM	transportation demand management
TSP	total suspended particulates
UCS	Union of Concerned Scientists
UNEP	United Nations Environmental Programme
VMT	vehicle miles traveled
VOC	volatile organic compounds