Energy Efficiency and Climate Change

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Glossary

energy efficiency Useful output divided by energy input.
energy intensity Energy consumption per unit of gross domestic or gross world product.
final energy Energy available for use in homes, factories, and for transportation after accounting for losses in conversion (for example, waste heat from an electric power plant).
global warming Increases in the earth's surface temperature brought about by the release of greenhouse gases.
greenhouse gases Gases in the atmosphere that tend to trap heat and contribute to global warming (for example, carbon dioxide).
gross domestic product (GDP) Total value of goods and services in a country.
gross world product (GWP) Total of gross domestic product for all countries.
kWh Unit of electrical energy equal to 3,413 Btus.
million tons of oil equivalent (Mtoe) 40 million Btus.
primary energy Energy available from sources such as petroleum and coal.
quads 10^{15} British thermal units.

Large quantities of fossil fuels are burned to meet the world's energy needs. The combustion of these fuels produces carbon dioxide, contributing to increasing concentrations of carbon dioxide in the earth's atmosphere. According to the Intergovernmental Panel on Climate Change, the increasing concentrations of carbon dioxide and other greenhouse gases in the atmosphere due to human activity are causing the average surface temperature of the earth to increase. Such human influences are expected to continue to contribute to rising greenhouse gas emissions and additional global warming through this century.

1. INTRODUCTION

Humans combust these fuels to provide energy for needs such as heating, transportation, refrigeration, and industrial processes. The efficiency with which fossil fuels can be converted to meet these needs determines how much primary energy will be combusted. The greater the end-use efficiency, the less fuel is needed and the less the impact that such human activities will have on global warming, all other factors remaining the same.

Over the past century, the efficiency of energy use has improved. For example, lighting has changed from the burning of candles that produced 1 lumen for every 6 watts of candle or wax burned, to incandescent electric lights that produced 17 lumens with each watt of electric input, to fluorescent lighting that produces 100 lumens per watt. So the energy intensity index, defined as the amount of primary energy needed to produce a unit of gross domestic product, continues to improve. If this index can continue to improve at a rate of 2% per year, the

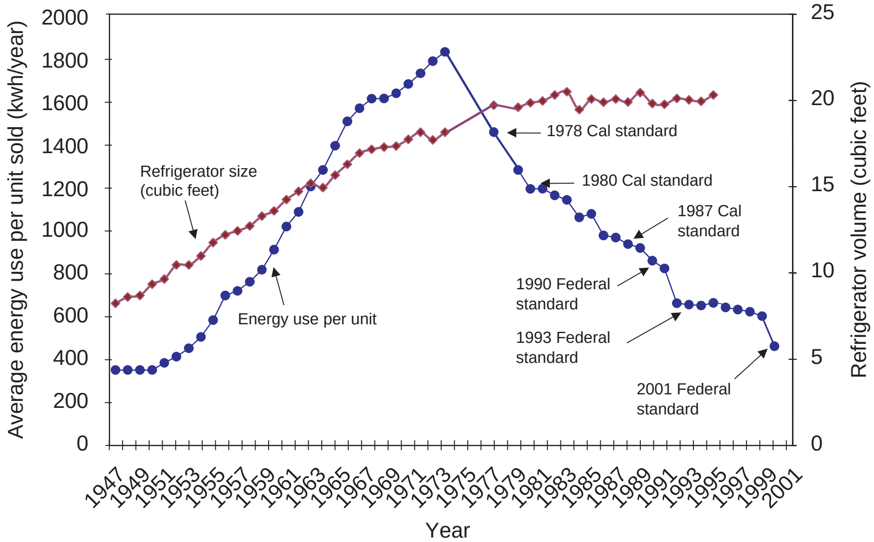

FIGURE 1 United States refrigerator use versus time. Annual drop from 1974 to 2001 is 5% per year. From David Goldstein of the Natural Resources Defense Council.

primary energy needs of the world can be limited even while increasing access to goods and services. Such an improvement in energy intensity also will lead to a reduction in carbon dioxide emissions and limit the extent of global warming.

2. IMPROVING TRENDS IN ENERGY EFFICIENCY

The efficiency of energy use is an important determinant of how much energy will be required to warm a home to a particular temperature or drive a car a certain distance. In our daily lives we often encounter the idea of energy efficiency when figuring how many miles per gallon our automobiles use while driving in town or on a freeway. Clearly, the more miles a car can travel on a gallon of gasoline, the less gasoline will be needed. The same concept applies to all uses of energy.

Since 1973, when the United States first experienced rapid increases in fossil fuel prices, considerable attention has been paid to improving the efficiency of energy use of various appliances and other products. The most effective path toward energy efficiency has been standards for autos, buildings, appliances, and equipment. Figure 1 shows the remarkable gains in refrigerators. Even while increasing in size, refrigeration has improved efficiency 5% every year since the late 1970s.

Figure 2 shows the results of these improvements. With an estimated 150 million refrigerators and freezers in the United States, the difference in consumption at 1974 efficiency levels compared to 2001 levels is the equivalent to avoiding 40 GW of power plants. A typical unit at a nuclear power plant is 1 GW, while the typical natural gas-fired combined cycle plant is 300 MW. This is based on saving 1400 kWh per year with the more efficient appliance and assuming power plant operation of 5000 hours per year.

Significant gains in efficiency also have been achieved with improvements in other appliances. Figure 3 illustrates improvements in three difference appliances (gas furnaces, central air conditioning, and refrigerators) compared to their respective consumption in 1972. This figure is taken from

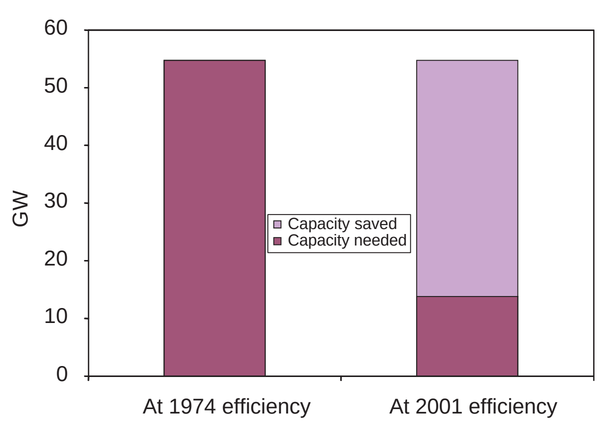

FIGURE 2 Electricity generating capacity for 150 million refrigerators and freezers in the United States.

Steven Nadel in the ECEEE 2003 Summer Study. Compared to consumption in 1972, new gas furnaces use 75%, central air conditioning units use 60%, and refrigerators only 25%. The figure also indicates that early standards were adopted by states. United States' national standards were not adopted until the late 1980s. Although these trends are encouraging, some other uses of energy have shown little improvement in efficiency since the 1980s. For example, average fuel efficiency for cars and truck remains at the same level as in 1985, even though there are no engineering obstacles blocking significant improvements in fleet efficiency. This was after significant improvement in CAFE standards from 18 miles per gallon for model year 1978 cars to 27.5 mpg for 1985 cars. However, even consideration of increasing CAFE standards remains a controversial topic.

3. THE COMBINED IMPACT OF COMPLIMENTARY EFFICIENCY IMPROVEMENTS

Efficiency improvements in appliance and building design and construction can often be combined to result in even larger energy savings. Figure 4 provides an example of this combined impact. Air conditioning operates to cool a home or a portion of a home based on the temperature setting of the

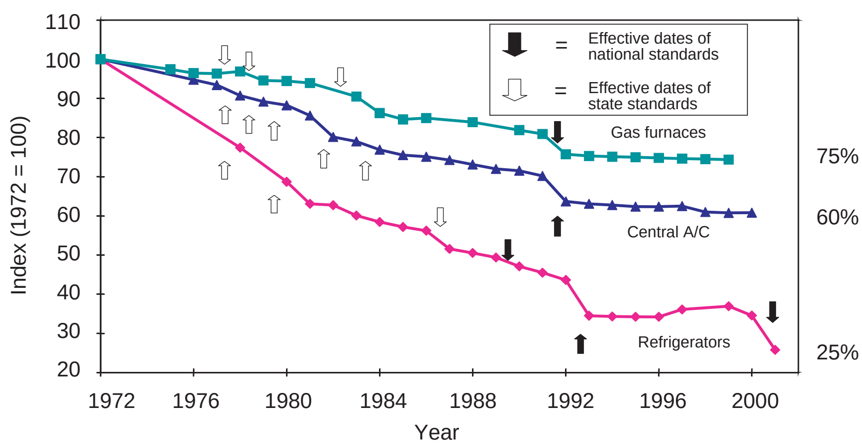

FIGURE 3 Impacts of standards on efficiency of three appliances. From S. Nadel, ACEEE, in ECEEE 2003 Summer Study, www.eceee.org.

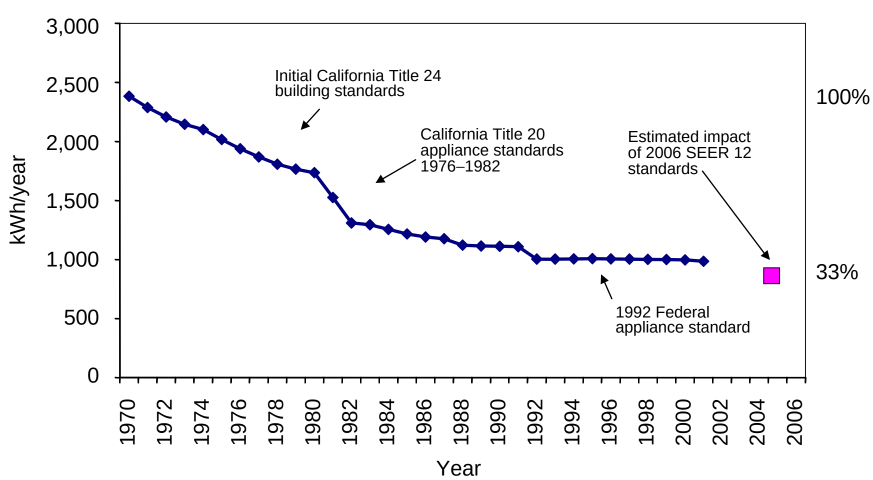

FIGURE 4 Annual usage of air conditioning in new homes in California. Annual drop averages 4% per year. From CEC Demand Analysis Office.

thermostat. The efficiency of the air conditioning equipment (for example, the compressor and air handlers) itself is known at the time of purchase and is required to meet a specific federal standard. However, how much it actually runs is also dependent on the characteristics of the building or home where the equipment is located. Prior to the 1970s many homes, especially in milder climates, had little or no insulation and single pane windows. As building standards were introduced, new homes were built to more stringent standards, resulting in lower requirements for heating and cooling to maintain the same temperature within the structure. As indicated in Fig. 4, the effect of combining both air conditioning standards and building standards has been to reduce energy use in a new California home to 40% of the usage in the early 1970s. With the implementation of newer standards in 2006, use is expected to decline to 33% of the 1970s levels.

4. EFFICIENCY IMPROVEMENTS REDUCE GENERATION REQUIREMENTS

Since the early 1970s, efficiency improvements have lowered energy demands and the need for peaking electrical power. To highlight the magnitude of such savings, we now consider how the U.S. demand for peak electrical power has been reduced, compared to what it might have been in the absence of efficiency improvements. The requirement for peaking power to meet air conditioner loads in the United States is about 250 GW. Standards only apply to the 200 GW of residential central systems and commercial rooftops air conditioning systems. By moving to current efficiency standards, equivalent to an energy efficiency ratio (EER) of 11, the United States has avoided about 135 GW of peak electricity load. This is about twice the peak load of the entire state of California and roughly equal to the total nuclear capacity in the United States. In addition, white roofs could save an additional 20 GW.

Enhancements in refrigerator and freezer efficiency save 200 billion kWh per year compared to consumption if refrigerators had remained at 1974 efficiency levels. That amount of electricity is nearly equal to annual electricity consumption in the state of California, about twice the amount of annual generation from existing renewables (not including hydroelectric) in the United States, and about one-third the quantity of electricity generated at nuclear stations in the United States in a year. Since the value of electricity at the point of consumption is worth nearly three times its value at the point of production, the value of improvements in refrigerator and freezer efficiency is worth the same as all the nuclear generation in the United States in a typical year.

Clearly, efficiency improvements have reduced the requirements for all forms of energy, even though some sectors, such as automobile transport, lag in this regard. Emissions of greenhouse gases have been proportionally reduced due to these efficiency gains. Yet it is generally accepted that the earth's surface temperature is on the rise, in great part due to human activity involving the combustion of fossil fuels. We now turn to past and estimated future trends in primary energy requirements.

5. HISTORIC PRIMARY ENERGY TRENDS IN THE UNITED STATES

Even with efficiency gains, energy requirements continue to increase. Figure 5 illustrates this trend. Primary energy use (not just electricity) increased by a factor of three over the time period of 62 years. Carbon dioxide emissions increased at nearly the same rate, as the vast majority of primary energy is provided from fossil fuels with only limited contributions from nuclear, hydroelectric, and other renewable energy sources.

Figure 6 shows a steady increase in per capita energy consumption from 1949 until the early 1970s. The flattening in 1974 is the impact of the OPEC oil embargo and high oil prices until the collapse of OPEC in 1985. Comparing Figures 5 and 6, we can see that much of the increase in primary energy is due to an expanding population, especially during the 1990s when per capita consumption was relatively flat.

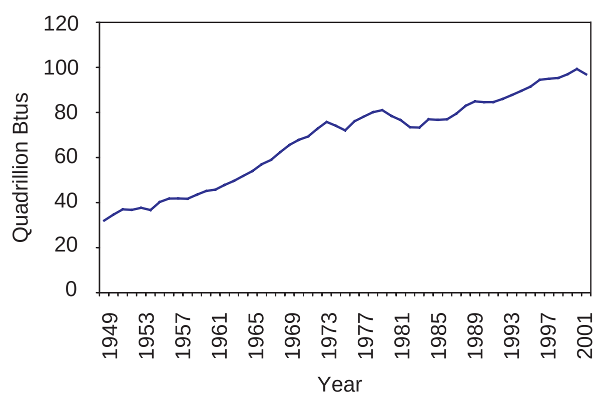

FIGURE 5 United States energy consumption, 1949 to 2001. From Table 1.5, *Annual Energy Review*; data for 2001 is preliminary.

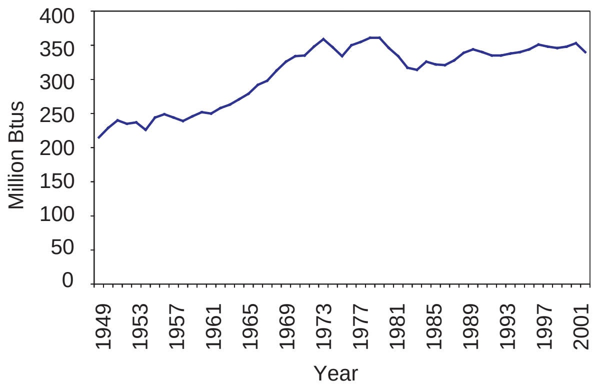

FIGURE 6 Energy consumption per person, 1949 to 2001. From Table 1.5, *Annual Energy Review*; data for 2001 is preliminary.

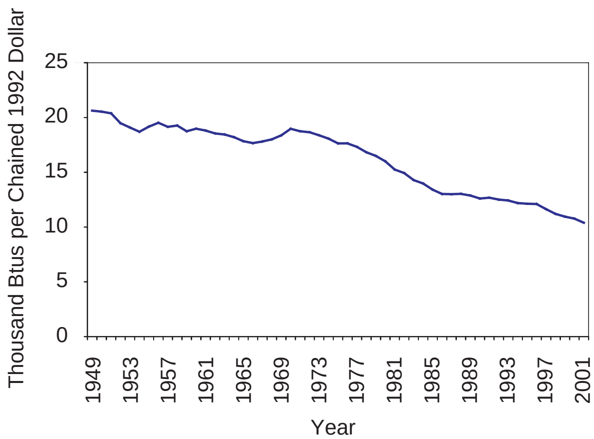

FIGURE 7 Energy consumption per dollar of gross domestic product, 1949 to 2001. From Table 1.5, *Annual Energy Review*; data for 2001 is preliminary.

6. ENERGY INTENSITY TRENDS IN THE UNITED STATES AND OTHER REGIONS

Another measure of interest to economists and energy analysts is how much energy is used per dollar of gross domestic product (GDP). This measure is referred to as energy intensity. The lower the number, the more efficient in terms of energy per dollar of GDP. Figure 7 shows that the United States improved its energy intensity at a rate of about 1.3% per year through this entire period. However, the rate of improvement is by no means uniform, as can be seen in the figure. Beginning in the early 1970s, the slope of the line changes as the rate of improvement in energy intensity increases.

Figure 8 provides similar data on energy intensities by geographic region. Five regions plus the world are included. Changes in energy intensity are not uniform throughout the world. Western Europe and North America have shown continual improvement over the time period, while other regions have remained flat or increased. China has shown dramatic and sustained improvement.

The next four figures illustrate annual rates of change in energy intensity data available from the United States Energy Information Agency (EIA). The EIA uses market exchange rate to compare gross domestic products across different countries. Market exchange rate is based on trading currency in international monetary markets.

Figures are provided for the United States, Western Europe, China, and the entire World. The

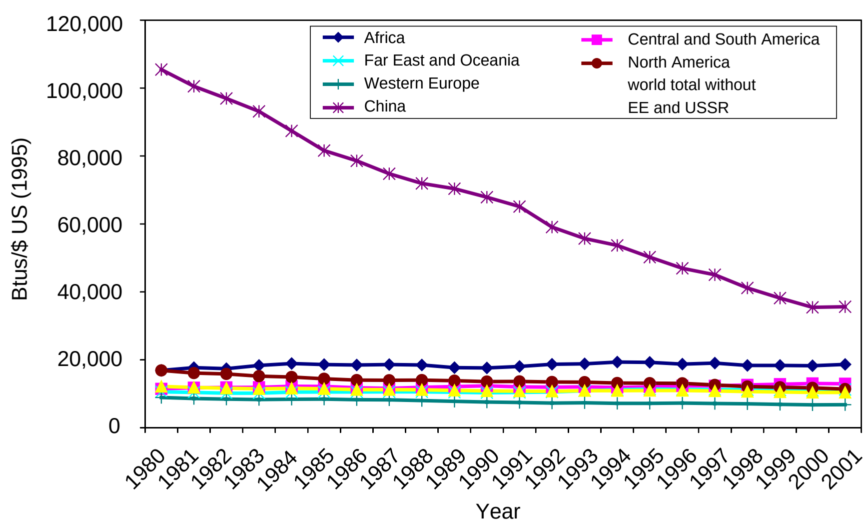

FIGURE 8 Energy intensity by geographic region including China, 1980 to 2001 (Btus/$US 1995). From Energy Information Agency (EIA) data.

vertical lines divide the time period (1981 to 2001) into three eras. Era 1 covers the latter years of high OPEC oil prices. Era 2 starts soon after the collapse of OPEC and the consequent stagnation of corporate automobile fuel economy (CAFE) standards. Era 3 begins with the significant impact of information technologies on business and the economy. The numbers written above each era reflect the average rate of change in E/GDP for that era. We introduce each of these figures and discuss trends of interest as illustrated in the figure.

Figure 9 tracks year to year changes in energy intensity and shows different rates of improvement in E/GDP in each of the three eras discussed earlier. In the early 1980s, the United States experienced improvements averaging −3.4% per year (improvements are indicated as negative numbers on these figures) and only −0.7% between 1986 and 1996. Improvements from 1997 through 2001 averaged −2.7%. Although many factors are at work, a number of analysts argue that the era improvements are the result of structural changes in the economy. The United States has moved away from energy intensive industry, such as steel production, and moved toward service and information-based firms, especially computer and internet firms. Such changes may portend not only less energy use for processes but improvements in scheduling, shipping, and other aspects of business practice due to the additional information availability.

Figure 10 shows a nearly constant improvement in the range of −1.3% per year and much less variability than in the United States. Europe already is considerably more efficient than the United States (see Fig. 8). In Fig. 11, we find nearly constant improvements in E/GDP in the range of −5.0% per year. Such improvement is dramatic. According to IEA's World Energy Outlook 2002, China's GDP has grown at about 8% per year since the 1970s to become the world's second largest consumer of primary energy. Finally, in Fig. 12 we find improvements in energy intensity averaging about −1.0% since the 1970s. Many factors contribute to the energy intensity of a county or a region within a country. As indicated by Figs. 8 to 12, the rate of change of energy intensity varies significantly throughout the world.

For energy intensity (E/GDP) to improve—that is, get smaller—GDP needs to increase more rapidly than primary energy, presuming that both are increasing. For example, primary energy use in the United States grew by 2.4% between 1999 and 2000. GDP grew by 3.7%, resulting in an improvement in energy intensity of 1.3% from 1999 to 2000. This article uses the convention of showing this as −1.3%. From the perspective of using energy better, the United States improved. Yet carbon emission also increased since the majority of primary energy comes in the form of fossil fuel—primarily coal, natural gas, and petroleum. If one is concerned about global warming, it seems that only three options are available to limit carbon emissions: (1) reduce the amount of primary energy requirements or limit the rate of growth in primary energy demand; (2) find

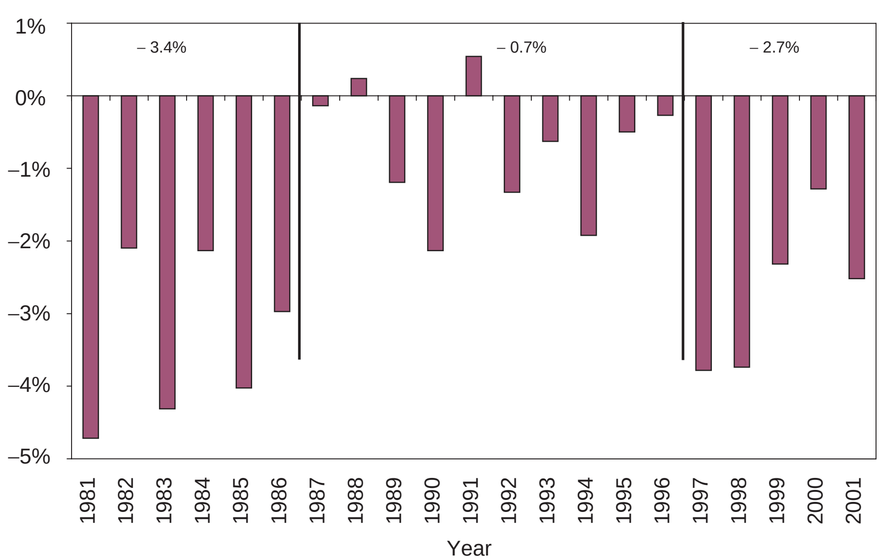

FIGURE 9 Annual rate of change in energy/GDP for the United States.

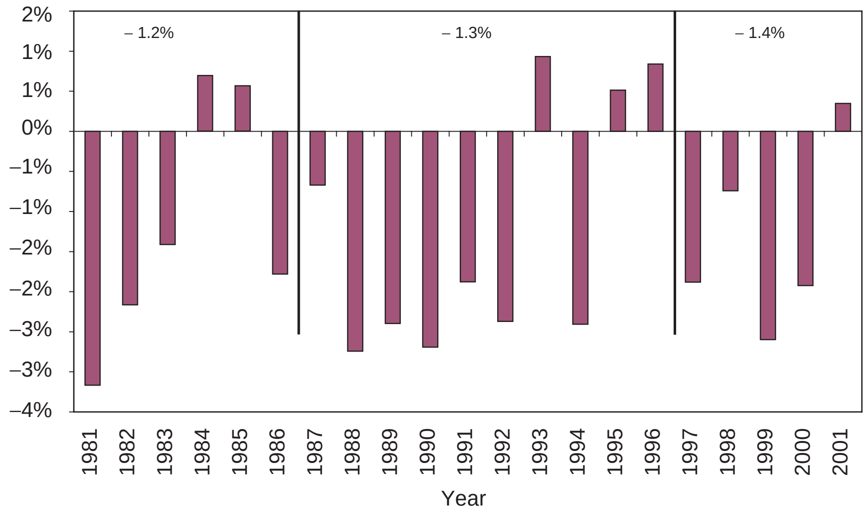

FIGURE 10 Annual rate of change in energy/GDP for Europe.

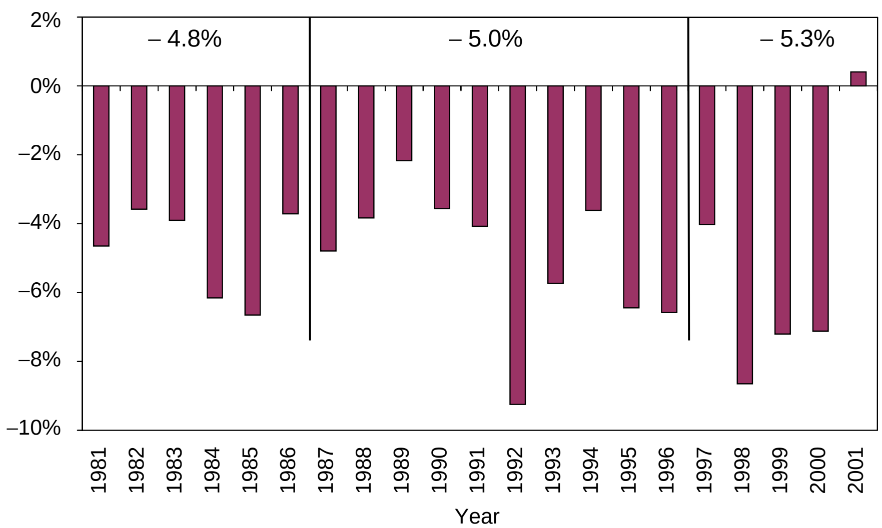

FIGURE 11 Annual rate of change in energy/GDP for China.

primary fuel sources that are not carbon based; and (3) sequester the carbon that is emitted. Not only are these options not mutually exclusive, but we expect all might well be necessary if we are to stem the tide of rising carbon concentrations in the atmosphere and global warming.

Even with improving E/GDP, concerns remain regarding primary energy demands for the world through the coming century and the amount of carbon that may be released into the atmosphere as fossil fuels are burned to meet these needs.

7. FUTURE PRIMARY ENERGY TRENDS FOR THE WORLD

Many different organizations have addressed the issue of how much energy might be needed in the future. Some have tried to forecast this amount; others have developed a host of scenarios to attempt to bound the magnitude of the problem. Estimates of future primary energy requirements vary considerably. Figure 13 illustrates the range of such scenarios. The scenarios all start at current levels on world energy demand, about 400 quads. By 2100, the range of

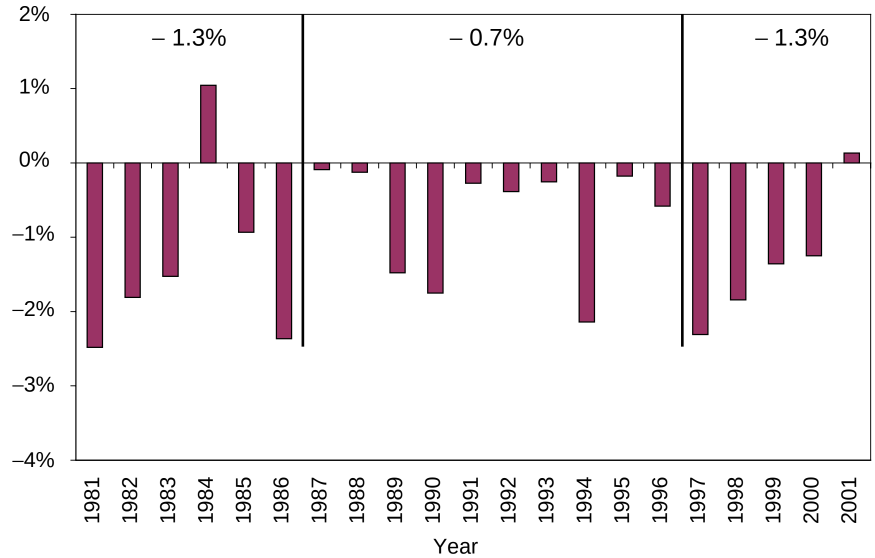

FIGURE 12 Annual rate of change in energy/GDP for the world. Note that Russia not included.

world primary energy demand is from 500 quads all the way to 2600 quads per year. These scenarios are predicated on different estimates of population growth, economic development, and energy intensity.

8. THE EFFECT OF EFFICIENCY IMPROVEMENTS ON PRIMARY ENERGY DEMAND

Efficiency improvements can drastically alter primary energy demand. We now discuss other cases that differ primarily in assumptions regarding the rate of improvement of energy intensity. Using the IPCC's IS 92a as the base case, Fig. 14 compares this case with two alternative trajectories of the world's primary energy consumption. The IS 92a case assumes E/GDP improving at −0.8% per year through 2020 and −1.0% per year thereafter through 2100. The second trajectory is taken from EIA's Annual Energy Outlook 2003. In the third case, energy intensity is assumed to improve at −2.0% annually through 2100. In assuming this improvement, total gross domestic product (or gross world product) is held at the same level as in the IS 92a case, and primary energy is set so that E/GDP improves by −2.0% per year.

Since the early 1990s when the IS 92a case was developed, primary energy demand has grown more slowly than anticipated. This explains the differences between the base case assumptions and the EIA International Energy Outlook as shown in Fig. 14. These differences result in a reduction of forecasted primary energy demand in 2025 of about 7.5%. However, if we assume that world energy intensity improves at a rate of −2% per year, world energy demand rises to only 510 quads by 2025 and then stays nearly flat through the end of the century. World demand is 400 quads per year.

The impact of improvements in energy intensity is dramatic. Primary energy demand is cut by more than 60% compared to the IS 92a base case. Put more dramatically, IS 92a requires, by 2100, in units of today's energy infrastructure, growth from 1.0 to 3.5, whereas the 2% per year scenario requires growth only from 1.0 to 1.3, at great savings of

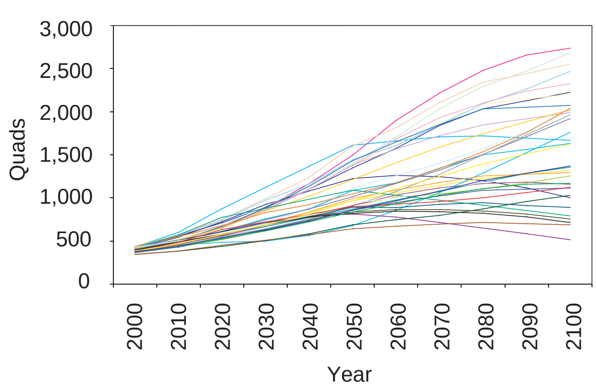

FIGURE 13 Primary energy 2000 to 2100. This figure is taken from data provided in IPCC Special Report on Emissions Scenarios 2001, Appendix VII.

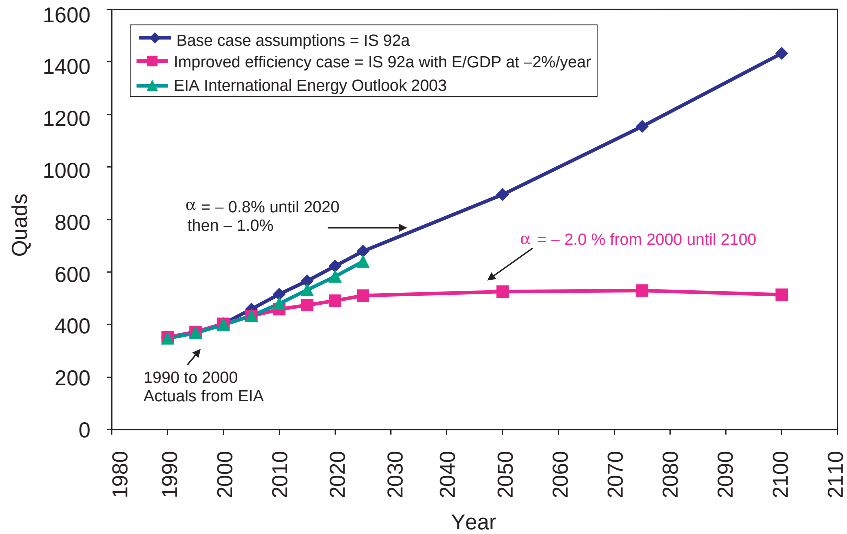

FIGURE 14 Primary energy demand in IPCC base case compared to other cases. α is the annual growth in energy intensity, E/GWP negative α indicates reduced energy intensity.

economic and environmental cost. While all this is occurring, per capita income rises to a worldwide average of nearly 25,000 (in 1995 US$). This is a level consistent with standards in developed European countries and Japan.

9. PATHWAYS TO IMPROVING ENERGY INTENSITY

We have seen that world energy intensity (E/GWP) is spontaneously dropping 1.3% per year, and that gaining another 1% per year for the coming century will cut demand and supply by another factor of 2.7. This extra 1% per year can by achieved by adopting and enforcing building, appliance, and vehicle fuel economy standards, and by ploughing about 1% of utility revenues back into efficiency programs designed to beat the standards. Examples of such programs are rebates for the purchase of super-efficient ("energy star") appliances, buildings, cars and trucks, and technical assistance to industries, architects, building owners and operators, and so on.

Standards are usually designed to reduce utility bills fast enough to repay a slightly higher first cost in 5 to 10 years, which is typically half the service life of the product. We call this a simple payback time (SPT) of 5 to 10 years. Efficiency measures to retrofit existing buildings and industry will also have SPTs that are safely shorter than the service life of the products installed. In contrast, investment in energy supply—power plants, transmission lines, refineries, dams, mines, and wells—typically has an SPT (from sale of energy) of 20 to 40 years, so efficiency is a better investment (although, of course, we need both), and the savings from efficiency, ploughed back into the economy, can stimulate jobs and growth.

Developed countries, which already have low energy intensity, can improve further by tightening and enforcing standards and extending their scope and by expanding efficiency programs. Reductions of CO_2 will then be an attractive by-product.

But later developing countries (LDCs), all of them lacking adequate energy supply, tend to focus on expanding their supply, and indeed rich countries should help them finance new supply. But first, for their own economic development and to reduce CO_2, more developed countries should attach conditions. Before financing supply with a 30-year payback time, developed countries should require that the host country develop standards and programs to capture all measures with a payback time of 3 to 5 years. Also, rich countries can help LDCs with technical assistance and training. These conditions should be adopted worldwide by donor countries, international banks, and host countries and their utilities. This is the cheapest way for the rich countries to delay climate change.

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Further Reading

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