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World Energy: Building a Sustainable Future

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World Energy: Building a Sustainable Future

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April 1992

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WORLD ENERGY: BUILDING A SUSTAINABLE FUTURE

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Preface

Much of this document is based on a longer book by the same authors, with Richard Howarth and Ruth Steiner. That book, entitled ***Energy Efficiency and Human Activity: Past Trends, Future Prospects,*** is being published by Cambridge University Press. The reader desiring more information and analysis of trends in energy use and the potential for energy conservation will benefit from that book.

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Units of Measurement

Energy units

The energy content of various fuels, heat, and electricity is expressed in different units around the world. In the course of our work with numerous sources from many countries, we have converted all units into Joules, the basic unit of the SI system. The units that we commonly use, and their equivalence to other units often found, are as follows:

EJ (exajoules) = 10^{18} Joules = 0.948 quads (10^{15} Btu) = 240 x 10^{6} toe = 239 x 10^{12} kcal
GJ (gigajoules) = 10^{9} Joules = 0.948 million Btu = 0.024 toe = 239 x 10^{3} kcal
MJ (megajoules) = 10^{6} Joules = 0.948 thousand Btu = 0.024 x 10^{-6} toe = 239 kcal

When referring specifically to electricity, we present data in Watt-hours (Wh) or Watts (W):

kWh (kilowatt-hours) = 10^{3} Watt-hours = 3.6 MJ
TWh (terawatt-hours) = 10^{12} Watt-hours = 3.6 PJ
kW (kilowatts) = 10^{3} Watts
MW (megawatts) = 10^{6} Watts
TW (terawatts) = 10^{12} Watts

"Primary energy" includes losses and own-use in the production of fuels, district heat, and electricity and in the delivery of district heat and electricity. Hydroelectricity and nuclear energy are counted in terms of fossil-fuel equivalent. "Final energy" refers to actual consumption by end users. We have included estimates of biomass use whenever possible. Energy statistics usually include consumption of fuels for non-energy purposes (chemical feedstocks, lubricants, bitumen, etc.). In our sectoral analyses, we have excluded such consumption wherever possible.

"Commercial energy" refers to all forms of energy other than biomass fuels (fuelwood, agricultural residues, and dung), traditional uses of wind and solar energy (e.g., water pumps and solar drying), and animal and human power. The term "commercial energy" is actually misleading, since much biomass fuel is traded in commercial markets or is used by industries, in many cases substituting for fossil fuels. It is still the most commonly used term for "modern" fuels, however, so we use it despite this flaw.

Monetary units

When comparing monetary units among countries, we usually make use of purchasing power parities rather than exchange rates to convert local currencies to a common unit. Use of purchasing power parity is designed to equalize purchasing powers of currencies in the respective countries. It is defined as the number of units of a country's currency required to buy the same amounts of goods and services in the domestic market as one dollar would buy in the United States. Thus, the unit in which GDP or energy prices is expressed is not a dollar *per se*, but rather a dollar-equivalent.

Other units

Measures of weight are given in metric tons (tonnes); one tonne = 1000 kilograms (kg).

Measures of volume are given in liters (l) or U.S. gallons; one gallon = 3.785 liters. One U.S. gallon = 0.833 Imperial gallons.

Measures of distance are usually given in kilometers (km); one kilometer = 0.62 miles.

Commonly-Used Acronyms

bn	billions
CCE	cost of conserved energy
CFLs	compact fluorescent lamps
DSM	demand-side management
GDP	Gross Domestic Product
HVAC	Heating, ventilating, and air-conditioning
ISIC	International Standard Industrial Classification
kg	kilograms
km	kilometers
LDCs	Developing Countries (Less Developed Countries)
LNG	Liquified Natural Gas
LPG	Liquid Petroleum Gas
mpg	miles per gallon
NICs	Newly Industrialized Countries
OECD	Organization for Economic Cooperation and Development
p-km	passenger-kilometers
RD&D	Research, Development, and Demonstration
smpg	seat-miles per gallon
t-km	tonne-kilometers
UEC	unit energy consumption
VA	value added

Note on Country Groupings

We use the terms "industrial countries" and "OECD countries" synonomously; the same for "transitional countries" and "formerly-planned economies", which includes the former USSR and Eastern Europe (including the former East Germany). "Developing countries" include all countries not in the other two groups, including those with relatively high per capita GDP (such as the Asian NICs).

EXECUTIVE SUMMARY

As the 20th century draws to a close, both individual countries and the world community face challenging problems related to the supply and use of energy. These include local and regional environmental impacts, the prospect of global climate and sea level change associated with the greenhouse effect, and threats to international relations in connection with oil supply or nuclear proliferation. For developing countries, the financial costs of providing energy to provide basic needs and fuel economic development pose an additional burden.

To assess the magnitude of future problems and the potential effectiveness of response strategies, it is important to understand how and why energy use has changed in the past and where it is heading. This requires study of the activities for which energy is used, and of how people and technology interact to provide the energy services that are desired. The authors and their colleagues have analyzed trends in energy use by sector for most of the world's major energy-consuming countries. The approach we use considers three key elements in each sector: the level of activity, structural change, and energy intensity, which expresses the amount of energy used for various activities. At a disaggregated level, energy intensity is indicative of energy efficiency, but other factors besides technical efficiency also shape intensity.

Past Trends in Energy Use

World energy use has risen by over one-third since 1970, and grew steadily between 1983 and 1989. The forces of activity, structural change, and energy intensity have shaped energy use in different ways in the industrial, developing, and transitional countries. In the industrial countries, whose share of world energy use declined from 60% to 48% between 1970 and 1990, activity pushed moderately upward on energy demand. Structural change pushed upward on demand in passenger travel (more reliance on cars and air), freight transport (greater use of trucks), and households (more living area and appliances per person), but pushed downward in manufacturing (shift toward less energy-intensive industries). Energy intensities declined significantly in most areas. In manufacturing, the OECD-average decline of 32% between 1973 and 1988 was largely due to ongoing technological innovation. In air travel and building heating, where there was also significant reduction in intensity, higher fuel prices played a larger role. For automobiles and home appliances, changes toward more energy-intensive characteristics (greater size and, in the case of automobiles, power) partially offset improvement in technical energy efficiency. On average, decline in energy intensities caused a reduction in OECD primary energy use of around 20% between 1973 and 1988. Since 1982, however, there has been a marked leveling off in most energy intensities, especially in households and automobiles outside the US.

In the developing countries, growth in energy use (including estimated biofuels consumption) averaged nearly 5% per year between 1970 and 1990, and their share of world energy use rose from 20% to 31%. Increase in activity levels has pushed strongly upward on energy use, though the pace of growth has varied among regions. Structural change has also contributed to increase in energy use. In manufacturing, there has been some shift toward energy-intensive industries, especially in countries with abundant energy resources. In passenger travel, the role of automobiles has grown, and trucks have grown in use in freight transport. In the residential sector, growth in the penetration of electric lighting and appliances has contributed to rising energy use. Change in energy intensities is difficult to judge. In manufacturing, the largest energy-using sector, there has been decline in some countries resulting mainly from adoption of more modern processes. There are signs of some improvement in other areas as well, but in general the degree of change appears to be much less than in the OECD countries.

In the formerly-planned economies, energy use grew at a moderate pace through 1988, but has declined since as the economies struggle to reform on a new basis. Activity increased in all sectors in these countries, but there was less change than in other parts of the world in sectoral structure and energy intensities. In manufacturing, the largest energy-use sector, there are signs of a modest decline in energy intensity in some Soviet industries. In this and other sectors, however, the improvement in energy efficiency was small compared to that which occurred in the West.

Future Prospects for Energy Use

Most observers expect that market forces will result in only modest increase in international energy prices during the next 20 years. Thus, one of the factors that contributed to improvement in energy efficiency in the past will probably be less strong in the future. Even with only moderate rise in energy prices, energy intensities in the industrialized countries will continue to decline in most sectors, especially in manufacturing, where technological progress is relatively independent of change in energy prices. In addition, historic and current energy efficiency policies and programs are having an impact in some areas. Averaged over all sectors, however, the net decline will likely be much smaller than that which occurred before 1985, and is unlikely to keep pace with the pressure on energy demand from rising activity. Certain types of energy-intensive activity, especially travel, will probably grow faster than GDP. Structural change at a macroeconomic level and in the manufacturing sector will contribute to lower aggregate energy intensity, but the shift toward energy-intensive modes is increasing energy use somewhat in transportation. In a scenario developed by the authors, average growth in OECD primary energy consumption is about 1.2% per year between 1985 and 2010.

In the developing countries, energy efficiency will improve with stock turnover and use of more modern technologies; but population growth, increase in per capita activity levels, and rise in various energy-intensive activities will lead to major increase in energy use. Along with continued urbanization, rise in income will bring considerable increase in demand for consumer goods. The adoption of more market-oriented internal policies and greater openness to trade and foreign investment should contribute to improved energy efficiency, but progress may be slow unless assistance is provided to help overcome the barriers. The slackening in the development of more energy-efficient technologies in the OECD countries could slow the progress toward higher efficiency in the developing countries.

Future energy use in the formerly-planned economies will depend on the pace and nature of reform and investment. Economic restructuring involving changes in the quantity and mix of goods produced and closing of many outdated facilities could greatly reduce the overall energy intensity of the economies, even without major efforts to encourage energy efficiency. Pricing reform should also have a significant effect, although the shortage of capital could hinder the response of energy users. Successful economic reform should eventually bring a surge in the demand for personal mobility and home comfort, and greater activity in the service sector, all of which would push energy use upward.

Overall, world energy use could plausibly grow by 25-35% over the next twenty years, and continue rising at a moderate pace thereafter. Given the current outlook for energy supply, this would bring increase in greenhouse gas emissions and many other environmental problems. For the developing and transitional countries, pursuing a conventional energy path would pose both economic and environmental burdens.

The Energy Conservation Potential

There is a large potential for cost-effective energy efficiency improvement in existing and new systems in all sectors and all parts of the world. Technical change in processes, equipment, and buildings comprises the largest part of the potential, but change in operations, maintenance, and in the operating environment are also important. In the industrial countries, reductions in energy intensities of 30-50% relative to current levels appear to be technically achievable and probably economic as well, considering life-cycle costs and a social discount rate. For the most part, achieving these reductions does not require development of new technologies, but rather more widespread adoption of technologies that are currently available or could be soon. The potential in the developing and transitional countries is more uncertain and depends on how easily modern technologies can be acquired, but could well be of a similar magnitude. Technologies that could bring even greater efficiency improvement are in various stages of development for most end uses.

As stocks of energy-using capital turn over and energy users make improvements on long-lived systems, energy efficiency will gradually increase in many if not most areas. But a variety of barriers cause the 'natural' adoption of higher energy efficiency to be much less than what is economically attractive for society. These barriers are especially large in the developing and transitional countries, and scarcity of capital and technical expertise adds to the problem. Removing energy price subsidies and cultivating a competitive business environment will encourage efficiency improvement, but public policies and programs are needed to realize more of the potential. In all countries, accelerating efficiency increase is especially important and promising in electrical end uses, since much savings is possible at lower cost than new electricity supply. Other strategies can also bring important energy savings, especially in transportation, where comprehensive approaches are needed to encourage greater reliance on modes with lower energy intensity.

Scenarios developed by the authors for the industrial countries estimate that a combination of higher energy prices (resulting from some internalization of environmental costs) and adoption of strong energy efficiency policies and programs could result in primary energy use in 2010 being 22% less than in a 'business-as-usual' case. With even stronger policies, and institution of substantial carbon taxes, energy use could be 44% less. In this 'vigorous effort' case, energy use in 2010 is nearly 30% less than in 1990. The average energy intensity declines at a rate close to that experienced in many countries during the period 1979-1982, when energy prices rose sharply and various policies were implemented. Sustaining such a rate over 20 years would not take an enormous amount of technological innovation, but would require a major and concentrated effort to accelerate the market penetration of highly energy-efficient technologies and practices.

Changing Energy Supply

Even with considerable progress in improving energy efficiency, the scale of future energy use is likely to bring growing environmental impacts and risks unless major changes in energy supply are accomplished. Indeed, in the developing and transitional countries, changes are needed now to reduce the local environmental costs associated with energy supply. Improving the efficiency of electricity supply, promoting more effective use of cogeneration, and developing natural gas for local use are important steps for the LDCs.

The chief barrier on the supply side is that measures that reduce environmental costs usually increase monetary costs. The wealthy countries may be willing to pay the price, and local pollution concerns will encourage gas, discourage coal (or make it cleaner), and probably bring modest penetration of alternative transport fuels. For other countries, creative financial and political solutions are needed to help overcome the barriers to use of cleaner fuels and technologies.

While the greenhouse problem may not play a major role in shaping energy supply in the next decade, major changes may be set in motion if evidence to confirm today's scientific consensus regarding the greenhouse effect accumulates. Modest carbon taxes or other schemes adopted by the industrial countries would give an additional boost to use of gas and help many renewable sources as well. While gas is attractive on several counts, it will ultimately be constrained by the concentration of global resources and infrastructural requirements. Nuclear energy could make a comeback with new technology, but this will be a slow process and building public confidence could prove difficult. Many renewable energy technologies are closer to being commercially viable than is commonly believed, and opportunities for technical improvements exist in many cases. Further technology development and institutional changes could greatly expand their role, and there is evidence that a future energy supply system based heavily on renewable energy sources may be both technically feasible and economically viable.

Building a Sustainable Energy Path

Without concerted effort, the problems related to energy supply and use will likely increase over time and impose a growing burden on human society and natural ecosystems. Managing them requires national and international actions to restrain growth in energy use and to develop energy supply systems that pose fewer costs and risks. Adjusting energy prices to reflect the full costs of energy use, including environmental costs, is a key step that will have positive effects on the supply and demand sides. But pricing alone will not overcome the barriers that prevent the realization of the energy efficiency potential, or those that hinder greater use of low-impact energy sources.

Increasing energy efficiency is an especially promising strategy because it offers economic as well as environmental benefits. A variety of policies and programs can accelerate efficiency improvement in new and existing systems by providing information, setting minimum efficiency standards or goals, and offering incentives to energy users or producers of equipment and systems. Targetting new systems is especially important in countries where stocks are growing rapidly. Involving trans-national equipment producers in international discussions is a strategy that could be very effective. Pushing the efficiency frontier through increased support for RD&D and innovative market-development strategies is also critical. Government must provide strong leadership, but important roles should also be played by utilities, industrial and professional associations, and the business community.

Efficiency programs and policies will be most effective if they are integrated into overall sectoral strategies and implemented to achieve multiple benefits. Efficiency improvement as a means of increasing economic productivity is especially important for developing and transitional countries. To reduce global environmental threats and build international equity, the industrial countries should help them (directly and by increased support for international efforts within multilateral development banks and UN organizations) with training, technical assistance, financing, and other means to increase access to modern technologies. Internal reforms with respect to pricing, competition, and trade are also important to create a foundation for ongoing progress. In addition, policies and programs adopted by the industrial countries that encourage development of energy-efficient technologies for their own economies can have a profound effect world-wide. To complement efforts to improve efficiency and conserve energy in other ways, increased RD&D is needed on the supply side to support renewables and other promising technologies that can help meet future energy needs without imposing unacceptable impacts and risks.

Chapter 1
Introduction

Civilization is not running out of energy resources in any absolute sense, nor running out of technological options for transforming energy resources into the forms our patterns of energy use require. What is running out, rather, is the capacity to expand energy supply at low cost—a capacity which was fundamental to the growth of material wealth in today's industrial nations and which had been the basis of expectations that today's less developed countries would be able to follow a similar path to prosperity (Holdren 1992).

As the 20th century draws to a close, the emerging global civilization holds great promise for overcoming many of the divisions that have led to conflict in the past, for improving living standards worldwide, and for expanding human rights. But it also faces great problems. The global distribution of wealth and control of advanced technology threatens to become increasingly skewed, leading to a world with a growing gap between the "haves" and the "have nots". In addition, the scale and nature of human activity threaten to bring a growing degradation of the environment on which our well-being depends.

The supply and use of energy contributes to environmental and other problems in many ways. Few would disagree that the impacts associated with energy are on the rise throughout the world. These include tangible impacts such as oil spills, coal and uranium mining wastes, loss of land to hydroelectric projects, and air pollution from burning fossil fuels. They include impacts that may be felt much more in the future than at present, such as the effect on climate from the release of CO_2 in fossil fuels, and the long-run risks of nuclear waste disposal. They also include events whose probability is small but whose potential impact is great, such as major accidents at nuclear plants or catastrophic failure of dams.

The impacts associated with supplying and using energy would be less problematic were it not for three key factors. One is the *scale of energy use*. World energy consumption is four times larger today than it was in 1950, and is rising without sign of abatement. This means more oil being pumped and shipped, more coal and uranium mined, more rivers dammed, more refineries and power plants, and more factories and vehicles burning energy and releasing pollution. The scale factor is compounded by the problem of *cumulative impacts*. As energy use has expanded, many of the most easily-harvested energy resources have been utilized. This means that harvesting an additional unit of fossil fuel, damming an additional river, or siting an additional power plant very often results in greater impacts per unit of energy produced than in the past. Moreover, as increasing amounts of pollutants and other insults are released into the environment, its capacity to absorb them gets consumed. Thus, additional pollution may begin to generate disproportionately more damage per unit of input. In some cases, problems that were barely perceived may suddenly assume ominous dimensions (as, for example, damage to forest ecosystems from acid precipitation).

The third factor *rising marginal costs of pollution control*, is related to the above two. As the scale of energy use increases, and the problem of cumulative impacts becomes more severe, it becomes necessary to increase the level of pollution control simply to hold total damage to an acceptable level. Yet the monetary costs of pollution control per unit of pollutant removed from effluents tend to increase with the removal percentage that is required. This increase in turn engenders resistance to more stringent control, and damage may grow as a result.

1.1. ENERGY PROBLEMS

While certain principles apply broadly, it is clear that there is no single "energy problem", but rather a range of problems that are related to supply and use of energy. The severity of different problems, how they are perceived, and the importance that is attached to them vary around the world. In some cases, the impacts are felt today, while in others the problems will (or may) be experienced most severely by future generations. Understanding the full range of problems and issues, and the connections between them, is essential, for a solution in one area may exacerbate the problems in another.

1.1.1. Local and Regional Environmental Problems

The supply and use of energy contributes to local environmental problems in all countries. Some impacts may cross national boundaries, as with large oil spills, acid precipitation from fossil fuel combustion, or release of radioactivity from a nuclear power accident.

Impacts on public health and safety, or risks to it, are usually of the greatest concern. Routine impacts include those from air and water pollution connected with energy supply and use, and "normal" radiation from nuclear power plants and related operations. Impacts may occur from mining, transport, and waste disposal as well as from actual energy use. The severity of local impacts varies greatly around the world, depending on patterns of energy use, the degree of pollution control, geographic factors, and the proximity of people to the pollution sources. As stated above, some impacts have low probability of occurring but very high cost if they do.

Damage to ecosystems from energy supply and use is the other main area of concern. Such damage may result from oil spills, acid precipitation connected with fossil fuel burning, as well as from routine operations of the various energy industries. In parts of the developing world, harvesting of biomass contributes to deforestation. Over the long run, damage to ecosystems may have consequences for society that are even worse than the more direct threats to human health and safety. These include potential loss of economic productivity from agriculture, forestry, fishing, and tourism, as well as a degraded experience of the natural world. Loss or deterioration of ecosystems is also of concern for the sake of the non-human forms of life that depend on them for their survival. Such life in turn contributes to human well-being.

The severity of local environmental problems related to energy, and their importance relative to other problems, vary among countries. The problems are especially acute in the formerly-planned economies. These range from severe air, water, and soil pollution connected to supply and use of coal, to the risk of radiation release from nuclear power plants whose safety is below Western standards. In both of the above examples, the potential impacts transcend national boundaries. Local impacts from coal supply and use are also acute in China and India.

Apart from environmental concerns, energy supply can also have social impacts. Resettlement of people when lands are flooded for hydroelectric projects is the most notable example, but other types of power plants and energy supply operations and facilities for waste disposal can also have negative social effects. The security requirements in a society heavily dependent on nuclear power (especially with recycling of plutonium) could also have social consequences.

1.1.2. The Threat of the Greenhouse Effect

There is increasing agreement in the scientific community that enhancement of the global greenhouse effect caused by release of carbon dioxide (CO_2) and other gases into the atmosphere could result in dramatic change in the global climate and sea level in coming decades. The Intergovernmental Panel on Climate Change concluded that if present emissions trends continue, global average temperatures could rise by roughly an additional 1 degree C by the year 2030. Regional impacts are difficult to predict. Some regions may experience more drought, others more precipitation and perhaps changes in the frequency and intensity of storms. Some of the impacts can be dealt with (at some cost), but the rate of climate change may outpace the ability of natural and human systems to adapt in some areas.

While many human activities contribute to the greenhouse effect, energy supply and use has accounted for over two-thirds of the equilibrium warming ultimately expected to result from growth in greenhouse gas concentrations over the past century. Carbon dioxide from fossil fuel burning has been responsible for most of this. Smaller roles are played by methane from coal mining and natural gas leakage and nitrous oxide from fossil fuel combustion. In contrast to many local environmental problems, the greenhouse effect is difficult to mitigate by removing the pollutant, since CO_2 is not easily removed from the exhaust gas stream. The threat of the greenhouse effect is also different in that no nation can escape from its impact on its own; slowing it requires concerted international action.

1.1.3. Threats to International Relations

Energy supply as it is now evolving poses two major threats to peace among nations. The first is the potential for conflict over control of oil in the Middle East, which is home to two-thirds of global oil reserves and will be the main source of the world's oil over the long run. This potential was made all too real by the recent Persian Gulf War, which brought both great human suffering and devastating impacts to the regional environment. The war eliminated a potential threat to security of oil supply in the near and medium-term, but seems to have done little to reduce the long-term potential for conflict. While the vulnerability of oil-importing countries to a cutoff of oil supply from the Middle East is not as great now as it once was (due to increase in oil storage and diversification of supply sources), it is likely to increase in the long run as production from other areas declines (or is absorbed by domestic consumption in the case of some of the developing-country exporters).

The second threat to peace is the danger that spread of commercial nuclear power will contribute to proliferation of nuclear weapons. Some contend that countries bent on acquiring nuclear weapons can get nuclear explosive materials through means other than via commercial nuclear power facilities. While this is true, it ignores the fact that the existence of a commercial nuclear power program makes it easier to acquire explosive materials and also provides a cover for such activity. Moreover, "countries that initially have no intention of acquiring nuclear weapons might later find the built-in weapons capability that comes with nuclear power too tempting to resist, particularly if their internal or external political circumstances change" (Holdren 1992). Without much stronger safeguards than currently exist, the spread of nuclear power would probably increase the rate at which nuclear weapons capability also spreads.

1.1.4. The Burden of Energy Supply on Development

All countries share in the concern over the environmental and political problems associated with energy use. For the developing countries, however, the more pressing problem is simply to provide enough energy to meet the needs and aspirations of their rapidly growing populations. While developing countries are beginning to give greater attention to the local environmental impacts of energy production and use, and are recognizing that global climate change could seriously impact them, they understandably give priority to providing energy for economic development.

The problem is that providing that energy is typically an enormous drain on national resources. Oil imports have contributed heavily (and continue to do so in many cases) to the foreign debt under which many countries suffer, and can consume a major share of foreign exchange. For the more populous oil-exporting countries, such as Mexico, Indonesia, and Nigeria, high growth in domestic oil demand limits export earnings in the long run. While oil imports worsen balance of payments problems, rapid increase in electricity use is placing a growing burden on capital resources. The power sector already claims a large share of total capital investment, yet electricity shortages plague much of the developing world, hampering economic development. A study by the World Bank found that the power expansion programs for the 1990s in the LDCs are expected to require financing averaging around $100 billion (1989 dollars) per year (Moore and Smith 1990). Yet the current investment level of about $50 billion per year is already jeopardized by overall national indebtedness and poor performance of many electric utilities. Given the scarcity of capital in many countries, even partially meeting the rising demands of the power sector would mean shifting resources from other critical areas.

Many of the concerns of the developing countries apply to the formerly-planned economies as well. Outside of Russia and a few other ex-Soviet republics, paying for oil imports with hard currency has become a major burden since the collapse of the old system. And while growth in electricity demand and electricity shortages are not the problems they are in the developing countries, the need to fix or replace parts of the electricity supply infrastructure poses a potential burden on the region's limited capital resources.

1.1.5. Linkages Among Problems

Many of the problems described above are interrelated. Climate change resulting from the enhanced greenhouse effect could hamper the ability of ecosystems to recover from local insults. It could also contribute to conflict among nations: the negative impacts on food and water supply, along with loss of coastal land, could exacerbate conflict over resources or national boundaries and increase migration from severely-impacted regions. In the long run, the linkage between local environmental problems and development prospects is especially great. The cumulative impact of such problems threatens both human health and safety and the ability of ecosystems to provide the services on which human well-being depends.

1.2. MOVING TOWARD SOLUTIONS

Just as there are many diverse problems connected to energy supply and use, so are there many potential solutions to them, or at least actions that can reduce the negative impacts. Dealing with the problems is matter of balancing costs (and risks) and benefits. A simple analysis is difficult, however. The costs are often uncertain and hard to compare with one another, and many of the impacts may not be felt for years or decades, raising the issue of intergenerational equity.

This booklet seeks to provide a context for consideration of the nature and range of current and prospective problems, and potential responses to them. Its basic premise is that slowing growth in energy use, or even reducing demand in some cases, is the most attractive way of dealing with most of the problems discussed above. That is not to say that other responses are not important and necessary. The problem is that most of these responses increase the *monetary* cost of energy in the process of restraining environmental and social costs, which makes their adoption more difficult, particularly outside of the wealthy countries. Energy conservation, especially through improvement in the efficiency of energy use, is a promising strategy because it can reduce the monetary cost of providing energy services, and provide other benefits at the same time. Energy conservation slows the rate at which the most attractive energy resources are used up. This not only lessens pressure on energy prices, which is particularly helpful for the poorer countries of the world; it also provides more time for further development of technologies that can support human activity in the long run.

Understanding the nature and magnitude of the problems and challenges that may arise in the future requires insight into where energy demand is heading. Such insight can only be built on a thorough understanding of the past. In the past decade, the authors and their colleagues have analyzed trends in energy use by sector for most of the world's major energy-consuming countries. Drawing on these studies, Chapter 2 provides an overview of how and why energy use has changed in the past 20 years, and considers the prospects for the future. In this and other parts of the booklet, we look separately at three groups of countries: the industrial ('OECD') countries, the developing countries ('LDCs'), and the formerly-planned ('transitional') economies. Chapter 3 discusses the potential for energy conservation over the next 20 years or so, primarily through improvement in the efficiency of energy use. It also describes strategies that can accelerate efficiency improvement, and presents scenarios of what might be achieved in the OECD countries with aggressive policies and programs. Chapter 4 considers the prospects and potential for making improvements in energy supply systems, including reducing losses and shifting the energy mix toward sources that pose fewer problems. Chapter 5 concludes the booklet with a brief discussion of key steps that, in our view, are needed to address the global challenge of energy, environment, and development.

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Chapter 2
World Energy Use: Past Trends, Future Prospects

World energy use has risen by over one-third since 1970. Although demand was steady in the 1974-75 and 1980-83 periods as a result of response to higher energy prices and slowing of economic activity, growth continued after each period of stagnation as real oil prices declined and economic growth resumed. Between 1983 and 1989, the course of world energy use was steadily upward, averaging 2.8% per year. There was little increase in 1990, but this was due to slowing of the industrial economies and the radical changes that were taking place in the formerly-planned economies.

Most of the growth in energy use since 1970 has been in the developing countries (Figure 2-1). Their share of the world total grew from 20% in 1970 to 31% in 1990. (Not counting biomass fuels, the developing countries' share would be about 27%.) The share of the industrial countries fell from 60% to 48%, while that of the formerly-planned economies rose slightly from 20% to 21%. Growth in energy use between 1970 and 1990 averaged 4.5% in the developing countries and 2.4% in the formerly-planned economies, but only 1.3% in the industrial countries. Although energy use in the developing countries has grown much faster than in the rest of the world, per capita consumption remains far lower (Figure 2-2).

The reasons for these changes are explored in this chapter. A few points are worth mentioning now, however. First, population grew much more in the developing countries than in the other groups, and economic growth was also somewhat higher. Further, many developing countries have been in a stage of development in which use of commercial energy tends to grow faster than GDP due to increase in the role of manufacturing and building of basic infrastructure, to cite two key factors. In the industrial countries, on the other hand, structural change in economic activity and maturation of physical infrastructure has contributed to decline in the energy/GDP ratio. This "structural" decline was complemented by response to higher energy prices and energy conservation policies, as well as ongoing technological innovation. In many developing countries, energy users have been somewhat insulated from higher energy prices, and information, technology, and capital to improve energy efficiency have been far more scarce than in the industrial countries.

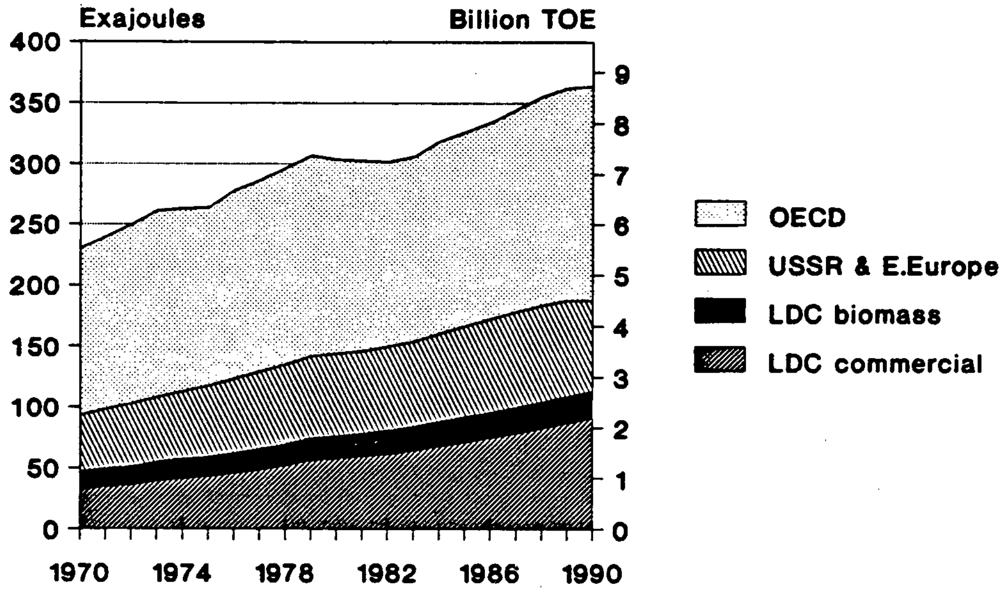
In the rest of this chapter, we take a closer look at how and why energy use has changed in each country group, and at the directions in which key forces are pushing. Before doing so, we describe the conceptual framework that we use to study energy consumption, and discuss several issues that are important to understanding change in energy use.

2.1. UNDERSTANDING TRENDS IN ENERGY USE: A CONCEPTUAL FRAMEWORK

Understanding trends in energy use requires study of the activities for which energy is used, and of how people and technology interact to provide the energy services that are desired. Broadly speaking, there are two large classes of energy uses: the transformation of primary energy sources into fuels, electricity, and heat; and all other activities. Total energy use ("primary energy") is the sum of the energy consumed directly by end-users ("final energy") and the energy "lost" in the making of energy products (and in delivery of electricity). Since final energy provides the energy services that users want, it is the main focus of our attention, but it is important to be aware that final use of electricity usually entails loss of considerably more energy in its production and delivery (approximately twice as much if electricity is produced from fossil fuels).

Figure 2-1

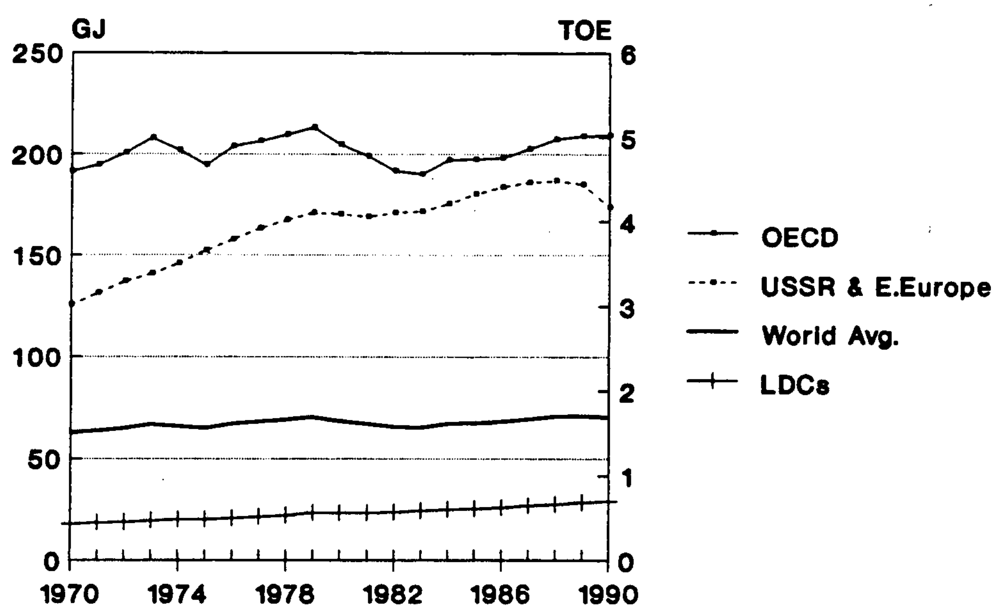
World Primary Energy Use 1970-1990



Sources: BP, IEA, & LBL

Figure 2-2

Primary Energy Use per Capita 1970-1990



The most aggregate description of the relationship between energy use and activity is the ratio of energy use to Gross Domestic Product (GDP). While appealing because it presents a societal overview in a single statistic, trends in the energy/GDP ratio do not shed light on the two basic phenomena that shape energy use: (1) change in the levels of different activities; and (2) change in the amount of energy used to accomplish them (their "energy intensity"). To understand these changes, one must look at specific sectors of activities. In our work, we examine five sectors: manufacturing, passenger travel, freight transportation, residential, and services (often called the "commercial" sector).[1]

Within each sector, it is helpful to organize data on energy use by various types of activity, and to express activity in a common unit. In manufacturing and services, classifying activities according to major economic categories is workable. In both cases, the framework used for GDP accounts provides a means for valuing various activities in terms of *value added*, the concept commonly used to express the net economic output of various activities. In manufacturing, data on energy use by subsector are often available; such data are much less common for the service sector.

In passenger travel, one can also divide activity by purposes (commuting to work, vacation, etc.). In freight transport, one can think in terms of the type of goods that are shipped (agricultural products, minerals, manufactured goods). In both of these cases, however, it is impossible to divide energy use in such a fashion. A more workable scheme is to use the modes of transport: automobiles, rail, bus, and air for passenger travel; truck, rail, and ship for freight transport. For each mode, it is often possible to estimate the amount of activity in a given period as the product of "how many" (passengers or tonnes of freight) and "how far" (kilometers). With careful use of energy data, and judicious application of certain assumptions, one can often estimate the energy used in each mode.

Structural change within the above sectors refers to shifts in the shares of total sectoral activity accounted for by the different subsectors or transport modes. It may increase or decrease energy use, depending on the energy intensity of the activities whose role is rising or falling. In manufacturing, for example, iron & steel, non-ferrous metals, paper & pulp, chemicals, and building materials are much more energy-intensive than other industries.[2] Thus, a shift away from the production of such goods decreases energy use relative to aggregate manufacturing activity. In freight transport and travel, a shift toward relatively energy-intensive modes such as trucks and automobiles increases energy use.

Structural change is shaped by factors specific to each sector. Economic changes obviously play a leading role in manufacturing and services. Household income and the cost and convenience of different modes are important in passenger travel. In freight transport, the modal structure is shaped by the type of goods that are moved. Mining and agricultural products, which are heavy relative to their value, are often transported via rail or ship, but the flexibility and speed of trucks tends to favor them as intermediate and final goods become more important in an economy.

Energy intensity expresses the amount of energy used per unit of activity. The aggregate energy intensity of each sector is determined by its subsectoral energy intensities and structure. The factors that shape subsectoral intensities vary among sectors. In manufacturing, changes in the product mix affect the energy intensity of particular industries. For example, the energy intensity of the paper & pulp industry is affected by shifts in production between energy-intensive pulp and finished paper goods. Change in the

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[1] We have not analyzed energy use in agriculture, mining, and construction, as energy-use data for these sectors are often uncertain. These sectors account for only about 10% of total final energy use in the industrial countries and somewhat more in the developing countries.

[2] For the eight OECD countries that we studied (see below), the average energy intensity in 1988 ranged from 31 MJ/1980$ of value-added for chemicals to 97 MJ for iron & steel. The average energy intensity of all other manufacturing was only 6 MJ/1980$.

scale of factories or equipment may impact energy intensities. All else equal, a larger factory often uses less energy per unit of output than a similar but smaller one, and a larger aircraft uses less energy per seat-kilometer than a smaller one.

Energy intensities depend on how equipment is operated and maintained and how well its capacity is utilized. In manufacturing, a production line that is operated at a low fraction of its capacity will usually be more energy-intensive than the identical system operated at full capacity. Similarly in transport, falling load factors (decline in the ratio of passengers to available seats) raise energy intensity even if the characteristics of the vehicle stock are constant. How vehicles are driven also affects energy intensity.

Technical energy efficiency, by which we mean the energy use of equipment or processes under some uniform operating conditions, is a major determinant of energy intensities.[3] It depends on the characteristics of various components, and how they interact. For example, the energy efficiency of a motor system is a function of the wiring, power conditioning equipment, controls, and transmission components, as well as the efficiency of the motor itself. Measures of technical energy efficiency are very difficult to estimate for an entire national stock of equipment or buildings, but they can sometimes be estimated for new equipment (such as cars or appliances).

Energy intensities are also affected by the type of energy that is used. For example, a change from oil-fired to electric heating equipment reduces the final energy intensity because the conversion of electricity to heat at the building is inherently more efficient than the conversion of oil to heat. If one counted primary energy, however, the switch from oil to electricity would *increase* energy intensity.

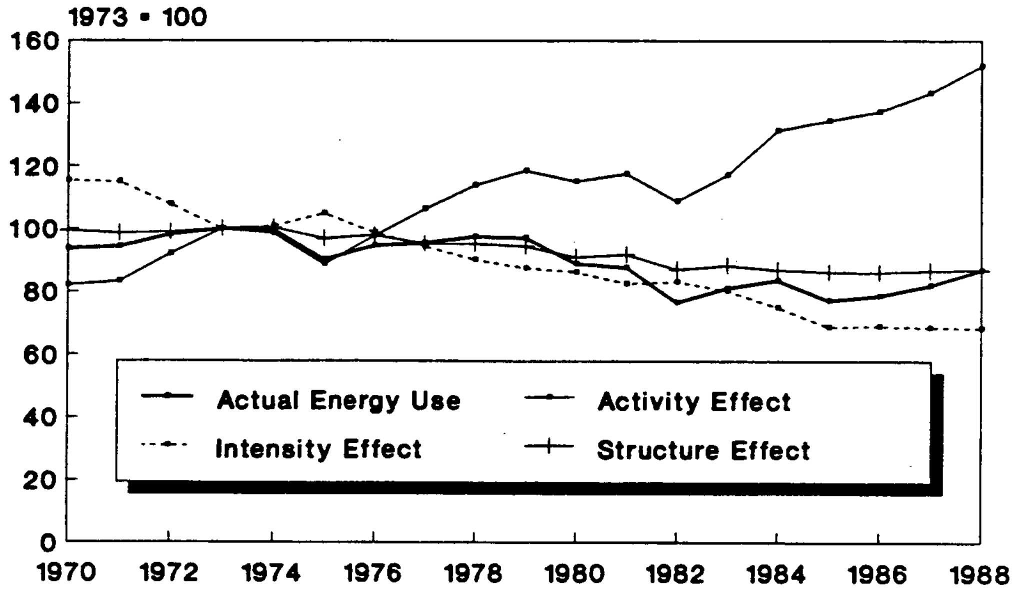
The residential sector is something of a special case. Measuring activity is difficult since there are many different energy-using activities that take place in homes but no single measure of "output." Here we use population as an indicator of residential activity. We define structural change with respect to household size, per capita ownership of energy-using equipment, and, for space heating, dwelling area per person. Thus, it partly describes change in the types of activities that take place in homes. Energy intensities are expressed in terms of energy use per person, per device, or per unit of area for each major end use. As in other sectors, residential energy intensities are shaped by equipment operation (e.g., household heating habits) as well as the technical energy efficiency of buildings and their equipment.

Together, change in activity, structure, and energy intensities shape trends in energy use in each sector, as Figure 2-3 illustrates for the US manufacturing sector. Final energy use declined by 13% between 1973 and 1988 even though aggregate activity (value added) grew by around 50%. If sectoral structure and energy intensities had remained constant, energy use would have increased by that amount. In fact, the structure of the sector changed in a way that dampened growth in energy use slightly. Decline in subsectoral energy intensities had an even more powerful downward effect. The combined result of these three forces was the 13% drop in energy use.

[3] Energy efficiency refers to amount of service delivered per unit of energy. Thus, when efficiency increases, energy intensity declines.

Figure 2-3

U.S. Manufacturing
Activity, Intensity, Structure Effects



2.1.1. Change in Energy Intensities: A Closer Look

In general, there are three basic ways in which change in energy intensities may occur: (1) modification of existing equipment or facilities (retrofit); (2) change in operation and maintenance; and (3) stock turnover -- the addition of new and retirement of old equipment or facilities. In the long run, stock turnover has the largest impact. In countries that are growing rapidly, or where a large part of the existing stock is obsolete, stock turnover can have a strong impact even in the medium term. In addition to the above factors, change in the operating environment and inputs also affects energy intensity in ways that are not always obvious. Growing traffic congestion increases the energy intensity of road transport modes, and the outside environment (e.g., presence of trees, color of surfaces) affects building energy use. The quality of fuels and electric power supply affects the energy efficiency of electrical equipment—both in terms of actual operation and choice of equipment; this is an important factor in developing countries.

Retrofit mainly effects buildings and factories. Improvement in the thermal properties of buildings or replacement of equipment may result from general-purpose renovation as well as from modifications made explicitly to conserve energy. Similarly, changes to industrial facilities designed to improve productivity generally may affect energy intensity.

Modifications in operation and maintenance may be short-term in nature, but some changes endure over time, or are only partly reversed. Procedures that enhance productivity are likely to endure in competitive sectors like manufacturing, air travel, and freight transport. This is less the case in homes and personal travel, where many behavioral changes that occurred in response to increased energy prices have partially or entirely reversed over time. The way in which equipment and buildings are operated changes with the characteristics of the technologies themselves. More powerful cars allow people to drive faster, but new technologies may facilitate more energy-efficient operation. Computerized control systems for buildings, industrial processes, and freight transport are increasingly being used to better manage operations. In many cases, decisions that formerly required people are now made by control technologies.

The impact of stock turnover on energy intensities may be positive or negative depending on the characteristics of existing and new equipment and facilities. The energy efficiency of new equipment or processes often improves over time—irrespective of energy prices—due to technological innovation, which may increase energy efficiency without that being a primary purpose of the change. In some cases, change in characteristics may push upward on energy intensity even as technological change improves technical energy efficiency. For automobiles, for example, increase in size and performance has partially counteracted the impact of improved technical energy efficiency in the OECD countries.

The rates of stock growth and turnover are key factors. In mature economies, the growth of the overall stock is relatively slow, but retirement of old equipment is often rapid. In developing economies, the addition of new equipment and facilities can be fast, but retirement of the old is usually slow. In general, where there are clear incentives to improve productivity, faster economic growth and the accompanying expansion of production results in more rapid incorporation of technological advances. If businesses successfully take advantage of opportunities during periods of higher economic growth, more resources are available for R&D to develop better technologies. For households, however, faster economic growth has a different effect. Increase in disposable income allows consumers to acquire new energy-using goods or replace old equipment with models that offer more service. It also allows purchase of more living area per person and attainment of a more comfortable indoor environment. All of these increase energy use. As the market for particular goods expands, innovations in production may result in lower real prices, making the products affordable to a greater portion of the population. The wealthy OECD countries are entering a phase in which marginal income is not increasing household energy use by very much, since the ownership of the main energy-intensive equipment is approaching saturation. In contrast, many middle-income developing countries are now in a period of rapid growth in ownership of appliances (and motor vehicles) similar to what occurred in Western Europe and Japan in the 1960s.

****

In the following sections, we use the framework of activity, structure, and energy intensity to explain past trends and outline future prospects for energy use. Because of the nature of the available data and the focus of our own research, we are able to look in greater depth and speak with more certainty for the industrial countries than for the developing countries and the formerly-planned economies. The data and analysis are primarily based on research conducted over the past decade by the authors and their colleagues in the International Studies Group at Lawrence Berkeley Laboratory. Appendix A contains a short discussion of the data sources used in this work. The sources are further described in the book cited in the Preface.

2.2. INDUSTRIAL COUNTRIES

2.2.1. Past Trends

After rising at a moderate pace in the early 1970s, primary energy use in the industrial countries declined sharply in 1974-75 and 1980-82 as users responded to higher energy prices and economic activity slowed. The increase in prices accelerated the historic decline in the energy/GDP ratio resulting from structural and technological change. Between 1983 and 1990, however, energy demand rose at an average rate of 2.7% per year. GDP growth was strong in this period, and the collapse of world oil prices in 1986 helped to diminish interest in energy saving. Electricity consumption increased faster than final use of fossil fuels, contributing to growth in primary energy use.

The US accounts for nearly half of total OECD energy use, though its share has fallen somewhat since 1970 (Figure 2-4). The share of Japan has grown slightly (from 9% to 11%), while the share of Western Europe has remained at about 33%. In most of the sections below we refer to eight countries ('OECD-8') whose energy use we have studied in detail. These are the US, Japan, West Germany, France, Italy, the UK, Norway, and Sweden. These include all of the G-7 countries except Canada, and account for about 85% of total OECD energy use.

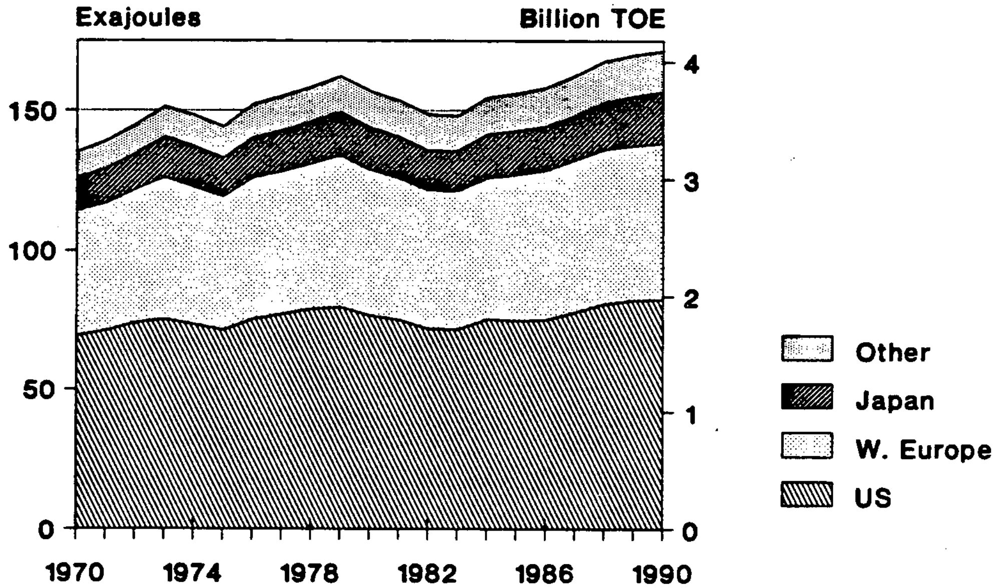
2.2.1.1. Manufacturing

The share of manufacturing in OECD final energy use declined from 36% in 1973 to 27% in 1988. For seven major countries, manufacturing value added (MVA) rose at an average rate of 2.3% per year between 1973 and 1988, but energy use fell by 1.2% per year.[4] OECD-7 aggregate manufacturing energy intensity fell a remarkable 40%. The decline was greater in the US and Japan (43% and 45%) than in Europe (34%). Structural change away from the energy-intensive industries accounted for about one-fourth of the decrease in aggregate intensity for the OECD-7. Particularly important was the decline in the share of iron & steel (the most energy-intensive sector) from 5.6% to 3.3% of total MVA. The one energy-intensive sector whose share grew (slightly) was chemicals, but the growth was in relatively less energy-intensive finished chemical products rather than in basic industrial chemicals such as ammonia and chlorine. Structural change played a more important role in the US and Japan than in Europe, which largely explains why the decline in aggregate intensity was less in Europe.

[4] Italy is not included in the manufacturing analysis due to data problems. The US accounted for 54% of total OECD-7 manufacturing energy use in 1988. See Howarth and Schipper (1991) for further discussion.

Figure 2-4

Primary Energy Use
Industrial Countries 1970-1990



Sources: BP & IEA

Decline in energy intensities at the industry level was the major force pushing aggregate intensity downward. For the OECD-7, the "structure-adjusted" manufacturing energy intensity declined by 32%. The drop in the three regions was rather similar: 32% in the US, 34% in Japan, and 30% in Europe.[5] For the OECD-7 average, the largest intensity reduction was in chemicals (37%). The decline in other energy-intensive sectors was 27% in paper & pulp and in iron & steel; 26% in non-ferrous metals; and 32% in building materials. Interestingly, the decline in non-energy-intensive industries (37%) was comparable to that in the energy-intensive sectors. This development reflects the trend toward higher value per unit of physical output as light manufacturing has shifted toward more "high-tech" products.

The trends have been very different for fuel intensity and electricity intensity. Structure-adjusted fuel intensity declined considerably in all countries, especially in the US, where the level in 1985 was 45% below the 1971 level (Figure 2-5a). Electricity intensity declined after 1975 in the US and Japan (but much less than fuel intensity), was fairly steady in West Germany and France (with some increase since 1984 in the latter), and rose in the UK (Figure 2-5b).[6] Switching from fuels to electricity in certain processes (especially in steel production) played a small role in shaping the above trends. Since there has been growing use of electrical processes in many industries, the trends in electricity intensity suggest that there has been some improvement in end-use efficiency.

Change in the product mix *within* industries (shift toward products that require less energy to produce per unit of value-added) contributed to decline in energy intensities. (Such shift may explain why the intensity decline in chemicals was larger than in other energy-intensive industries.) In general, however, most of the decline was due to improved efficiency in the manufacture of particular products. The key factor was the introduction of new production processes, which was a continuation of a long-term trend more than a response to higher energy prices. Improvements in operations and maintenance, retrofits to save energy, and retirement of older facilities also played a role.

2.2.1.2. Passenger travel

Domestic travel accounts for about 22% of final energy use in the industrial countries, and automobiles account for nearly 90% of this. Total domestic passenger-kilometers (p-km) grew by about 40% between 1973 and 1988 in the US, Europe, and Japan, but energy use for travel rose much less than that in the US. Aggregate travel energy intensity (energy use per p-km) increased slightly in Europe, rose substantially in Japan, but declined by 18% in the US. Because the US accounts for 70% of total OECD-8 travel energy use, the decline there caused OECD-8 travel energy intensity to decrease by 13%. Structural change played a small role in increasing aggregate intensity in the US and Europe, but had a major effect in Japan, where the role of the automobile rose considerably in the 1980s. (In the US, it already accounted for 90% of travel in 1970.)

Adjusted for structural change, travel energy intensity rose slightly in Europe and Japan, but declined by 15% in the US. Automobile energy use per km fell by 30% in the US, but there was little change in Europe and Japan, which began the period well below the US (Figure 2-6).[7] The decline in the

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[5] "Structure-adjusted" energy intensity describes how energy intensity would have evolved had the structure of the manufacturing sector remained in its 1973 configuration. Within Europe, large declines in "structure-adjusted" energy intensity in the UK and France were partly balanced by smaller declines in West Germany.

[6] Since there was growth in industrial electricity cogeneration in the study period, and the energy used in cogeneration is counted as fuel use, the true increase in electricity intensity was somewhat higher than is the case if one counts only purchased electricity (as we have done).

[7] The decline in the US would have been somewhat larger but not for growth in the use of light trucks as passenger vehicles. Automobile energy use per *p-km* declined less in the US and rose slightly in Japan and Europe due to a drop in the average load factor of car travel.

Figure 2-5a

OECD Manufacturing Fuel Intensities

Constant 1973 Industry Structure

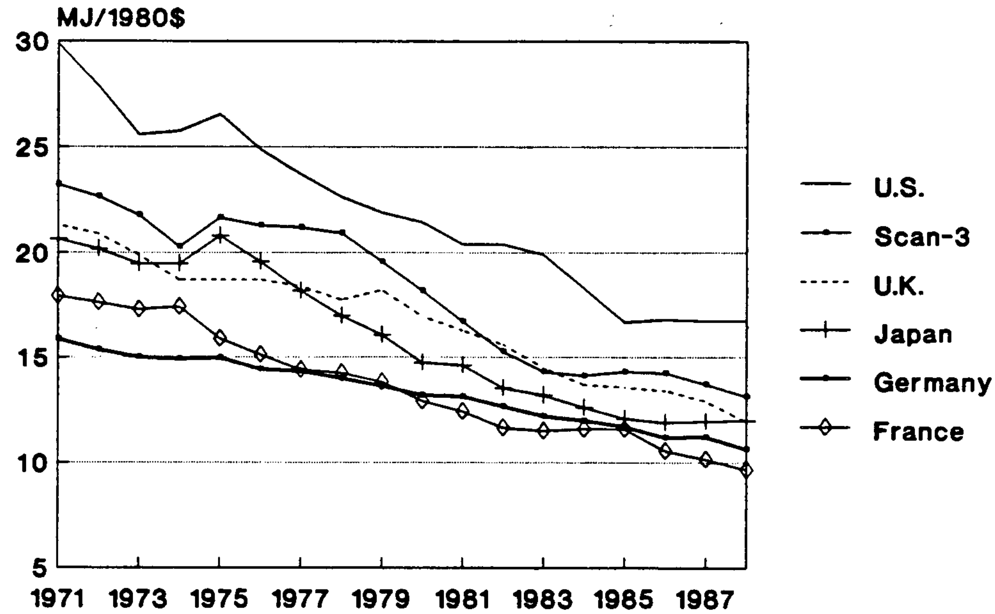


Figure 2-5b

OECD Mfg Electricity Intensities

Constant 1973 Industry Structure

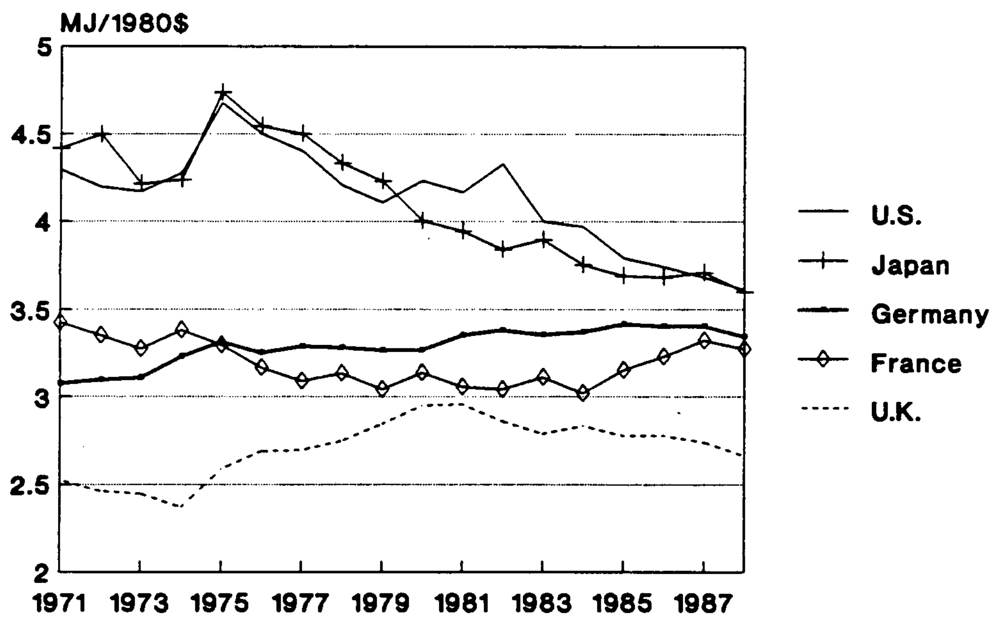
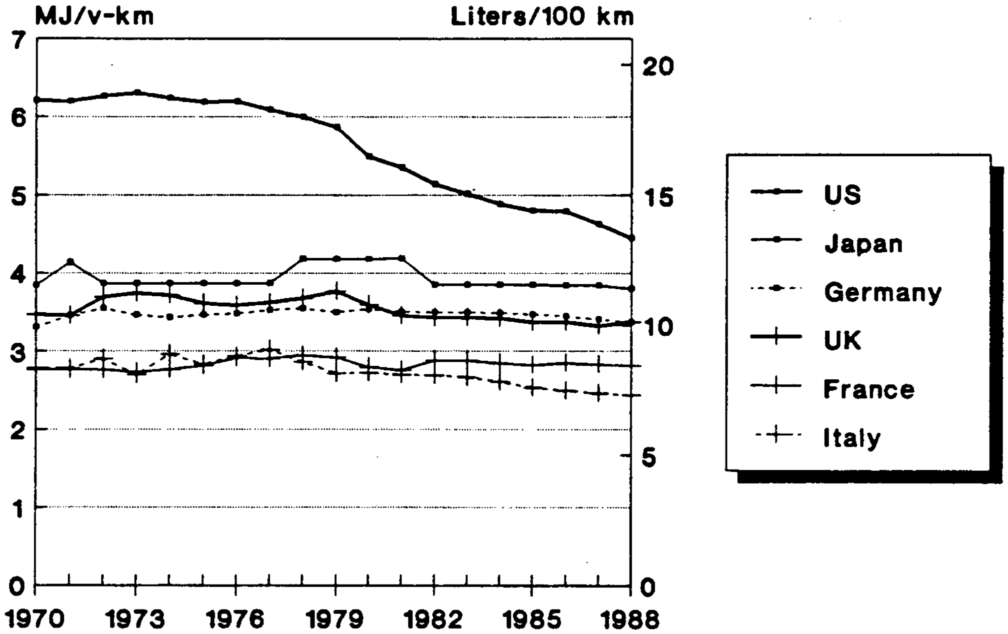


Figure 2-6

OECD Automobile Energy Intensities



US was the result of dramatic decrease (50% between 1973 and 1982) in the fuel intensity of new automobiles. As these cars have come to play a larger role in the automobile fleet, average intensity has steadily declined. In Europe and Japan, there has been only minor decline in the fuel intensity of new cars, as increase in size and power has offset gains from technical efficiency improvements. This phenomenon has caused the decline in new car fuel intensity to level off since 1982 in the US as well. In all of the countries, rising traffic congestion has dampened improvement in fleet fuel economy.

A large drop in the energy intensity of air travel contributed to the decrease in aggregate travel energy intensity. Domestic air travel intensity fell by 50% in the US between 1970 and 1988, and declined considerably in Europe and Japan as well. The main cause was introduction of new aircraft that were much more fuel-efficient than those they replaced. Retrofitting old planes with new engines and increased load factors also played a role.

2.2.1.3. Freight transport

Freight transport accounts for only half as much energy use as travel (about 10%) in the industrial countries. Energy use for domestic freight transport in the OECD-8 increased at an average rate of 2.3% per year between 1973 and 1988, somewhat faster than the annual increase in tonne-km of 1.9%. The increase in aggregate intensity was higher in Europe and Japan than in the US, as structural change toward greater use of trucks played a larger role, especially in Japan.

Trucks account for 85% of total energy use for domestic freight transport in the OECD-8. The energy intensity of freight trucking (energy per tonne-km) increased by about 13% in the US between 1973 and 1988, declined by 16% in Japan, and remained about the same in Europe. In the US, it appears that improvement in the technical efficiency of trucks was offset by increase in operating speeds on inter-city highways, growing traffic congestion in urban areas, and factors related to the operation of trucking fleets and the nature of freight carried. There is evidence of increase in the number of empty backhauls. In addition, it appears that the weight carried per volume of truck capacity declined. Both of these factors would result in reduced tonnage per distance traveled and contribute to higher energy intensity.

2.2.1.4. The residential sector

Energy use in the home accounts for around 20% of final energy use in the OECD countries. Space heating accounts for around 60% of this, but its role has declined since 1973. Final energy use per capita declined by 15% in the US between 1973 and 1988, but rose by 10% in Europe and by 46% in Japan. Increase in the market share of electricity for space heating, water heating, and cooking pushed down final energy use in all cases.[8] Decline in household size worked in the opposite direction, since per capita energy use rises as household size decreases.

Three structural factors that increased residential energy use were growth in home area per capita, increase in the levels of heating equipment (toward either central heating or use of more or larger heaters), and growth in appliance ownership. In the latter two cases, the effect was much larger in Europe and Japan than in the US, where these changes had begun already in the 1960s. This difference is a major reason why energy use per capita rose in Europe and Japan but fell in the US.

The energy intensity of space heating (energy use per square meter, adjusted for the heating equipment factor mentioned above) dropped considerably: by 45% in the US, 28% in Europe, and 35% in

[8] To account for this effect, we sometimes use the concept of "useful" energy, which is equal to final energy use minus estimated conversion losses at the home. Useful energy consumption per capita declined by 11% in the US but rose by 12% in Europe and by 59% in Japan.

Japan (Figure 2-7).[9] Probably the most important factor was energy-saving retrofit and installation of more efficient heating equipment in older homes. Introduction of new homes that were more energy-efficient than the average also played a role, particularly in the US, as did reduction in average indoor temperature (the decline has reversed somewhat in the 1980s, however). In contrast to space heating, water heating energy intensity ("useful" energy) rose by nearly 30% in Europe and by 60% in Japan due to greater use of central heaters with storage and growth in ownership of clothes washers and dishwashers. There was little change in intensity in the US, however, where central heaters were already the norm in 1970.

For electric-specific appliances, improvements in the technical energy efficiency of new appliances pushed downward on intensity (energy use per device). These improvements were especially large in the US for refrigerators and freezers. As with automobiles, however, the effect of higher efficiency was partially offset by increase in the size and/or features of many appliances (Schipper and Hawk 1991). A weighted-average energy intensity of seven major appliances fell by 13% in the US and by 2% in West Germany, but rose by around 40% in Japan, where increase in size was especially strong.[10]

2.2.1.5. The service sector

The service sector accounts for 11% of final energy use in the industrial countries.[11] Between 1973 and 1988, services energy use grew at an average annual rate of 0.8% in the US and Europe but by 3.9% in Japan. In each case, the rise in energy use was much less than the increase in services value added. Aggregate energy intensity declined by 28% in the US and Europe and by 15% in Japan. The figures on energy use mask very different trends for electricity and fossil fuels, however. While fuel intensity declined by 36-43%, electricity intensity increased by 15% in the US, 36% in Japan, and 28% in Europe. The share of electricity in OECD-8 services final energy consumption rose from 25% in 1973 to 40% in 1988.

Structural change in sectoral composition plays a much smaller role in the service sector than in manufacturing, since the various subsectors (offices, education, health, retail, etc.) do not differ greatly in their energy intensity. In Japan, the only country for which a lengthy data series on energy use and area by subsector is available, structural change in the sector's composition pushed slightly upward on aggregate energy intensity between 1973 and 1988. In the US, it appears that there was little change in the relative importance of different subsectors.

The decline in fuel intensity resulted mainly from addition of new buildings with lower heating requirements, retrofit improvements to older buildings, improved energy management, and changes in indoor temperature. Increasing popularity of electricity for heating played a role in some countries. This also pushed upward on electricity intensity, as did growth in the penetration of computers and other office equipment. While improvements took place in the efficiency of lighting, and various equipment and building envelope measures reduced cooling requirements, these changes were not large enough to overcome the forces that pushed intensity upward.

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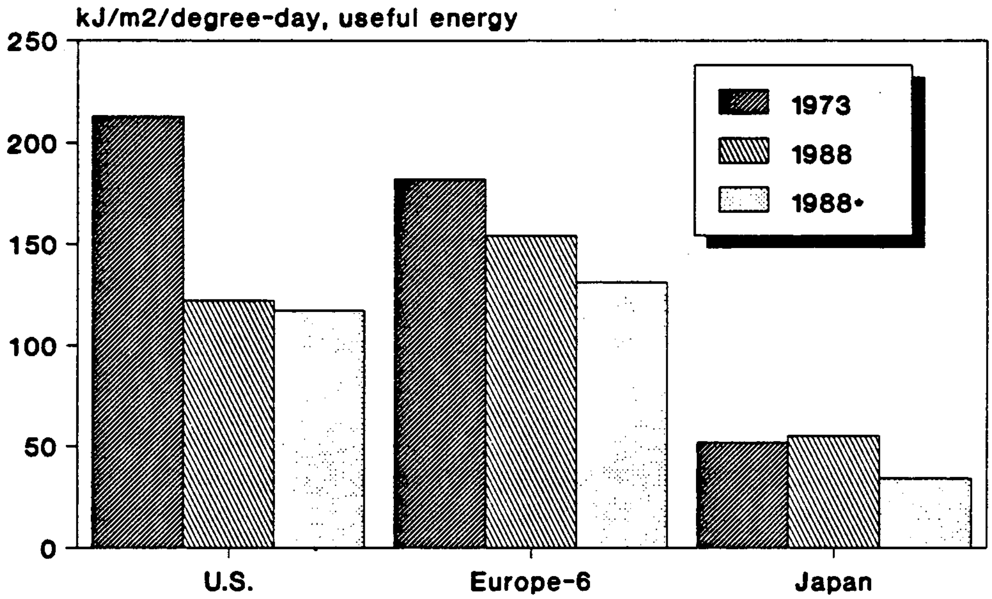
[9] The figures refer to the decline in "useful" energy, adjusted for climate change. The adjustment for increase in the number and size of heaters in Japan is a rough estimate.

[10] The seven appliances are refrigerator, freezer, refrigerator-freezer, clothes washer, dryer, dishwasher, and air conditioner (in the US and Japan). The weighting is based on 1980 appliance penetration in each country.

[11] The share of primary energy use accounted for by the service sector is somewhat higher since the sector is relatively more electricity-intensive than the others.

Figure 2-7

OECD Space Heating Intensities 1973-1988



* Adjusted for increase in heating equipment

2.2.1.6. Summary

To judge the overall impact of change in activity, structure, and energy intensities, we performed an analysis of the three largest industrial economies—the US, Japan, and West Germany—examining changes in over 20 subsectors or end uses. The impact of each force has differed among the three countries, as shown in Table 2-1. Increase in sectoral *activity* placed strong upward pressure on manufacturing energy use in the US and Japan, but less so in West Germany. It played a major role in passenger travel and in the service sector in all three countries. It had a somewhat weaker impact in freight transport, and very little impact in the residential sector. Weighting the activity impacts according to each end use or subsector's share of energy use in 1973, we find that the cumulative impact of growth in activity levels was to increase primary energy use by 39% in the US, 54% in Japan, and 21% in West Germany.[12] In each case, the energy-weighted average of activity change was less than the growth in GDP.

Structural change contributed to significant reductions in energy use only in manufacturing. In passenger travel, increase in the share of automobiles and airplanes raised energy use slightly in the US and West Germany, but by 21% in Japan. Growth in the role of trucks increased freight transport energy use more in Japan and West Germany than in the US. Structural change had the greatest impact in the residential sector. Increases in home floor area, heating equipment, and appliance ownership raised energy use by about 40% in the US and by about 60% in the other countries. In the service sector, data from the US and Japan indicate that there was little net impact. Overall, the weighted effect of structural change within the five sectors was to raise primary energy use by 7% in the US, 1% in Japan, and 15% in West Germany.

Change in *energy intensities* had a significant impact in reducing energy use in most sectors. In manufacturing, it reduced energy use by 27-29% in the US and Japan and by 14% in West Germany. In passenger travel, it reduced energy use in the US but increased it in the other countries. In freight transportation, it reduced energy use by 13% in Japan and by 20% in West Germany, but had little effect in the US. In the residential sector, it reduced energy use by around 25% in the US and West Germany, but increased use by 21% in Japan. As a weighted average, changing energy intensities reduced primary energy use by 21% in the US, 16% in Japan, and 15% in West Germany.

2.2.1.7. How much did energy efficiency improve?

While it is clear that improvements in *technical energy efficiency* have played an important role in shaping energy intensities, it is difficult to disentangle them from other factors. (We are using the term "energy efficiency" to refer to energy use with the level of service held more or less constant.) For example, some of the decline in home heating energy intensity was due to lower indoor temperatures, which could be considered a reduction in the level of service. For automobiles and home appliances, increase in the average level of service countered the effect of improved energy efficiency.

It is usually difficult to estimate change in the average technical energy efficiency of a given subsector or end use. One exception is jet aircraft, for which the fleet-average energy efficiency (seat-miles per gallon) nearly doubled between 1970 and 1989. In some cases, energy efficiency trends can be known for new equipment or estimated for new buildings. The existence of a testing program for new appliances in the US has allowed tracking of the trends in "energy factors" that express energy efficiency (adjusting for

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12 To assess the relative impact of the changes on primary energy use, we allocated losses in electricity supply to each end use or subsector according to its share of total electricity consumption. Manufacturing accounts for a much higher percentage of total energy use in Japan than in the other countries, so changes in that sector play a large role in the weighted average.

Table 2-1. Impacts of Changing Activity, Structure, and Energy Intensities on Sectoral Primary Energy Use, 1973-1988

Indicator/sector	Definition/description of factors	United States (%)	Japan (%)	West Germany (%)
PRIMARY ENERGY USE				
Manufacturing		-6	0	-7
Passenger travel		11	76	56
Freight transport		40	33	17
Residential		14	89	18
Services		36	82	25
Total		12	27	12
ACTIVITY				
Manufacturing	manufacturing value-added	52	64	18
Passenger travel	passenger-km	36	40	33
Freight transport	ton-km	34	18	24
Residential	population	16	13	-1
Services	service sector value-added	54	71	58
Weighted average[a]		39	54	21
GDP		45	83	34
STRUCTURE				
Manufacturing	subsector value-added shares	-12	-15	-8
Passenger travel	modal mix	3	21	5
Freight transport	modal mix	3	30	15
Residential	heated area and appliance ownership per capita, occupants per dwelling	39	57	63
Services	subsectoral mix	na	na	na
Weighted average[a]		7	1	15
ENERGY INTENSITIES				
Manufacturing	subsectoral energy intensities	-27	-29	-14
Passenger travel	modal energy intensities	-19	5	12
Freight transport	modal energy intensities	1	-13	-20
Residential	useful space heat energy per heated area, electricity per appliance, useful energy per capita for cooking and hot water	-25	21	-23
Services	energy per unit of value-added	-11	3	-21
Weighted average[a]		-21	-16	-15
Energy/GDP ratio		-26	-34	-23

[a] Weighted by sectoral shares of 1973 energy use.

Note: The approach we use to quantify the relative impacts of change in activity, structure, and energy intensity on aggregate sectoral energy use is rooted in the use of fixed-weight or Laspeyres indices. See Schipper and Meyers et al. (1992) or Howarth et al. (1991) for discussion.

changes in size where appropriate). There has been considerable improvement in energy efficiency, especially for refrigerators and freezers (Figure 2-8). Similarly, test data for new cars in the US show much improvement in the fuel economy of cars in each size class.[13]

2.2.1.8. The impact of energy prices

Energy prices indirectly affect the levels of sectoral activity through macroeconomic impacts. These are usually of a short-run nature, however. Prices may also affect sectoral structure in the short run, but the important impacts are long-run in nature.[14] For example, historically low gasoline prices contribute to reliance on the automobile as a travel mode. Energy prices also have a long-run effect on the structure of the manufacturing sector. Countries with relatively low prices tend to have more energy-intensive industries.

The main impact of energy prices is on energy intensities. It is important to distinguish between short-term response (mostly change in behavior or operations), medium-term investment in new equipment, and long-term development and adoption of technologies that are less energy-intensive. Historically low gasoline prices in the US have encouraged automobiles with higher fuel intensity than in Western Europe and Japan, but increase in prices contributed to interest in more fuel-efficient cars in the US in the 1970s and early 1980s. In the residential sector, increase in oil prices caused both switching away from oil for space heating and a decline in intensity among households that continued to use oil (part of which was due to greater use of secondary heating fuels such as wood and electricity) (Figure 2-9). There has been little upward response to the sharp drop in oil prices in 1986, which suggests that indoor comfort was relatively satisfactory in the mid-1980s.

In manufacturing, the impact of changing energy prices on intensities is difficult to determine. In the industrial countries, the "structure-adjusted" manufacturing energy intensity fell at about the same rate between 1960 and 1973 as between 1973 and 1988, despite there being almost no change in energy prices in the earlier period and major increase in prices in the latter (Figure 2-10). One might be tempted to conclude that the rise in prices had no effect at all, and that "autonomous" technological change alone was the cause of intensity decline. However, value added grew substantially faster in the earlier period than in the latter. Since investment in new facilities is a principal source of intensity reduction, one would expect there to be more intensity decline in the earlier period. Thus, the increase in energy prices obviously had an effect in the 1973-88 period, but it appears to have been smaller than the autonomous effect of technological change.[15]

2.2.1.9. The role of energy conservation policies

Along with higher energy prices, government energy conservation policies played a role in causing decline in energy intensities in some sectors. The main target of government programs has been the residential sector (Wilson et al. 1989). Dissemination of information and exhortation to conserve energy has been extensive, but the impact seems to have been small and/or short-lived. Energy labeling for new appliances was instituted in North America, but here too it appears that the impact on consumer behavior was relatively small. Efficiency standards probably had the strongest impact on energy intensities.

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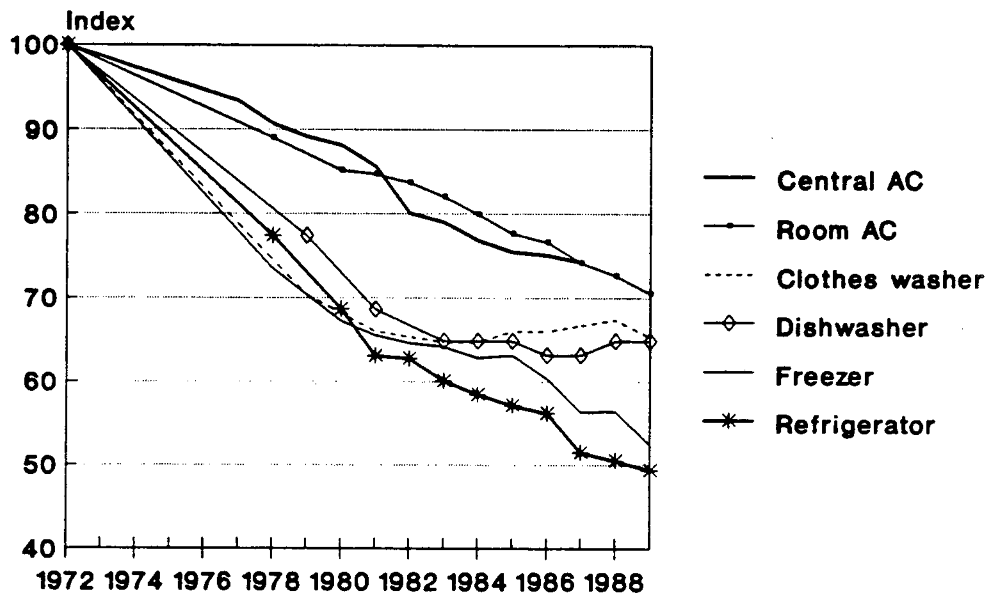
[13] In fact, there has been an increase in the level of service (in terms of performance) within each size class.

[14] Automobile driving was mildly responsive in the short-run to change in fuel prices; people switched to other travel modes, but only for a time.

[15] Manufacturing energy intensities in 1973-88 fell more in the US and Japan, which experienced increases in energy prices that were greater than those in Western Europe.

Figure 2-8

U.S. New Electric Appliances Specific Energy Intensity Indices *



*Shipment Weighted Energy Factors

Figure 2-9

Oil Heating Intensity in OECD Countries

Single-Family Homes with Central Heat

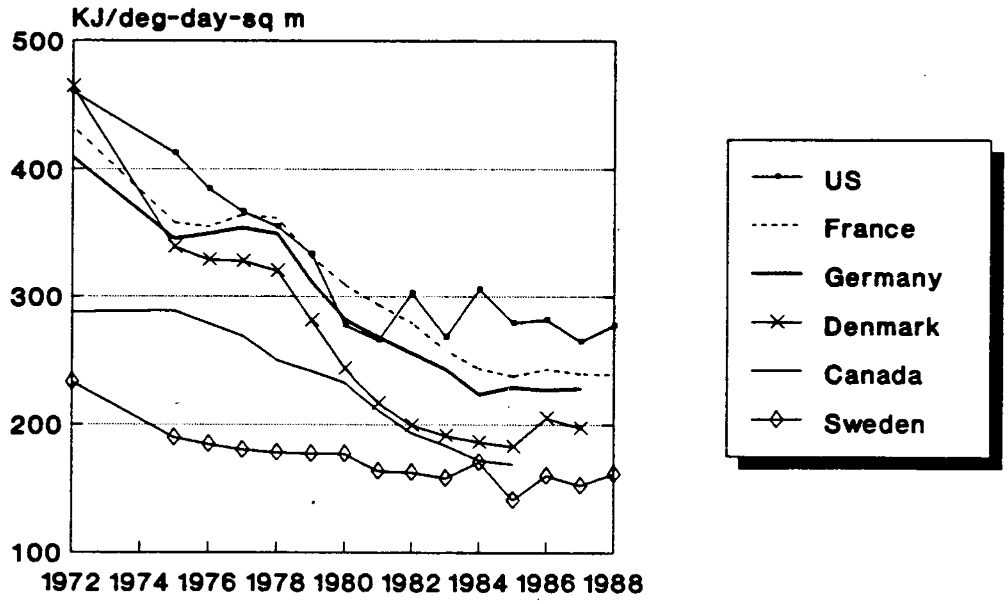
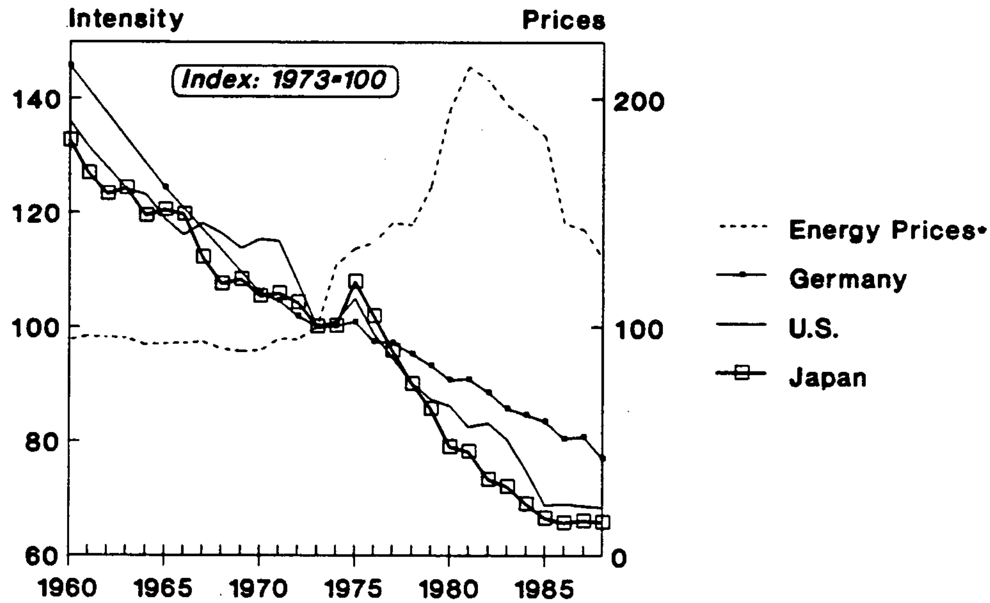


Figure 2-10

Long-Run OECD Mfg. Energy Intensities

Constant Industry Structure



* Real cost of energy inputs in US.

Building codes for new houses in Western Europe and some US states raised efficiency levels above what the industry would have done on its own. In the US, California, New York, and eventually the Federal government adopted appliance standards that accelerated efficiency improvement. In Japan and West Germany, voluntary agreements between government and domestic manufacturers led to higher efficiency in appliances. Grants for retrofit of existing homes were popular in Western Europe, and the US had tax credits for conservation investments, but the degree to which these incentives increased energy-saving activities over what would have occurred otherwise is uncertain.

In transportation, the US was the only country that established mandatory fuel efficiency standards for new cars and light trucks. There has been considerable debate about the influence of the standards, which began in 1978 and became gradually tighter. An analysis that used detailed manufacturer data indicates that they were at least twice as important an influence as gasoline prices (Greene 1990). The fact that new car fuel economy today is much better than in the 1970s, even though real gasoline prices have fallen to a level below that of the early 1970s, suggests that the standards did contribute to technological change. In most other industrial countries with automobile industries, voluntary targets for fuel economy improvement were established during the 1970s. The impact of these programs, all of which had expired by 1985 or 1986, varied among countries (IEA 1991).

In addition to government programs, many electric utilities in the US and, to a much lesser extent, in Western Europe have implemented programs to encourage electricity conservation by their customers. Until recent years, however, the scale of these programs was fairly modest, so their national impact was not large in the 1973-88 period.

2.2.1.10. Recent trends in OECD energy intensities: signs of a plateau

Since 1982, the energy intensity of many end uses in the industrial countries has ceased its previous declining trend or has even increased. It is not surprising that this should occur, since real prices of fuels have declined, and many energy conservation programs were discontinued or weakened. Much of the easy-to-cut "energy waste" was trimmed between 1973 and the early 1980s, and the most attractive technical improvements were made.

The plateau in energy intensities has been more apparent in "consumer" than in "producer" sectors. In the latter, competitive pressures and technological change have contributed to continued reduction in energy intensities. The decline in fuel prices has lessened interest in making investments for energy conservation, but addition of new capital stock has tended to reduce average energy intensities. Even so, there are signs of a plateau. The structure-adjusted manufacturing energy intensity in the US and Japan was unchanged in the 1985-88 period. For air travel, there was less decline in energy intensity in the 1984-88 period than previously. In freight transport, truck energy intensity shows a plateau in the US and Western Europe since 1982, and has declined more slowly than before in Japan. In the service sector, the historical decline in fuel intensity has slowed since 1982 in the US and Western Europe, and there has been no change in Japan. Service-sector electricity intensity shows roughly the same trends after 1982 as before, but this result is difficult to interpret, since there has been increase in equipment and improvement in end-use efficiency at the same time.

Consumer-dominated sectors show a clear plateau in energy intensities. Home heating energy intensity has declined only slightly in the US and Western Europe since 1982, and has increased in Japan. Retrofit of older homes has slowed, and households have increased indoor temperatures somewhat. In the US, there has also been a plateau with respect to the thermal integrity of new houses. For electric appliances, estimates of stock-average energy intensities show a plateau (or even rise in intensity) in recent years in many cases due to increase in size and features. In the US, the technical energy efficiency of new appliances has continued to decline for refrigerators, freezers, and room air conditioners due to imposition of State efficiency standards and anticipation of Federal standards.

The energy intensity of automobiles followed the same trend after 1982 as before in Europe and Japan—essentially no change. In the US, the intensity has continued to decline as newer vehicles replace older ones. For new automobiles, however, there has been a plateau in average fuel economy in the US, and less decline than previously in Italy and France (Figure 2-11). In Japan, new car fuel intensity has noticeably increased as consumers have moved to larger and more powerful vehicles. The plateau for new cars will have a larger effect on fleet fuel intensity in years to come than it did in the late 1980s.

2.2.2. Future Prospects

The population in the OECD countries is expected to grow at around 0.6% per year in the 1990s, with a gradual slowing in the first decade of the next century. Since the labor force will grow more slowly in the future, the rate of increase in labor productivity must accelerate if historic rates of economic growth are to be maintained. Most economic forecasters expect GDP to grow somewhat more slowly in the 1990s than in the 1980s. The consensus view in 1991 showed an average growth rate of 2.5-3.0% per year in the 1990s. If macroeconomic policies are unfavorable, high interest rates and trade imbalances persist, and protectionism increases, international trade and investment would be hurt, and economic growth would falter. Growth is expected to be below the average in the US, about equal to the average in Western Europe, and well above the average in Japan. For each of the above, the rate of growth will gradually slow in the early 21st century.

2.2.2.1. Manufacturing

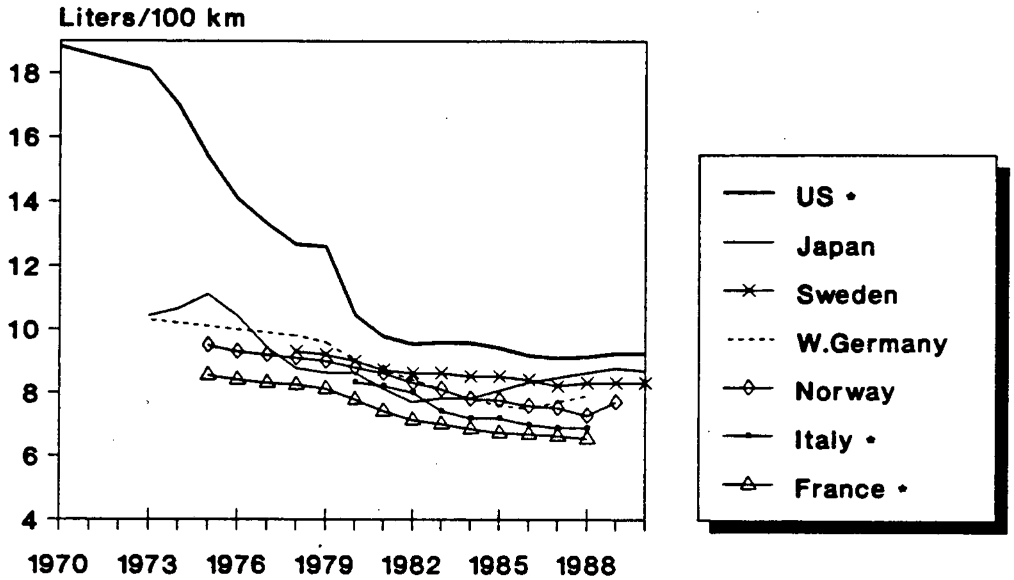
Manufacturing value added is expected to increase at a lower rate than GDP in most OECD countries, but is projected to grow faster than GDP in the US. Growth in output will be increasingly concentrated in products with relatively low energy requirements per unit of value, such as computers, medical instruments, pharmaceuticals, and other "high-tech" goods. The role of energy-intensive industries such as steel, nonferrous metals, and cement will continue to decline, and growth in these industries will come primarily from higher-value-added products.[16] Among other energy-intensive sectors, chemicals is expected to grow most rapidly, but less of the sector's value-added will come from energy-intensive industrial chemicals. Among non-energy-intensive industries, growth is likely to be faster in sectors such as office, medical, and communications equipment than in traditional areas such as transport equipment, food, and textiles. These changes will have some impact on energy use, since the faster-growing sectors are less energy-intensive than the others.

OECD manufacturing energy intensities will continue to decline as industries adopt new production techniques and implement other measures to enhance productivity. The rate of decline in fuel intensities will probably be somewhat slower than in the past, but the lower rate of increase in fuel prices may have only a modest impact, since prices are not the major determinant in adoption of new production techniques. The trend toward products with higher value will decrease energy intensity in many industries (for example, the shift from industrial chemicals to specialty plastics and pharmaceuticals within the chemical industry). Electricity intensities will decline far less than fuel intensities, and may increase in

[16] The decline in the role of energy-intensive industries is partly the result of a long-term trend toward lower consumption of certain basic materials relative to GDP. Consumption of steel and cement per unit GDP has been falling since 1960 in the US (since 1950 for steel) and since 1970 in West Germany (Williams et al. 1987). These trends reflect the maturation of transport and buildings infrastructure, reduced waste in manufacturing processes, improvements in the strength and durability of materials that have permitted manufacturers to do more with less, and the shift away from steel towards modern composite materials.

Figure 2-11

New Automobile Fuel Economy, Test Values
OECD Countries, 1970-1990



* Includes diesels
US includes light trucks

some cases due to the growing use of automation and electrical processes. At the same time, however, the electrical processes themselves will become more efficient. In most cases, electricity is being used more to control processes, which leads to greater overall efficiency, than as a direct substitute for fuels.

2.2.2.2. Passenger travel

Travel will probably grow faster than GDP in most OECD countries. The combination of more leisure time and growth in both personal and business long-distance links will increase travel substantially. Rising traffic congestion may constrain urban travel somewhat, but expansion of metropolitan areas may increase the distance of many trips. Travel to work may increase less rapidly in the future,[17] but international integration of economic activity is likely to increase the frequency and distance of work-related trips. Eventually, advances in telecommunications may make some work-related travel unnecessary. The area with the greatest potential for growth is leisure and vacation travel. Movement toward four-day work weeks and more vacation will give people time to travel longer distances, and foreign vacation travel seems likely to increase as it becomes more familiar and comfortable.

The structure of travel in the OECD countries is moving towards greater energy intensity as auto use continues to grow in urban travel and air travel increases. In the US, there are reasons to expect some slowing in growth in automobile travel, since nearly all adults are by now licensed drivers, most drivers have access to their own vehicle, and time constraints and traffic congestion may limit the increase in travel per driver. In Europe and Japan, on the other hand, there is still considerable room for increase in automobile ownership and distance travelled per driver. In Europe, decontrol of air fares and economic integration are likely to bring strong growth in air travel. As high-speed rail expands, it will compete with air (and automobiles) for medium-distance trips in Europe and Japan. Since differences in the energy intensities of high-speed rail, automobiles (on the open road), and air travel have diminished, small shifts among modes in the range of distances where they compete will have a relatively modest impact on energy use.

The key issue for automobile energy intensity is the extent to which growth in size and performance will cancel the impact of improvements in technical energy efficiency, and the degree to which market forces or government policies encourage manufacturers to incorporate design changes that increase fuel economy while also providing the amenities that consumers want. In the US, fuel intensity will decline considerably even if the plateau in new car fuel economy continues, since new cars are substantially less energy-intensive than the fleet average. With gradual improvement in new car fuel economy, a decrease of 35-40% in the fleet average energy intensity between 1988 and 2010 is plausible. In Western Europe and Japan, new cars have similar fuel intensity to the fleet average, but some improvement (perhaps 25-30%) is likely as new technologies are incorporated.

The energy intensity of air travel will continue to decline with the addition of new aircraft, but the rate of improvement is likely to be well below that achieved in the past. The plateau in fuel prices means that manufacturers are placing less emphasis on fuel efficiency than in the past. Energy intensity will nonetheless decline due to stock turnover, increase in the average size of aircraft, and rise in load factors.

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[17] Commuting of women will be less a source of growth in the future, since the percentage of women who are in the labor force is already high in most countries. Increase in working at home will reduce commute trips, as will movement toward a four-day work week.

2.2.2.3. Freight transport

Freight tonne-km is likely to grow slower than GDP as goods with higher value per unit weight come to play a greater role in the OECD economies. Shipments will be smaller and more time-sensitive as the use of "just in time" manufacturing (in which both inputs and products are dispatched and received as available and needed) increases. Origin and destination points seem likely to increase in number and become more dispersed.[18] In addition, intra-urban movement of goods associated with business and personal services is on the rise. All of these changes point to an increasing role for trucks and vans.

OECD-average truck fuel intensity is likely to slowly decline as various fuel-saving technologies gradually penetrate into the fleet. Competition is likely to lead to improvements in operations, including better matching of truck specifications to missions, reducing empty or low-load return trips, and improved maintenance.

2.2.2.4. The residential sector

The population is growing relatively slowly in the OECD countries, but the number of households is increasing at a faster rate due to decline in household size. Many of the structural changes that pushed upward on energy use in the past will have much less impact in the future. Home area per capita will grow mainly due to decline in household size, but might level off by 2010 due to space constraints and a slower rate of decrease in household size. Further growth in central heating penetration in Europe will be minimal (mainly in the UK). Growth in ownership of the major appliances will have a much smaller impact in the future. Ownership of refrigerator-freezers, freezers, and clothes washers is approaching saturation. Of the other major appliances being added, only clothes dryers represent a significant use of electricity. Air conditioning is already widely present in the US and Japan; it has begun to appear in southern Europe, but its penetration is expected to be limited. Ownership of home electronics is growing, but these devices use relatively little electricity. One development that could be a major consumer of electricity is high-definition TV, which uses much more power than conventional TV.

In North America and Western Europe, the energy intensity of space heating will continue to decline, but probably much more slowly than in the past, when rising prices and subsidies for retrofit encouraged substantial energy saving. Since new housing is being added slowly (especially in Western Europe), the rate of decline will depend mainly on retrofit activity. Without major increase in energy prices or new subsidy programs, such activity may be modest, and relatively little change in indoor temperatures is likely. In Japan, intensity is likely to rise as indoor comfort improves, but space heating will remain a relatively minor end use.

The energy intensity of water heating may increase somewhat in Europe and Japan due to growing use of larger storage tanks, often in combination with central heating. Cooking energy use per capita is likely to decline slightly due to change in equipment and in cooking habits, as well as improved efficiency of devices. Halogen-element cooktops and microwave and convection ovens are penetrating the market for reasons of speed and convenience, and offer energy saving as a side benefit.

For most electric-specific appliances, energy intensity will decline as the stock turns over. In the US, appliance efficiency improvement is being strongly pushed by national standards and utility incentives. In Europe, momentum is building for standardized energy efficiency labeling and perhaps standards as well. For some appliances (especially refrigerators in Europe and Japan), improvement in

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[18] Improved communications systems, computer-aided design and manufacturing, flexible manufacturing, and increases in labor productivity is changing economies of scale on the producer side, and the growth of suburbs and small cities is increasing the number of destination points for goods.

technical energy efficiency is being balanced by growth in size and features. Two-door refrigerator-freezers with full freezing capability and automatic defrost are becoming more common.

2.2.2.5. The service sector

Service sector value added will continue to grow more rapidly than GDP in most OECD countries, but floor area may increase more slowly than value added. In Europe and Japan, floor area per employee is 20-30% less than in the US. While this suggests room for growth, the high cost of real estate could constrain that. Expansion of floor space is likely to be especially strong in health care and leisure-related buildings, both of which are relatively energy-intensive.

Fuel intensity will continue to decline with building retrofit and addition of new buildings, but the rate of decline is likely to be much slower than in the past. Electricity intensity will be pushed upward by gradual growth in use of electricity for heating and the rising penetration of computing and other office equipment. However, the efficiency of most end uses will increase as new lighting and window technologies, more efficient motors and compressors, and computer-controlled energy management systems penetrate the market. Utility DSM programs are likely to play a significant role in improving electric end-use efficiency in the US, and will probably become more important in Europe and Japan as well. The net effect of the above forces is difficult to judge; on balance, we believe that OECD-average electricity intensity is tending to decline slightly.

2.2.2.6. OECD energy use in 2010: a scenario

Building on past trends and judgement about the future, we constructed a scenario that describes how activity, structural change, and energy intensities may evolve and affect energy use in the OECD countries over the next 20 years.[19] The scenario assumes that OECD-average GDP grows at 2.8% per year. Manufacturing (and other industry) grows at 2.4% per year, while services value added increases at 3.1% per year. Domestic travel grows faster than GDP (3.1%), while freight transport increases slower (2.4%). Population rises at 0.6% per year. Weighting the activity growth rates by the share of 1985 energy use accounted for by each subsector or end use, the combined effect of activity growth is to increase final energy demand at a rate of 2.4% per year. The main reason why growth in the energy-weighted "activity factor" is lower than GDP is that manufacturing and freight transport, which are relatively energy-intensive per unit of value added, grow more slowly than GDP, while services grows faster. The activity effect on electricity demand is lower (2.1%), since the sectors where electricity is relatively important (households and services) are together growing more slowly than transport, in which electricity use is very small.

The effect of structural change varies among the sectors (and for fuels and electricity). In manufacturing, structural change toward less energy-intensive industries decreases energy use by 0.4% per year, somewhat less than in the past.[20] The impact is greater on fuel use than on electricity demand, since the industries whose importance is declining are more fuel-intensive than the others. In passenger travel, growth in the share of air and automobiles increases energy use by 0.2% per year, while rise in trucks pushes freight energy demand up by 0.3% per year. Structural change has the largest impact in households, increasing energy use by 1.2% per year, although the effect is smaller than in the past. (In this

[19] Details of the scenario are described in Appendix B. The scenario considers fuels and electricity separately in some 25 end uses or subsectors. The base year is 1985.

[20] The rates describe the impact on energy use of structural change alone; i.e., how energy use would evolve if activity and energy intensities remained constant. Structural change in manufacturing does not include shifts in the product mix within industry groups; this effect is part of intensity change.

case, the impact is greater on electricity than on fuels, since the driving factors are growth in ownership of electric appliances and a shift toward electricity in space and water heating.) In the service sector, we define structural change differently than in the historical analysis. Decline in the share of floor area heated with fuels has a downward effect on fuel use, but growth in electric heating and penetration of other electrical equipment pushes upward on electricity use. The total effect of structural change (weighted by 1985 energy use patterns) is to increase final energy demand by 0.1% per year, and primary energy use by 0.3% per year.

Taken together, activity growth and structural change increase final and primary energy demand at rates of 2.6% and 2.7% per year, respectively. Decline in energy intensities means that actual energy use will grow much less than this, however. The scenario reflects our judgment about intensity changes that are likely to occur if energy prices evolve as currently expected and if policies and programs now in place or under development are reasonably effective. The changes are depicted graphically at the end of Chapter 3. In many cases, the stock-average intensities in 2010 are near the average values for new technologies in 1990. The intensity reductions are mostly in the 15-25% range (industrial fuel intensity declines much more, in keeping with past trends). The reductions are not large enough to balance the growth due to the activity and structural changes described above. OECD primary energy use rises at an average rate of 1.3% per year, and is about 40% higher in 2010 than in 1985.

2.3. DEVELOPING COUNTRIES

2.3.1. Past Trends

Primary energy use in the developing countries increased over two-fold between 1970 and 1990.[21] There was some reduction in the pace of growth after the two oil-price shocks, but slower growth in oil-importing countries was largely balanced by rising use in the oil exporters. Between 1982 and 1990, LDC energy use grew at an average of 5.1%/year. Growth has varied among regions, however (Figure 2-12). The pace of increase has been above the average in China and the rest of Asia, and also in the Middle East. Growth was much less in Latin America and Africa due to slower economic growth in those regions. China accounted for 31% of total LDC energy use in 1990, the rest of Asia for 26%, Latin America for 22%, Africa for 10%, and the Middle East for 11%.

2.3.1.1. Manufacturing

Manufacturing accounts for an estimated 35-40% of final energy use in the developing countries. Its output and energy use have grown significantly since 1970.[22] Not including China, manufacturing value added averaged growth of 3.9% per year in the 1980s, well below the average of 7.4% registered in the 1970s.[23] Growth in output has been much higher in Asia and the Middle East than in Latin America and Sub-Saharan Africa (especially in the 1980s).

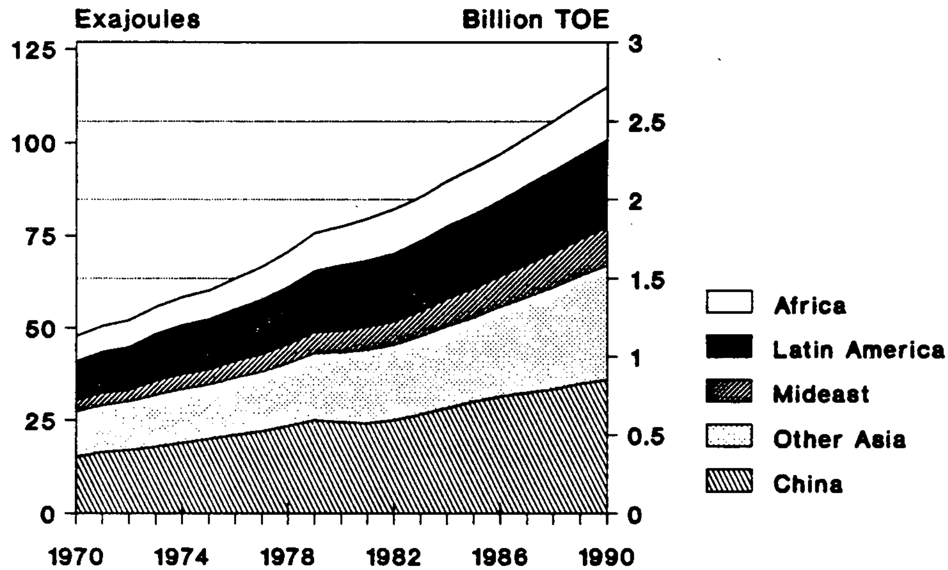
[21] We include estimates of biomass energy use in this section, but they are subject to considerable uncertainty (see Appendix A). Growth in commercial energy use was faster than that of total energy use due to the transition away from biomass fuels.

[22] Manufacturing output and energy use in the developing countries as a group is dominated by China, India, and Brazil. China alone accounts for nearly half of total LDC manufacturing energy use.

[23] Data on value added are from the United Nations Industrial Development Organization (UNIDO 1990). The data are expressed in real prices, converted to US dollars using 1980 exchange rates. China is not included in the UNIDO statistics due to lack of comparable data. If it were included, the average growth would be considerably higher.

Figure 2-12

Primary Energy Use
Developing Countries 1970-1990



Note: Includes biomass. Commercial energy use rose from 32 EJ in 1970 to 91 EJ in 1990. Sources: BP, IEA, LBL.

The structure of manufacturing in the developing countries as a group has become somewhat more energy-intensive since 1975. Again excluding China, the share of the five energy-intensive industries in total value-added increased from 18% to 20%. Iron & steel and non-ferrous metals especially grew faster than the average. Structural change has varied among countries, however. Many oil-rich countries have used their resources to build energy-intensive industries (especially petrochemicals), and some countries have used their hydro resources to expand basic metals industries (e.g., Brazil and Venezuela). Other countries, especially in Southeast Asia, have developed more labor-intensive industries. In China, the historically large share of heavy industries in total output has declined somewhat.

There are indications that manufacturing energy intensities declined in some countries, especially where substantial investment in new facilities has occurred. In China, aggregate industrial energy intensity declined by a remarkable 45% between 1980 and 1988. Between 1980 and 1985, when intensity declined by 27%, intensity reductions within particular industries accounted for around three-fourths of the total decrease (Liu et al. 1991).[24] In East Asia, there is clear evidence that the rapid growth in manufacturing contributed to decline in energy intensity. In Taiwan, aggregate energy intensity averaged decline of 5.1%/year between 1978 and 1987 mostly due to reduced intensities at the industry level (Li et al. 1990). In South Korea between 1975 and 1987, aggregate energy intensity fell by 2.6%/year. Here too, reduced intensities at the industry level played the dominant role (Korea Energy Economics Institute 1989). The situation has been different in Brazil, where aggregate energy intensity increased at an average rate of 0.9% per year between 1973 and 1988 (Geller and Zylbersztajn 1991). Compared to Taiwan and Korea, there was less introduction of new factories and equipment, and the availability of cheap hydroelectricity favored the development of steel and aluminum industries. Although this contributed to increase in aggregate energy intensity, there was decline in energy intensity in the iron & steel, paper & pulp, non-ferrous metals, and cement industries.

2.3.1.2. Passenger travel

Passenger travel accounts for only about 5% of final energy use in the developing countries, but it has contributed to growing demand for petroleum products. The magnitude of growth in travel is uncertain, since the reported statistics often do not include reliable estimates of private travel by cars and two-wheelers.[25] Even so, data for several countries show considerable increase in per capita travel in the past two decades: 7% per year in South Korea and Brazil (through 1985 for the latter), and 11% per year in China. The levels of per capita travel (especially in China) are well below the European average, however.

Buses and, in a few countries, rail, still account for a large majority of motorized travel in most developing countries. In South Korea, for example, the data show a decline in the shares of buses and rail, but they still accounted for 60% and 24% of total travel in 1987, respectively, while cars (including taxis) accounted for only 14%. In China, rail dominates travel, but its share declined from 70% to 53% between 1970 and 1988, while the share of road modes (mostly buses) increased from 23% to 41%. Use of automobiles has grown considerably, especially in Latin America and the Middle East, where higher income and urbanization have led to much greater per capita car ownership than in Asia and Africa. In much of Asia, where cities are more crowded, there has been growing use of mopeds and motorcycles.

[24] Energy intensity declined more in non-energy-intensive industries (30%) than in energy-intensive ones (18%). This was likely due in part to the faster growth (and addition of new factories) of non-energy-intensive industries, and perhaps to change in their product mix as well.

[25] The data in this section include motorized modes only. Walking and bicycles account for a significant amount of travel in the developing countries.

Lastly, domestic air travel has increased considerably in large countries in the past decade.

Change in energy intensities is difficult to assess. Bus and rail systems have probably not seen very much efficiency improvement in most countries. For automobiles, it is likely that the efficiency of new cars has increased in keeping with international trends in vehicle technology, but there are signs of a shift to larger, more powerful cars in some countries. In Brazil, the transition from gasoline to ethanol-fueled cars reduced average fuel intensity, since the latter are inherently more fuel-efficient, and there has also been improvement in the fuel economy of new gasoline and ethanol-fueled cars. As in the industrial countries, it seems likely that the worsening of urban traffic conditions has dampened improvement in the actual fuel economy of automobiles and buses.

2.3.1.3. Freight transport

Freight transport accounts for around 10% of final energy in the developing countries. Its activity and energy use have grown substantially. The ratio of reported freight activity (tonne-km) to GDP has declined slightly since 1980 in China (a result of the "lightening" of economic output), changed little in South Korea since 1970, and risen significantly in Brazil (perhaps reflecting greater transport of mining and logging products from the Amazon region). Structural change in freight transport has also varied across countries, but it appears that the role of trucks has grown. China and India, which together account for a large share of total LDC domestic freight transport, still rely heavily on rail (and ships in China), but the role of trucks has risen in both countries. In South Korea, the share of trucks increased from 11% in 1970 to 48% in 1987, while rail declined considerably. In Brazil, on the other hand, the data show a decline in the share of trucks from 62% in 1973 to 54% in 1985, and an increase in the share of ships.

Here too, lack of data makes it difficult to assess how energy intensities have changed. For trucks, however, energy intensity may have declined in some countries (such as India and Brazil) due to a shift from gasoline to diesel-fueled trucks and an increase in the role of heavy trucks, which use less energy per tonne-km than medium or light trucks (if their capacity is utilized).[26] Improvement in the fuel efficiency of gasoline and diesel trucks has probably been minimal, however. Similarly, the energy intensity of rail transport has declined in India due to increasing use of diesel and electric locomotives in place of steam locomotives using coal, but the efficiency of diesel and electric locomotives has not improved very much. In China, steam trains are still predominant, but greater use of diesel locomotives has decreased energy intensity.

2.3.1.4. The residential sector

The residential sector accounts for about 35% of final energy use in the developing countries. The high share is due to the heavy reliance on biomass, which is utilized with very low efficiency. Cooking is the dominant end use, and space heating is relatively minor outside of China and Korea. Although trends in residential energy use are hard to estimate with precision, it appears that combined kerosene & LPG consumption per capita was fairly level in Latin America (with growth in Brazil since the mid-1980s), rose considerably in South Asia, but declined in some other Asian countries. Trends in biomass use are rather uncertain. Data for Brazil show a significant decline in per capita consumption since 1970, while estimates for several Asian countries show relatively little change. What is clear is that residential electricity use has grown rapidly, especially in Asia.

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[26] In Brazil, the share of diesel-fueled trucks increased from about 50% of the fleet in 1973 to over 85% by 1985, while the fraction of heavy and semi-heavy trucks rose from 15% to 28%.

Change and growth in equipment ownership has been a significant force. For cooking, the transition from biomass (or coal in China) to kerosene and gas has advanced further in urban areas, especially in Asia, and in rural areas of Latin America.[27] For electricity, growth in the penetration of appliances and lighting has been important. Rural electrification has advanced considerably since 1970, and lighting is the first end use that households acquire. The largest growth in ownership of major appliances has occurred for TV sets and refrigerators.[28] There has also been growth in ownership of clothes washers in some countries.

The transition away from biomass has probably decreased cooking energy intensity (measured in terms of final energy), since kerosene and LPG stoves are usually much more efficient than biomass cooking. Lighting energy use per electrified household has probably risen in countries where electrification levels were already relatively high in 1970 (Latin America). For electric appliances, there is evidence that efficiency has improved for new models, but the average energy intensity has likely increased due to the increasing purchase of larger and more feature-laden appliances.[29]

2.3.1.5. The service sector

The service sector accounts for only around 5% of final energy use in the developing countries. The end-use structure of demand is uncertain, but space cooling has probably grown in importance. Trends in fuel consumption are rather uncertain, but electricity use has increased rapidly, especially in Asia, where growth averaged 10% per year between 1980 and 1988. Growth in electricity use has been mainly due to rapid construction of new buildings, many of them more modern and energy-intensive than older buildings. In the warm, humid climates characteristic of many developing countries, air-conditioning is a major consumer of electricity, especially in the high-rise offices and modern hotels that have gone up in many countries. Service-sector electricity intensity has risen particularly fast in Southeast Asia and in the Asian NICs.

2.3.1.6. Summary

Growth in activity has been the major force pushing LDC energy use upward. In general, activity levels have risen faster in Asia, the Middle East, and North Africa than in Latin America and Sub-Saharan Africa, though per capita activity remains higher in Latin America. Growth in manufacturing output was especially rapid in Asia. Structural change within sectors has contributed to increase in energy use. In manufacturing, there has been some shift toward energy-intensive industries, especially in countries with abundant energy resources. In passenger travel, the role of automobiles has increased, and trucks have grown in use in freight transport. In the residential sector, growth in the penetration of electric lighting and appliances has contributed to rising energy use.

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[27] The transition to LPG was already well-advanced in Latin American cities in the early 1970s; in Asia, movement from biomass to kerosene and from kerosene to LPG has been occurring rapidly in the past decade (Sathaye and Tyler 1991). In Sub-Saharan Africa, there has been less change in fuels, and even movement back to biomass.

[28] In Thailand, for example, the percentage of households owning a TV set increased from 11% in 1976 to 56% in 1986 (Meyers et al. 1990). For refrigerators, the increase was from 5% to 21%. In Brazil, ownership of TV sets grew from 39% to 66% between 1974 and 1988, while refrigerators increased from 36% to 63%.

[29] In Brazil, test data show that the average energy use of new one-door refrigerators of 250-300 liter size declined from 490 kWh per year in 1986 to 435 kWh in 1989 (Geller 1991). In South Korea between 1980 and 1987, manufacturers report a decline from 672 to 240 kWh per year for 200-liter refrigerators, and from 82 to 60 W for 14-inch TV sets (Meyers et al. 1990). In many countries, growth has occurred in the market share of two-door refrigerators (with separate freezer), color (and larger) TV sets, and automatic clothes washers.

In manufacturing, there appears to have been decline in energy intensities in some countries resulting mainly from adoption of more modern processes. In passenger transport, there may have been some decrease in automobile energy intensity in countries where new vehicles have entered the fleet in large number, though worsening of urban traffic conditions has pushed intensity upward. In freight transport, growing use of diesel trucks has probably reduced energy intensity somewhat. In homes, the energy intensity of cooking has declined due to the shift away from biofuels, and there are some signs of modest improvement in appliance efficiency.

2.3.2. Future Prospects

Although the rate of population growth is slowing in the developing countries, the absolute increase in numbers is enormous. Projections from the World Bank show growth for the 1988-2000 period averaging 1.9% per year. The projected growth is much slower in China (1.3%/year), which has historically had strict population control policies, than in the middle and low-income countries (1.9% and 2.2%, respectively). Among all groups, the rate of growth is expected to gradually slow over time, but the projections still show an increase of 80% (about three billion people) in the population of today's developing countries between 1988 and 2025.

The economies of the developing countries are strongly linked to the industrial economies. Their prospects will be shaped by the growth of industrial country markets and access to them, the availability and cost of capital for investment, and the terms of trade. For severely indebted countries, the level of debt relief will be an important factor. Domestic policies and institutions are also very important. In many countries, there is a move toward greater reliance on market mechanisms and the private sector, and increasing recognition of the importance of international trade and finance for economic growth. The main scenarios in the World Bank's *World Development Report 1991* envision average annual GDP growth of 4.1-4.9% in the developing countries as a whole in the 1990s. The projected growth is higher than average for East Asia, close to the average for South Asia, and below the average for other regions.

2.3.2.1. Manufacturing

In contrast to the OECD countries, manufacturing is growing faster than GDP in most of the developing world. Prospects differ considerably among regions, however. Light manufacturing is growing rapidly in East Asia; prospects are less buoyant in South Asia, but the moves toward more liberal economic policies in India may attract investment needed for industries to modernize; in Latin America, growth in manufacturing will be higher in the 1990s than in the stagnant 1980s due in part to the new economic policies being instituted.

Overall, it seems likely that the importance of energy-intensive industries will increase somewhat, but change in the composition of manufacturing will vary. Basic materials such as steel and cement will be needed to build infrastructure, but the intensity of material use could decline as new technologies are disseminated from the industrial countries. The low cost of labor will encourage growth of export-oriented assembly and other light industry. Relatively industrialized countries like the Asian NICs will move toward products with higher value added, but large countries such as China, India, Brazil, and Mexico will continue to have substantial heavy industries. Countries endowed with relatively low-cost energy resources may use them to support expansion of energy-intensive industries.

Introduction of more modern processes, along with improvements in generic equipment and in operations and maintenance, will decrease energy intensities. The strength of these forces will depend on the financial condition of industries and the availability of capital for modernization, the extent of competition and profit incentives, access to modern technologies, availability of skilled personnel, energy pricing, and support for indigenous R&D and its transfer to industry. The market-oriented economic policies that are gaining favor are likely to increase competition and foreign investment, both of which should accelerate modernization and reduce energy intensities. Energy intensities will also be affected by change in the scale of industrial facilities. In many countries, small plants account for a substantial share of production in certain industries (such as building materials) and are generally much more energy-intensive than larger plants. The extent to which small-scale industries, which may be inefficient but important for employment, give way to larger, more modern facilities will depend on market proximity as well as government policies. As in the industrial countries, the trend will be very different for electricity intensities, which will likely rise, than for fuel intensities.

2.3.2.2. Passenger travel

A number of factors are causing considerable growth in travel in the developing countries. Acquisition of automobiles and motorcycles permits more travel for people who formerly relied on walking, bicycles, or mass transit. Urbanization generates more travel between cities and the countryside, and workers employed in manufacturing are more likely to need to travel to work than are those in traditional agriculture. In addition, rising participation of women in the labor force will increase travel. Whether traffic congestion and inadequate transport infrastructure will constrain travel remains to be seen.

As in other parts of the world, automobiles and air seem destined to account for a rising share of travel. The rate at which automobile ownership increases will depend on income growth and distribution, investment in mass transit, and policies affecting automobile purchase (import duties, taxes, registration fees). Asian countries currently have low levels of automobile ownership relative to Latin America; this suggests considerable room for growth, but congested conditions in cities may favor two-wheelers over cars for some people. Throughout the developing world, land-use planning—or the lack of it—will have a major impact on the overall amount of urban travel and its modal structure. For long-distance trips, considerable growth in air travel is likely.

Future trends in automobile energy intensity are hard to judge. The growing globalization of automobile production could accelerate the penetration of new technologies into LDC car manufacturing, but gains from improved technical efficiency will be somewhat offset by increases in size, power, and use of accessories such as air conditioning and automatic transmission. Tighter regulations regarding exhaust emissions may be a factor. Rising traffic congestion may increase the fuel intensity of cars and buses. For bus and rail travel, improvement in vehicle energy efficiency is possible, but transport companies (often state-owned) are generally lacking in capital to invest in new vehicles. Subsidy of diesel fuel often lessens the incentive to invest in more efficient vehicles, or to undertake improvements in maintenance and operations that would contribute to lower fuel intensity. Reduction in energy intensity is likely to be slow. For air travel, the degree of improvement as new aircraft enter the fleet will depend on whether the carriers are able to purchase relatively state-of-the-art aircraft, or are forced to purchase planes second-hand from Western airlines due to lack of capital. Privatization of national airlines and encouragement of joint ventures could allow more rapid modernization of aircraft fleets.

2.3.2.3. Freight transport

Freight activity will increase substantially with economic growth, but tonne-km may grow slower than GDP in more developed countries. While movement of agricultural and mining products (including fuels) will continue to be important, over time manufactured goods with higher value per unit weight will come to play a greater role. The shift toward lighter products, along with expansion of internal distribution networks and other factors, will favor use of trucks. Except for China and India, most developing countries lack extensive rail infrastructure, and capital constraints will limit its development. Rail will continue to be important in China and India, but trucks will increase their share of total tonne-km.

Water-borne freight transport will continue to be significant in a number of countries.

In many countries, a large share of the truck fleet still uses gasoline engines, so a gradual transition to diesel engines will reduce fuel intensity, as will replacement of older diesel trucks with newer ones. (In India, the transition from gasoline to diesel-fueled trucks is nearly complete, while in China most trucks still use gasoline.) Improvements in highway conditions will allow trucks to operate more efficiently. Modest reduction in rail energy intensity may result from rationalization of operations and perhaps some improvement in the efficiency of diesel locomotives. In China, the transition from steam to diesel or electric locomotion will reduce energy intensity.[30]

2.3.2.4. The residential sector

The combination of rising population, urbanization, increase in per capita income, and further spread of household electrification in rural areas will lead to tremendous growth in demand for residential energy services in the developing world. Household size will fall with urbanization and decline in fertility rates, which will increase *per capita* energy use for many purposes.

Change in fuels will continue to have a major impact on cooking. Among urban households, the transition from biomass to modern fuels is nearly complete in Latin America, but there is still much change likely in Asia (in China, the shift is from coal to gas). In Sub-Saharan Africa, the transition may be slow due to low incomes and fuel distribution problems. In Asia and Africa, the transition will be much slower among rural households, who have greater access to biomass resources and also lower income. Growing shortage of biomass fuels could accelerate the transition, but many poor households may lack the income to purchase modern stoves and fuels. Policies toward subsidization of kerosene and LPG will play an important role in determining the speed of the transition away from biomass.

Rural electrification will continue to add to electricity demand. While efforts over the last two decades have brought electricity to a relatively high percentage of villages in much of the developing world, in most cases there are relatively few households that are connected. As new households are able to afford connections, electricity demand will increase. Among already-electrified households (and those that will be) there is enormous room for growth in appliance ownership. The real cost of most appliances has declined over time, which means that households can acquire them at lower income levels than was the case for OECD households in the past. Penetration of TV sets is already relatively high, but penetration of refrigerators is still low (20-25%) even in middle-income countries like Thailand and the Philippines, and is lower still in populous countries such as India, China, and Indonesia (Meyers et al. 1990). Past experience suggests that refrigerator ownership will grow rapidly once countries move into middle-income status. The other major appliance whose penetration is likely to grow considerably is the automatic clothes washer. A key uncertainty is the extent to which use of air conditioning, which is very energy-intensive, will grow. Its market penetration is currently very low (2% of homes in the Philippines, 1% in Thailand, and 4% in Brazil); but the experience of Taiwan or northern Mexico suggests that its use could rise rapidly in hot climates as households reach upper-middle income levels.

The energy intensity of cooking will decline as the transition away from biomass fuels continues. (The effect will be greater in Asia than in Latin America.) For households that continue to rely on biomass fuels (perhaps the majority in rural areas of Asia and Africa), scarcity of premium biomass fuels, growth of fuelwood markets, and improvements designed to make stoves cleaner and easier to use may lead to an increase in the efficiency of stoves and in the care with which they are used. For households

[30] Switching from diesel to electric locomotion greatly reduces final energy intensity, but has little effect on primary energy intensity, assuming fossil-fuel electricity generation.

already using modern fuels, there may be some increase in intensity as people move to larger stoves. In addition, the proliferation of rice cookers and other small devices will increase the electricity intensity of cooking.

For electric appliances, improvement in technical energy efficiency is likely, but much of the gain may be cancelled by increase in size and features. Similarly for lighting, gains from using fluorescent rather than incandescent lamps may be balanced by growth in the number of lamps per dwelling. For space heating, modest reduction in intensity may occur in China, but some of the gains from increasing equipment efficiency and building thermal integrity will probably go to improving indoor amenity levels. For water heating, intensity may rise in many countries as storage heaters become more popular.

2.3.2.5. The service sector

Service-sector floor area will grow rapidly in much of the developing world. The business services that have fed growth of the service sector in the OECD countries are now expanding in many developing countries. In the public sector, growth in population will require increase in education and health-care buildings. Hotels and other facilities for tourists will also grow substantially.

As new buildings enter the stock, rise in the levels of building services will push upward on energy intensity. The new office, retail, and tourism-related buildings that are being added usually have higher amenity levels than the stock average. Given the warm climate that prevails in much of the developing world, growth in use of space cooling will probably have a substantial impact on electricity intensity, and proliferation of office equipment will increase cooling loads. Refrigeration in stores and restaurants will also grow. Opportunities to increase end-use efficiencies through retrofit and design of new buildings abound, but the numerous obstacles that exist (lack of capital, technical skills, and energy-efficient products) suggest that the pace of improvement may be slow unless the barriers are addressed by governments, utilities, and other actors.

2.4. FORMERLY-PLANNED ECONOMIES

2.4.1. Past Trends

Primary energy use in the formerly-planned economies increased at a much slower rate in the 1980s (2.2% per year) than in the 1970s (4.4% per year), when industrial output was still expanding. Some of the growth in the 1980s was associated with increased Soviet oil and gas production and transport. The former USSR dominates the region's total energy use, and its share rose slightly from 70% in 1970 to 74% in 1988 (Figure 2-13). The discussion below mainly refers to the former USSR, which we have studied in some detail, but many of the characteristics and trends apply for the other countries as well.

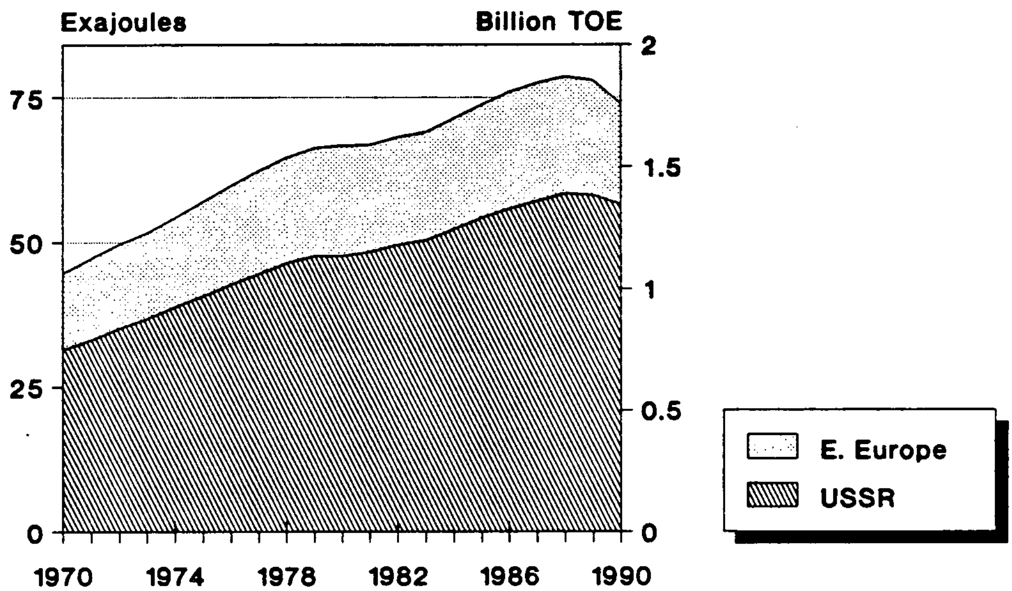
2.4.1.1. Manufacturing

Manufacturing accounted for around 35% of final energy use in the mid-1980s in the former USSR, and for a somewhat higher share in Eastern Europe. While the 1970s and 1980s were marked by considerable change in the manufacturing sector elsewhere, manufacturing in the formerly-planned economies, relatively isolated from competition and administered by government policy, saw growth in production but relatively little technological change. The sector continued to be dominated by the heavy industries that were established in the 1950s and 1960s.

Historical data on Soviet manufacturing energy use and production are uncertain. Industrial energy use (which includes mining, construction, and agriculture) grew at an average of about 2.5% per year between 1970 and 1985. This was less than the estimated growth in industrial output (around 3.5%), but

Figure 2-13

Primary Energy Use
Formerly Planned Economies 1970-1990



Source: BP, IEA

some of that growth came from oil and gas production, which means that manufacturing output grew more slowly. Assessing the structural evolution of manufacturing is likewise difficult due to lack of disaggregated data, but trends in per capita production suggest that there has been some decline in the role of the steel and cement industries since the mid-1970s. Although per capita steel production leveled off, production per unit GDP was still much higher than in the OECD countries; this was also the case in Eastern Europe (Dobozi 1990). As for energy intensities, the available data show no reduction in energy use per tonne between 1975 and 1985 for the Soviet steel and cement industries, and an increase for the pulp and paper industries. Given the maintenance of low energy prices and lack of incentive for technological innovation, this is hardly surprising.

2.4.1.2. Passenger travel

Travel has accounted for a very small share of final energy use (about 5%) in the formerly-planned economies due in part to the low levels of automobile ownership. Despite restrictions on travel, growth in reported p-km in the Soviet Union averaged 4-5%/year between 1973 and 1987. Although rail and bus dominate travel (with 31% and 28% of total p-km in 1987), automobile and air travel have increased their shares (to 21% and 12%). This development has contributed to an increase in aggregate travel energy intensity. The intensity of automobile travel itself has declined as more small cars entered the fleet. (Large official cars accounted for a considerable share of the Soviet fleet in the early 1970s.) The energy intensity of Soviet air travel has also declined slightly since the early 1970s due mainly to an increase in aircraft size. Load factors have remained constant at nearly 100%.

2.4.1.3. Freight transport

Freight transport accounts for around 13% of final energy use in the formerly-planned economies. Activity and energy use have grown considerably in the past two decades, in part because of the increase in oil and gas shipments (primarily by pipeline) in the former USSR.[31] Excluding pipelines, rail accounted for about 80% of Soviet tonne-km in 1988. Unlike in other parts of the world, there has been little increase in the role of trucks since 1970, which reflects the continued dominance of heavy products in the economy, the lack of development of the distribution system, and the relative unimportance of consumer goods. Because of the dominance of rail and large shipments of bulk materials, the aggregate energy intensity of Soviet freight transport is lower than Western European levels. Rail energy intensity (final energy) has decreased, first through replacement of coal traction by oil, then through electrification. The fuel intensity of trucks has also fallen somewhat, mainly because of an increase in the share of diesel trucks.

2.4.1.4. The residential sector

Energy use in the home accounts for around 20% of final energy use in the formerly-planned economies. Space heating accounts for around 75% of this due to the cold climate and the relatively low electricity demand from home appliances. Residential energy use per capita in the former USSR grew at an average rate of about 1% per year between 1970 and 1985. Most of the growth was in district heat, which serves the majority of urban homes. There has also been growth in electricity use, but it remains relatively insignificant. Change in equipment has played a modest role; the 1970s saw some switching from reliance on stoves for heating to district heat in the USSR. There was also growth in the ownership of refrigerators and TV sets. Lack of data make it difficult to evaluate trends in energy intensities, but it

[31] Pipeline shipment of oil and gas (a substantial amount of which was destined for export) accounted for one-third of total Soviet tonne-km in 1987 and most of the growth in the total since the mid-1970s.

appears that there was a slow decline in heating intensity in the USSR in the 1970s and 1980s, perhaps due to gradual improvement in equipment and building practices. A similar trend is apparent in Poland between 1980 and 1985 (Leach and Nowak 1990).

2.4.1.5. The service sector

The service sector accounts for only around 6% of final energy use in the formerly-planned economies. Most of it is for space heating. Services energy use in the former USSR increased at around 4% per year between 1970 and 1985, which was somewhat faster than the estimated growth in floor area. This increase in energy intensity, which took place primarily in the 1970s, may reflect modest increase in indoor comfort levels. There is some indication that heating intensity declined slightly in the 1980s; part of the reason is the greater size of new buildings, which have lower heat losses per square meter of floor area. Electricity use per square meter rose by about 30% between 1970 and 1985, but it is very low by Western standards.

2.4.2. Summary

Activity increased in all sectors in the formerly-planned economies, but much less than in the OECD countries in most cases. Structural change had a modest effect on energy use. In manufacturing, there are signs of a decline in the role of steel and cement production in the Soviet Union since the mid-1970s. Automobiles and air increased their share of passenger travel somewhat. In the residential sector, increases in heating equipment and appliance ownership also pushed moderately upward on energy use.

Some heavy manufacturing and air travel exhibited a decline in energy intensity in the Soviet Union. It appears that the intensity of space heating in homes declined slightly. Trucks became less energy-intensive as diesel trucks increased their penetration. Overall, the improvement in energy efficiency in the formerly-planned economies was small compared to that which occurred in the West. Given the lack of incentives for improvement, this is hardly surprising.

2.4.3. Future Prospects

Population is projected to grow slowly at around 0.5% per year in the formerly-planned economies in the 1990s, and could be lower still if emigration is high. Economic prospects are very uncertain, and vary among the countries. They will depend on the success of the liberal economic policies that many governments are adopting, the capacity of people and institutions to adapt to the ways of a market economy, and the degree of foreign investment in existing and new industries. The ability of governments to maintain a course of reform in the face of rising unemployment and declining real income is also a key factor. As with the developing countries, establishment of a reasonably stable environment for investment and fair access to Western markets will also be important. If the foundations for healthy economies are laid in the 1990s, the first decade of the next century could see fairly robust growth.

2.4.3.1. Manufacturing

The manufacturing sectors in the formerly-planned economies are likely to undergo a radical transformation over the next 20 years, but the pace of change is difficult to assess. Much of the old manufacturing infrastructure is obsolete in terms of competing in the world market, or is simply not needed in the new economic order being established. The extent of investment from the OECD countries will strongly influence the sector's evolution. In the near-term, it seems likely that manufacturing production will decline considerably before recovering, especially in the former Soviet Union. With time, however, manufacturers will target the tremendous latent domestic demand for consumer products, and industries have the capacity to be a low-cost supplier to OECD markets.

The sector's composition will shift strongly away from the energy-intensive industries that dominated the old centrally-planned economies. The production of energy-intensive materials such as steel and cement will decline as a share of total output, and perhaps in absolute terms, as the shift from bureaucratic production targets to market signals removes the artificial incentives for production. Russia and a few other countries have relatively low-cost energy and other natural resources that may be utilized to support heavy industries, but in general light manufacturing will grow much more rapidly.

Substantial decline in fuel intensities is likely, in part because a significant share of the historic production capacity may not be in operation by the year 2000, and certainly not by 2010. Introduction of market pricing will encourage energy-saving practices in those factories that survive restructuring. As industries become more competitive, operations will become more efficient in general, and production will be better matched to factory capacity. The extent of foreign investment in new production capacity, which will generally be considerably more energy-efficient than even relatively modern Eastern factories, will be a major factor. The rate of intensity decline will depend on the pace and nature of reform and the ability of industrial managers to adapt to the new system. Change in the quality of process inputs will also play a role. Assessing the future is very difficult, especially since the mix of products is likely to change so greatly, but it seems plausible that fuel and heat intensities could be one-third or more below the level of the late 1980s by 2010. Electricity intensities will decline much less as improvements in efficiency are balanced by greater use of electrical processes.

2.4.3.2. Passenger travel

Internal and external travel is likely to grow considerably as the economic situation improves. Per capita travel in the Soviet Union in the late 1980s was only half of the Western European average despite the country's great size. Disintegration of the Union will probably lessen travel among the former Republics, but there will be much more traffic between each new nation and the world outside the borders of the former USSR. In Eastern Europe especially, travel links with the West for tourism and business will increase greatly. Bus and rail will continue to carry most passengers, but the automobile share will rise. Car ownership in the former Soviet Union could easily grow from the 1985 level of around 50 per 1000 persons to 100-150 over the next 20 years. Already there is a huge influx of used cars from the West in Eastern Europe.

Since automobile ownership will grow considerably from its current low level, the fuel intensity of new cars will have a rapid impact on the fleet average. New-car intensity will be shaped by the designs used in the joint ventures with Western manufacturers. The most popular cars produced by Soviet manufacturers nominally require 7-9 liters/100 km (26-34 mpg), but they are relatively small, low-powered, and lacking in accessories. Over 10-15 years, it seems plausible that the average new car would be similar in technology, size, and performance to the current Italian average (about 7 liters/100 km, or 34 mpg). Combined with improvements in the quality of fuel, roads, parts, and vehicle maintenance, the current fleet average of 11-12 liters/100 km (20-21 mpg) could drop to 7-8 (30-34 mpg) by 2010. Future automobile intensity will also depend on the numbers and characteristics of used cars imported from Western Europe.

2.4.3.3. Freight transport

The ratio of freight tonne-km to GDP is certain to fall as the role of bulk raw materials (including fuels) declines. The disintegration of the USSR may lead many former Republics to build new facilities to produce locally what was previously produced elsewhere. This would place more factories closer to markets, reducing the distances that finished goods travel. On the other hand, the growth of trade with the West will bring significant increase in freight shipments destined for export. The overall tonnage of goods shipped may fall, but the distances may increase. While trucks play a much smaller role in freight transport than in the West, especially in the former Soviet Union, their importance will rise as consumer and other finished goods come to play a larger role in the economy and as production becomes more decentralized.

The energy intensity of rail may decline eventually as operations are rationalized and modernization of the rolling stock occurs. Change in the type of goods carried may also affect intensity. With time, the fleet of trucks is likely to grow considerably, so new trucks, which will be more energy-efficient than the current average, will play an important role. Much of the truck fleet still uses gasoline engines, so the transition to diesel engines will reduce fuel intensity. On the other hand, the rise of small-scale agriculture and expansion of urban distribution systems may bring growth in the number of small trucks and vans, which generally use gasoline.

2.4.3.4. The residential sector

Household size will eventually fall as more housing is built by the private sector. House area may grow, particularly if private initiatives lead to increased construction of low-rise and detached housing. Central heating penetration will increase, particularly outside of large cities with district heat, and ownership of various electric appliances will also grow.

The energy intensity of space and water heating is likely to decline as energy prices rise from their historic very low levels, but the pace of retrofit will probably be slow due to lack of funds and an industry skilled in retrofitting the large apartment buildings that dominate the housing stock. Until metering becomes widespread (even at the building level), the incentive for retrofit investment will be weak; most energy-saving improvements will probably be associated with general building renovation. New buildings may be much more energy-efficient than the stock average, but here too progress may be slow due to lack of funds, materials, and expertise.

The efficiency of electric appliances can be improved more quickly than that of buildings. The stock may turn over fairly rapidly as incomes rise, and the introduction of Western technology through joint ventures will increase efficiency considerably relative to historic practices. At the same time, growth in appliance size and features is likely, which will counter some of the efficiency improvement.

2.4.3.5. The service sector

The service sector in the formerly-planned economies is relatively undeveloped; the average area per capita is less than 5 m^2, about half the level of Italy. Office and retail space in particular will increase considerably to meet the demands of the emerging private sector. Growth will also occur in lodging and restaurants.

Heating intensity may decline somewhat due to retrofit of existing buildings and addition of new ones. This may be partly balanced by increase in indoor comfort levels, however. Electricity intensity may rise considerably as new office buildings and hotels enter the stock and as communication and computing equipment proliferates. For heating and electric end uses, there is much room to improve efficiencies, but also strong obstacles.

2.5. PROSPECTS FOR WORLD ENERGY USE

Even with only moderate rise in energy prices, energy intensities in the industrial countries will continue to decline in most sectors, especially in manufacturing, where technological progress is relatively independent of change in energy prices. In addition, energy efficiency policies and programs are having an impact in some areas. Averaged over all sectors, however, the net decline will likely be much smaller than that which occurred before 1985.

The decline in intensities is unlikely to keep pace with the pressure on energy demand from rising activity. Certain types of energy-intensive activity, especially travel, will likely grow faster than GDP. Structural change at a macroeconomic level and in the manufacturing sector will contribute to lower aggregate energy intensity, but the shift toward energy-intensive modes is increasing energy use somewhat in transportation. The scenario described earlier shows average growth in OECD primary energy consumption of about 1.2% per year between 1985 and 2010. The same rate is seen in recent projections from the US Department of Energy that used macro energy-economy models (US EIA 1991).

In the developing countries, energy efficiency will improve with stock turnover and use of more modern technologies; but population growth, increase in per capita activity levels, transition away from biomass fuels, and rise in various energy-intensive activities will lead to major increase in energy use. Economic growth will be particularly strong in much of Asia, and is likely to be higher than in the 1980s in Latin America. Along with continued urbanization, rise in income will bring considerable increase in demand for consumer goods. Moreover, the slackening in the development of more energy-efficient technologies in the OECD countries could slow the progress toward higher efficiency in the developing countries.

The outlook for the formerly-planned economies is very uncertain. Economic restructuring involving changes in the quantity and mix of goods produced and closing of many outdated facilities could greatly reduce the overall energy intensity of the economies, even without major efforts to encourage energy efficiency. Pricing reform should also have a significant effect, although the high cost of capital could hinder the response of energy users. On the other hand, successful economic reform should eventually bring a surge in the demand for personal mobility, home comfort, and greater activity in the service sector, all of which would push energy use upward. The pace and nature of reform and investment is obviously the critical factor. As things look now, it could be some time before energy use in these countries reaches the peak level of 1988.

How do the various forces affecting world energy use add up? We have not attempted to construct scenarios of world energy use. The US DOE projections cited above show an average growth rate in world total primary energy over the next 20 years of about 1.3% per year. The 1989 World Energy Conference projections envisioned growth through 2020 of between 1.2% and 1.6% per year (WEC 1989). Recent scenarios by sector and region done for the US Working Group on Global Energy Efficiency show (in the base case) demand growing through 2025 at about the same rate as the WEC's high projection (Levine et al. 1991). None of these (or other long-range) projections are very sophisticated at capturing the complex interactions among factors and regions, and there remains the inherent uncertainty about the future. These projections are by no means destiny, but neither are they implausible. A world in which energy use grows by 50% over the next 30 years may not be desirable, but it is not improbable unless stronger actions are taken to conserve energy.

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Chapter 3
The Potential for Energy Conservation

The previous chapter described how changes in activity, structure, and energy intensities have shaped energy use in the past, and discussed where these forces are leading. Potential for energy conservation exists in each of these elements. Reducing growth in activity is not seen as desirable in most circles, but there are instances in which less activity does not mean a loss of well-being, and may even enhance well-being (for example, if land-use planning reduces the distances that people need to travel to conduct their affairs). And of course, reducing growth in population also slows the pace of increase in energy-using activities, and has many other benefits. Shifting the mix of activity in certain sectors toward a less energy-intensive structure is another means of conserving energy that can be beneficial in other ways as well. This strategy is especially important in transportation.

The largest practical potential to conserve energy lies in reducing or slowing growth in energy intensities. This potential has two aspects. The most important is improving the efficiency of energy use, which means reducing the amount of energy needed to provide the service levels that people want. The other aspect, which is more controversial, involves changing the type or level of service in various end uses such that energy intensity is reduced. This could include, for example, modifying consumer buying patterns toward smaller, less powerful cars.

This chapter describes the potential for improving energy efficiency in different sectors and parts of the world, and discusses strategies for accelerating efficiency increase such that more of the potential is realized sooner rather than later.[1] It is increasingly recognized that there are many benefits associated with improving energy efficiency, including reduction in private energy costs, environmental damages and risks, and capital requirements to provide energy services. From a societal perspective, improving efficiency is often cheaper than providing new energy supplies. But much of the efficiency increase that is attractive for society (even disregarding environmental benefits) is not taken up by energy users.

While it is clear that the potential is much greater than what is being realized, the magnitude of the potential, and the ease with which it could be achieved, is the subject of debate. Part of the reason for differing assessments is because people use the word 'potential' to mean different things. We begin this chapter with a consideration of what is meant by the 'energy efficiency potential'. We describe some of the key opportunities in each sector, and present estimates of the energy efficiency potential in different countries. We then describe some of the barriers to realizing the efficiency potential, discuss strategies for accelerating improvement, and illustrate what such strategies might accomplish for the industrialized countries. With sufficient effort, much efficiency increase can be realized, but other ways of conserving energy are also important.

3.1. UNDERSTANDING THE ENERGY EFFICIENCY POTENTIAL

The potential to increase energy efficiency in any particular area refers to changes that might take place in the existing stock and in new systems within some time period. The broadest conception of it is usually called the *technical potential*, which describes what the impact would be if the best available technologies and techniques (or those that probably will be available in the time frame in question) were used in all possible applications. This typically means that all existing systems are upgraded and all new systems that enter the stock utilize the best technology available when they do so. Estimates of the

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[1] This chapter addresses *end-use* energy efficiency. The potential to improve the efficiency of energy supply (including use of cogeneration) is covered in Chapter 4.

technical potential are most reflective of the real world if they incorporate an approximation of how the stocks will evolve in the future. Analysts may take care to recognize constraints such as physical applicability and equipment manufacturer infrastructure, or may assume that some constraints could be overcome with sufficient effort. Analysis of efficiency measures must account for possible interaction among measures and take care to avoid double-counting of energy savings.[2]

The *economic potential* brings in the element of costs and benefits. In principle, it can be defined as those improvements whose cost is less than the benefits that result over the system lifetime. Energy savings are the main benefits considered; their value depends on what perspective is considered. From a private perspective, the value depends on the price of the avoided energy use over the relevant time period (which is subject to some uncertainty), and the extent to which future benefits are discounted (formally or not). The private discount rates used in evaluating to energy efficiency measures vary greatly; they are usually much higher among households than among large companies. From the societal perspective, the marginal cost of energy is the relevant criterion. The proper social discount rate is subject to some debate, but it is most common to use a rate that corresponds to the real interest rate on long-term public funds (3-10%). The societal perspective should also account for the environmental benefits of energy-saving measures; while these are increasingly being brought into consideration, they are not included in most analyses of the economic energy efficiency potential. For electricity efficiency measures, there is also the perspective of the utility to consider, and the issue of avoided power demand (kW) as well as electricity savings (kWh).

For some end uses, the economic efficiency potential can be described fairly accurately, and one can see how it changes under different assumptions regarding energy prices or discount rates. Sometimes, however, it is difficult to examine energy efficiency improvement in isolation; changes that enhance energy efficiency may have other impacts as well. In many cases, these impacts represent additional benefits to the user, which means that the true cost of improving efficiency is less than the apparent cost.[3]

A useful method of evaluating the cost-effectiveness of particular energy-efficiency measures (or sets of measures) involves deriving a *cost of conserved energy (CCE).* Calculation of a CCE (expressed in money per unit of energy saved) involves annualizing the cost of an efficiency measure over its lifetime and dividing by the annual amount of energy it saves. The CCE can be compared to the price of energy (or the estimated societal cost).[4] The CCE method allows one to depict the cumulative impact of many measures in a *supply curve of conserved energy*, as we illustrate later in this chapter.

The degree of uncertainty in estimating the costs and benefits of efficiency measures is much greater with respect to retrofit and operational changes in the existing stock than for new buildings and equipment. For example, the cost and energy savings of going from a standard motor to an energy-efficient motor are well understood. But the cost and savings of making improvements in existing motor systems -- or building or factories -- in a given country is much more uncertain. Sometimes the features of new equipment and buildings, or the cost structure of production, are also not known sufficiently to develop reliable estimates of the cost and savings that would result from various improvements. Another element

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[2] For example, there is interaction between use of more efficient space conditioning equipment and measures applied to building shells. Use of high-efficiency equipment will save less energy if building thermal integrity has been improved already.

[3] For example, reducing cooling requirements in design of a new building allows a reduction in the size of the HVAC system, which usually saves money. This effect should be taken into account in deciding how much efficiency improvement is cost-effective.

[4] In the case of electricity-saving measures, one can also estimate the cost of avoided peak demand, and compare this to a utility's marginal cost per kW delivered.

of uncertainty in estimating the efficiency potential is how equipment is utilized in actual use; higher utilization means that energy savings accumulate faster and the extra investment is paid back more quickly.

While descriptions of the economic potential for improving energy efficiency sometimes gloss over the degree of uncertainty in their estimates, they usually have a number of conservative judgments built into them. In most cases, they compare the cost of saving energy to current energy prices; increase in prices enhances the cost-effectiveness of measures. Moreover, they usually do not consider the full range of measures or technologies that can be applied, selecting instead those few whose impact can best be characterized.

Full realization of the economic efficiency potential is very unlikely for many reasons, the main one being that the criteria of energy users differ from social criteria. Assuming a particular evolution of energy prices, one can attempt to assess what the market might achieve 'on its own'; this might be referred to as the *market potential*. It is important to bear in mind that the extent to which energy-efficiency opportunities are adopted depends heavily on the rate of replacement or upgrading of existing factories, buildings, vehicles, and other equipment. A variety of policies and programs can accelerate the response of the market, as we describe in the next chapter. How much they might actually accomplish is the *achievable potential*. The cost of programs should be considered in evaluation of this potential.

Our main focus in this chapter is the economic efficiency potential. It is important to keep in mind that the long-run potential to improve energy efficiency, as defined by thermodynamic principles, is far greater than what is economic in the near term. Technologies that are generally not economic today may become so in the future if mass production, R&D, and greater familiarity with design and management techniques reduce the cost of improving efficiency. Moreover, technologies that are still in the early stages of development, or ones that have been envisioned only in principle, promise to keep the energy efficiency resource from being exhausted.

3.1.1. Elements of the Energy Efficiency Potential

Most descriptions of the energy efficiency potential focus on *technical change* in processes, equipment, and buildings. Such change, which often occurs primarily for reasons other than improving energy efficiency, takes place through replacement of the old by the new and through retrofit of existing systems. In most cases, it represents the largest part of the potential (especially in the medium or long run). Another part of the efficiency potential lies in *change in operations* that reduces energy use while maintaining (or improving) the level of service provided. This includes more frequent maintenance of equipment as well as use of control technologies that manage equipment more carefully.

There are also elements of the efficiency potential that are external to the technology itself, but interact with it. *Change in the inputs to processes or equipment* may allow them to operate more efficiently, or encourage selection of more efficient equipment. Two examples that are particularly important in the developing and transitional countries include improving the quality of transport fuels and electric power supply. Shifts in raw inputs (such as utilizing scrap rather than virgin material) can save energy in certain industries (and also provide indirect savings in mining or forestry). Another element is *change in the operating environment* that allows for energy savings. Examples include improvement in traffic flow and in physical road conditions. Another example that has gained attention in the US, and is potentially important in the developing countries, is measures to reduce the urban 'heat island' effect, which adds to space cooling requirements in buildings.[5] The potential energy savings from external

[5] The main measures to mitigate the 'heat island' effect are planting trees, which has other benefits as well, and painting roof and road surfaces a light color.

measures can be difficult to quantify, but they should not be ignored.

Understanding the full energy efficiency potential requires considering all of the above elements and interactions among them, as we illustrate with the example of motor systems.[6] Using a more efficient motor represents only part of the potential. Avoiding oversizing in system design is important, since motor efficiency drops off sharply below about 40% of the rated load. Controlling the motor's speed with electronic adjustable-speed drive rather than traditional controls can yield sizable energy savings, and also extend equipment life by allowing for gentle start-up and shut-down. Proper selection, installation, and maintenance of transmission hardware (belts, gears, chains) can greatly enhance system performance and efficiency. Improving the quality of the electricity that powers the motor can reduce energy use, enhance equipment performance and process control, and reduce downtime from damaged equipment.[7] Using larger wires in the power lines supplying the motor can reduce distribution losses. Lastly, careful, ongoing monitoring and maintenance of the entire motor system can save considerable energy, and contribute to more reliable operation and extended equipment life.

Several things stand out in the above example that also apply for many other end uses: (1) improving the efficiency of the equipment itself represents only part of the potential; (2) the design and installation of the system (or construction in the case of buildings) plays a key role; (3) how the user manages the entire system is very important; and (4) measures that improve energy efficiency often provide other benefits as well.

Although different in character from most types of efficiency measures, switching from one fuel to another to provide a particular service can result in energy savings in some cases, and environmental benefits as well. Considering the primary energy consumption associated with final use, switching from electricity to another fuel can often result in major savings, especially if electricity is used for direct heating. In other cases, electro-technologies offer such a large efficiency gain that switching to them saves energy even accounting for losses in electricity generation and delivery. Heat pumps and electric arc furnaces used in steelmaking are two prominent examples. Various electro-technologies are being increasingly used in industrial applications because they improve productivity and product quality. Many of them offer net energy savings as well. The economic potential for fuel switching depends on the relative costs of competing fuels in particular places.

3.2. KEY OPPORTUNITIES FOR IMPROVING ENERGY EFFICIENCY

In this section, we describe some of the main opportunities for improving energy efficiency in each sector. Their importance varies among countries depending on the relative role of different sectors and end uses, and how they are evolving. Since the current energy efficiency of the stock and of new equipment and buildings also varies among countries, the impact of implementing measures will differ. And since energy prices and costs of efficiency improvement vary around the world, technologies and measures that are economic in one place may not be in another, and *vice versa*. The ease with which they can be implemented also varies greatly; energy-efficient equipment may not be readily available in some places, or efficient practices may not be well known. We discuss these and other barriers in the next chapter; here our goal is to present a sense of the nature and magnitude of the potential. The options described by no means exhaust the overall efficiency potential.

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[6] The example is drawn from Nadel et al. (1991a).

[7] At the plant level, this may involve monitoring and repair of faulty devices or use of specialized power-conditioning equipment; actions by electricity supply companies can also improve power quality—this is especially important in many developing countries.

3.2.1. Manufacturing

The two main opportunities for increasing energy efficiency in manufacturing are adoption of improved basic production technologies and change in cross-cutting technologies and practices. Adoption of new production technologies can have a major impact in energy-intensive industries, as illustrated by recent studies of several US industries (Energetics 1988). The analysts estimated the impact relative to mid-1980s average practice with (1) demonstrated state-of-the-art technology, and (2) advanced technologies that are under development and likely to be available in the future. In the steel industry, which accounts for a considerable share of industrial energy use in many countries, energy intensity could be reduced by 40% with state-of-the-art technology, and by 46% using advanced technology. A key technology is the electric arc furnace, which uses mostly scrap and has already greatly increased its market penetration throughout the world. Energy savings are also possible in making iron and steel from virgin ore and in casting of products.

The comparable values are 30% and 49% in pulp and paper. Promising technologies include continuous digesters, oxygen bleaching, upgraded evaporators, and improved methods of paper drying. The potential intensity reductions from current-best and advanced technology are 31% and 55% in cement production, 21% and 44% in glass production, and 34% and 53% in textiles. In all of the above industries, the savings that would result from applying the technologies considered in other countries may be more or less than the figures given, depending on the nature and current state of the technology in local industry. The cost-effectiveness of advanced technologies will depend on energy prices and the market conditions faced by industries.

The chemical industry is quite diverse, so the efficiency potential is rather difficult to assess, but various technologies can improve efficiency in separation and concentration processes, which account for most of the energy used. Process changes that shorten the steps needed to produce a given chemical (and reduce energy requirements) might arise through improvements in catalysts/reagents and photochemistry or through application of biotechnology. Process changes can also reduce energy use in food processing.

Electricity-intensive processes such as electrolysis and electric arc furnaces are major consumers of energy in the aluminum, chemicals, and steel industries. For aluminum production, a recent US study estimated that a 30-50% reduction in energy intensity is possible through use of advanced technologies that may become available in the 1990s (Faruqui et al. 1990). Increasing aluminum recycling can also reduce electricity use since producing secondary aluminum requires only about 5% of the energy necessary to produce aluminum from bauxite. In chlor-alkali production, selective membrane cells consume 15-30% less electricity than conventional mercury or diaphragm cells (and also improve product quality and reduce adverse environmental and health impacts). The membrane process is already widely used in industrialized countries but not in developing countries. Various available technologies can improve their efficiency. For India, an average savings potential of 30% has been estimated with a cost of conserved energy of around $0.01/kWh (Nadel et al. 1991b). A promising new technology for producing steel or steel alloys is the "plasmamelt" process. If scrap metal is used, it consumes only about one-third as much electricity as a normal scrap-based electric arc furnace (Eketorp 1989).

In addition to change in industry-specific production technologies, there is potential to increase the energy efficiency of cross-cutting technologies used in most industries. Two major areas for savings are waste heat recovery and improving combustion efficiency. The industries with the greatest waste heat are primary metals, food processing, pulp and paper, non-metallic minerals, and chemicals. High-temperature heat can be "cascaded" to other thermal uses or used to generate electricity (so-called "bottoming cycle cogeneration). Low-temperature heat can be upgraded with a heat pump. In combustion, which uses a large amount of industrial energy, various measures can increase the thoroughness of combustion and the transfer of heat to working fluids. Newer technologies also promise energy savings in separation processes such as distillation, drying, and evaporation, which are used in many industries.

Motors to power pumps, fans, compressors, and machine tools account for two-thirds or more of industrial electricity use in most countries. Use of energy-efficient motors and variable speed drives can reduce motor electricity use significantly, and electricity can also be saved with optimal sizing of equipment and power cables and improvements in power quality and drivetrain components. A recent analysis for the US estimated that motor electricity use can be reduced by 16-40% with measures that are generally very cost-effective (Nadel et al. 1991a). For lighting, another cross-cutting industrial electricity use, use of more efficient technology could reduce energy use by an estimated 35-50% in US manufacturing.

Across industries, energy savings are available with improved maintenance and housekeeping and process management and control. The efficiency of space conditioning energy use, which is significant in the engineering and assembly industries, can be improved. In design of new industrial plants, efficiency can be enhanced by integrating operations to allow better utilization of equipment, sequencing process operations properly, and avoiding oversizing of equipment.

Making general estimates of the cost of many energy efficiency improvements in manufacturing is difficult. For retrofit, costs are often site-specific, and data on equipment costs are often lacking. In addition, some measures that increase energy efficiency often have other benefits (and may be implemented mainly for those reasons), so allocating the entire cost to energy saving is inappropriate. This applies especially with respect to new production technologies.

3.2.2. Passenger Travel

In the industrial countries, by far the greatest potential to save energy lies in improving automobile fuel economy. Such improvement is becoming increasingly important in the rest of the world, as well. The technologies available for improving the fuel economy of conventional automobiles without reducing size and performance characteristics fall into two broad categories.[8] The first is load reduction, or decreasing the power required of the engine. Using existing or near-term technologies to reduce air drag, rolling resistance, weight, drivetrain friction, and accessory loads, a 20% reduction in load, yielding a 9% improvement in fuel economy, should be achievable. The second area is increasing the effectiveness with which the energy in fuel is converted to useful work for powering the car. Simulations predict that use of current or near-term technologies for improving mechanical efficiency, combined with the 20% load reduction, would result in a total efficiency increase of 80%, without sacrificing size or power.[9] The costs of these technologies are somewhat uncertain, but most of them are likely to be cost-effective relative to the level of gasoline prices (not including taxes) likely to obtain over the 1990s, and many of them have a CCE well below this level.

The technologies considered above could be introduced in new cars over a period of 10 to 15 years. Much more could be achieved in perhaps 20 years, although the changes would involve greater technological ingenuity and/or higher costs. Among the most promising technologies are "stop-start," which turns the engine off when idling, recovery of energy in braking, and full control of valve timing, which would eliminate the need for a throttle as well as improve engine power. Another direction involves solving the diesel engine's emissions problems. A similar improvement could be achieved by switching to a

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[8] The discussion draws on Ross et al. (1991). The quantitative changes described are relative to the average new car in the US in the late-1980s. The average fuel economy of the automobile fleet can also be increased through changes in size, performance, and other characteristics, as we discuss in the next chapter.

[9] The net gain in fuel economy is from 24 mpg in the base case to 44 mpg.

high-octane fuel like methanol or methane and designing engines for that fuel. Together, advanced technologies and use of non-gasoline engines would enable a vehicle to have the average performance and size of current US new cars with a fuel economy of around 65 mpg (3.6 l/100 km). Even more striking improvement can be achieved with very small cars appropriate for commuting and other in-town uses. With their much lower weight and air drag, such vehicles could achieve as much as a factor of two better fuel economy than an average size car with similar acceleration.

In developing and transitional countries, there is also much potential to improve automobile fuel efficiency through use of various technologies, especially in the midsize and large cars that are purchased (or will be) by companies and wealthier individuals. Improved "lean-burn" engines may be a promising technology that will boost efficiency for smaller cars. Equally or perhaps more important (because it affects the entire fleet) is improving the purity of gasoline (to allow use of technologies such as fuel injection) and encouraging better vehicle maintenance. Fuel efficiency can also be enhanced by improving roads and traffic flow.

Efficiency improvement in jet aircraft offers potential energy savings the world over, since the market for aircraft is highly international. The best current generation equipment delivers 50-70 seat-miles per gallon (smpg), while new aircraft in the early 1990s are expected to achieve 65-80 smpg (Greene 1990). Technologically-achievable efficiencies for post-2000 aircraft—using propfans as the standard engine—are estimated at between 110 and 150 smpg, but it is not clear at what fuel price such aircraft might be economic.

In developing and transitional countries, there is considerable potential to save energy by improving the fuel economy of buses and the collective taxis that are popular in many countries. Replacement with new vehicles offers much savings, as does better maintenance. In some countries, there is room to save energy by switching from gasoline to diesel vehicles. Traffic management options that provide buses with dedicated lanes can also enhance their fuel economy.

3.2.3. Freight Transport

Trucks represent the major opportunity for improving end-use energy efficiency in freight transport. Although the diesel engine is already a rather efficient power plant, and weight reduction is a less promising strategy for trucks than it is for automobiles, fuel economy can be increased by improvements in aerodynamics, engine efficiency and control, and the drive train, and through use of radial tires. Relative to the average US heavy truck of 1982, implementation of commercially available technologies can raise fuel economy by an estimated 65% at a CCE well below the price of diesel fuel (Sachs et al. 1991). An additional 10% improvement could be obtained from changes in driver behavior. Use of "progressive shifting", in which the driver shifts from lower gears at lower engine speed, can be encouraged with electronic engine controls. Advanced engine technologies that are not yet commercial (such as adiabatic engines designed to operate at higher temperatures with lower heat rejection, and use of Rankine cycle technology to utilize exhaust-gas heat) could increase fuel economy another 10%.

In many developing and transitional countries, there is a large potential to save energy by switching from gasoline to diesel trucks, though shortage of diesel fuel or lack of production of diesel engines are problems in some cases. Improving the quality of diesel fuel can contribute to better engine performance. Improving highway conditions is also important, since key efficiency measures such as turbocharging engines and aerodynamic improvements bring relatively less savings at the low speeds and stop-and-go movement commonly found on highways. For rail systems, energy efficiency can be enhanced through improvements in operations and infrastructure. In China, much energy could be saved by moving from steam locomotives to diesel and electric ones.

3.2.4. The Residential Sector

In the industrial and transitional countries, there is a considerable potential to improve the energy efficiency of **space heating** through retrofit, in construction of new homes, and with more efficient heating equipment. Even in the OECD countries, where there has been much retrofit activity since 1973, a large fraction of most housing stocks still has poorly insulated walls, and additional ceiling insulation is cost-effective in many cases. A recent West German study estimated that investments saving around 40% of baseline heating energy are cost-effective from a social perspective (Ebel et al. 1990). A US government study estimated that energy savings of 30-35% could be attained over the next 20 years through retrofits in dwellings built before 1975, but only about half of this was estimated to be cost-effective (US EIA 1990). (The smaller cost-effective potential reduction in the United States relative to West Germany partially reflects lower residential energy prices.) The cost-effectiveness of retrofits depends on whether energy-saving improvements are made on their own or as part of general renovation.

The potential to improve energy efficiency is greater in new homes. Use of high levels of insulation, advanced windows, and careful air-infiltration control can reduce heating requirements by 50-75% relative to current average building practice in most cold-weather countries. The degree of improvement that is cost-effective varies depending on energy prices and the nature of current practice. High-efficiency furnaces (or electric heat pumps in moderate climates) offer additional energy savings.

In the Former East Bloc, the potential to improve the energy efficiency of existing and new residential buildings is much greater than in the West. The economic potential is hard to judge, given the uncertainty regarding the eventual market prices of heating fuels and district heat, but is probably in the 25-50% range for retrofits, and higher than that for new buildings. In China, which accounts for most of the space heating energy use in the developing world, there is also much potential to improve building thermal integrity and heating equipment efficiency. Simulations suggest that energy use can be reduced by 40% relative to mid-1980s practice, even allowing for increase in indoor temperatures, which are generally lower than desired (Huang 1989).

There are modest opportunities to improve the energy efficiency of **water heating** through better insulation of tanks and piping, electronic ignition of gas water heaters, and higher efficiency gas burners. Separation of water heating from space heating functions in large boilers promises significant reduction in losses. Much larger savings are available from heat-pump water heaters, which may be cost-effective in warm climates. Reducing the demand for hot water while maintaining desired services is another area of potential savings at low cost.

The opportunities to improve **cooking** energy efficiency vary greatly around the world. At the cutting edge of technology, devices such as halogen-element cooktops and microwave ovens offer higher energy efficiency as well as speed and convenience. At the other end of the technology spectrum, there is much potential to improve the efficiency of biomass stoves. It is difficult to generalize across the developing world; roughy speaking, a doubling of efficiency seems possible with well-designed stoves, relative to average current practice. The actual savings are very dependent on how the user operates the stove. There is also some potential to improve the efficiency of the kerosene and LPG stoves that are used by many households.

For **electric-specific appliances**, detailed engineering-economic analyses of efficiency improvement have been conducted in the United States. For the most popular type of refrigerator, incorporation of cost-effective design options would reduce electricity use by 28% relative to the average model produced in 1989 (Turiel et al. 1991). Use of evacuated-panel insulation for walls, which would result in an additional 12% savings, is also cost-effective, but its long-term reliability is not yet clear. Other technologies that could reduce energy use further (such as a two-compressor system) might be cost-effective with higher-than-expected electricity prices. A recent French study found a cost-effective savings potential of around 33% for European refrigerators and upright freezers, and 44% for chest freezers (Lebot et al. 1991).

For clothes washers and dishwashers, the US analysis found that design options that reduce energy use (including energy to heat water) by 30% are cost-effective. In the US, a change from vertical- to horizontal-axis clothes washers would reduce energy use by about two-thirds relative to the baseline (such washers are the norm in Europe). For clothes dryers, the cost-effective reduction is only 15%, but much greater savings (about 70% relative to the baseline) are possible through use of a heat pump dryer, which has significantly higher cost but might be cost-effective in the future. Increasing the spin speed during the spin dry cycle of a clothes washer can also reduce drying energy use considerably.

Much efficiency improvement is also possible for air conditioners, whose use is likely to grow significantly in the developing world. The most efficient central and room air conditioners produced in the US in 1991-92 had energy-efficiency ratios of over 16.0 and 12.0, respectively, which was 30-40% greater than th efficiency of average new devices. Designing buildings with higher thermal integrity and less solar gain, and planting trees for shading, can also reduce energy use for cooling (and permit use of a smaller device). A recent study for Thailand found that installing 7.5 cm of insulation in the attic of a typical single-family house would decrease cooling needs by 30% (Parker 1991).

The residential end use where probably the greatest percentage improvement in efficiency is possible is **lighting.** Compact fluorescent lamps (CFLs) use only 20-25% of the electricity of standard incandescent lamps to produce the same light output. Although the initial cost of CFLs is many times that of incandescent lamps, they are economic in many applications, and are especially attractive in developing countries, where lighting is often a major part of the peak electric load. Realizing the full potential of CFLs will require changes in design of lighting fixtures (or of CFLs) so that they fit in more applications. In many developing countries, using fluorescent tube fixtures in new installations rather than incandescent fixtures can yield major savings in the future.

3.2.5. The Service Sector

The opportunities to improve energy efficiency in the service sector vary among building types and climate conditions. In cold climates, space heating represents a major opportunity, but in warmer climates it is less important or not used at all. Space cooling is often very important in warm climates, and in certain types of buildings (e.g., high-rise offices) even in moderately cold climates.

Space heating energy efficiency can be improved through similar measures as in homes. The potential savings from building shell and equipment efficiency measures are usually less than for homes,[10] but commercial buildings offer greater opportunity for recuperation of heat from exhaust air, improving distribution of heat from warmer to cooler parts of buildings, and use of control systems. In the transitional countries, the nature of the building stock and the cold climate make for a large potential. In the former Soviet Union, heating energy intensity could probably be reduced by at least 30-35% through retrofit and better management. The situation in China is somewhat similar, though increase in indoor comfort may balance some of the savings.

From the standpoint of primary energy, the largest energy savings potential lies in electrical end uses. Indeed, most cross-sectoral studies of improving electricity efficiency have found a larger cost-effective savings potential in this sector than in any other. One reason is that electricity prices for

[10] This is especially the case in modern high-rise buildings, where energy use for heating is relatively small in most climates because of the large contribution of internal heat gains.

commercial customers are usually higher than for other classes. Another is that lighting is a major end use in commercial and public buildings, and its efficiency can be considerably improved at low cost. Savings are available through use of higher-efficiency fluorescent lamps, magnetic and solid-state electronic ballasts, and use of optical reflectors in fixtures. Much energy can also be saved by better lighting system design and control, including use of timers, photocell controls, occupancy sensors, daylighting controls that automatically reduce lamp output when daylight is sufficient, and "task lighting," which allows general area lighting levels to be reduced. A study of the US commercial sector estimated an overall economic savings potential of nearly 70% (Nadel et al. 1991c).

For space cooling, which usually uses electricity and is becoming increasingly important in the developing countries, energy requirements can be cut considerably by reducing external and internal heat gains,[11] increasing equipment efficiency, and reducing distribution losses. Add-on features such as economizers and variable air volume controls can save considerable amounts of energy, as can energy management and control systems that regulate the operation of HVAC systems. A study of New York State estimated that HVAC efficiency measures could reduce electricity use for space cooling in commercial buildings by over 50% (Miller et al. 1989). In new buildings, careful design offers even more opportunities for reducing cooling energy use.

Other areas for electricity efficiency improvement include motors used in HVAC systems and refrigeration equipment. (Improvements will also occur in the energy efficiency of office equipment, but not for energy-cost considerations.) Studies in several OECD countries indicate that the overall economic potential for electricity savings from retrofit and improved management of existing buildings is in the 20-40% range. For new buildings, the potential reduction in electricity demand per square meter relative to typical practice can be even greater.

Most of the above measures can yield substantial electricity savings in developing countries. For example, a study of large commercial buildings in Thailand found that a combination of commercially available high-efficiency lamps, ballasts, and fixtures can save 70% of typical lighting energy consumption with an average CCE less than half the price of electricity (Busch et al. 1991). Conversion from incandescent to fluorescent lighting and use of higher-efficiency lamps in street lighting also offer a significant savings potential in many countries, as does more efficient refrigeration.

3.3. THE SIZE OF THE EFFICIENCY POTENTIAL

The overall energy efficiency potential is spread over a great many factories, buildings, and vehicles, and lies in both new and existing systems. The size of the efficiency resource within a given sector or in an entire country depends on the potential in many end uses, and the relative importance of each end use. For new systems, the cumulative impact of making particular efficiency improvements depends on the extent to which the systems penetrate the stock in the time frame considered. If stock turnover is faster, the impact will be greater.

Why is it necessary to gain an understanding of the size of the efficiency potential? If energy efficiency is to be taken seriously as a resource to be tapped, it is important to know how large the resource is in different areas. And as with fossil fuel resources, it is useful to know how much of the efficiency resource is economic at different levels of energy prices.

[11] Improving lighting efficiency reduces heat gains inside the building, which lessens the cooling load. Along with saving energy in space cooling, this may allow downsizing of HVAC equipment, especially in design of new buildings. The effect works in the opposite direction for space heating, but the gains from reducing the cooling load are more valuable in most climates.

A growing number of studies have developed estimates of the efficiency potential in particular sectors and across sectors for many countries or parts of countries. These differ in breadth and depth of coverage, the time-frame considered, and in the assumptions about technology performance, cost, and applicability. The reliability of the data on the existing stock and new equipment varies, as does the construction of the base case against which the efficiency potential is measured.

The most common way to depict the overall energy efficiency potential is estimate the reduction in energy use that could be achieved in each end use if the best available or potentially-available technology and techniques were fully penetrated across the entire stock, and then calculate the total savings that would occur based on the existing end-use structure of energy demand. An example of this approach is the study of the technical efficiency potential in West Germany conducted for the Enquete Commission (1990). The estimated technical potentials vary considerably among end uses (Table 3-1). They are relatively smaller in industry, which improved efficiency considerably since 1973, than in buildings and transport. Including the potential in refineries and power plants, the total savings potential in primary energy (based on 1987 end-use patterns) was estimated at 35 to 44%.

Table 3-1. Technical Potential for Energy Efficiency in West Germany (% reduction in 1987 energy consumption)

End Use	%	End Use	%
Residential[a]		Commercial	
Space heating, existing	70-90	Process heat	~40-50
Space heating, new	70-80	Space heating	~50-70
Water heating	10-50	Industry	
Refrigerators	60	Basic industry, fuels	15-20
Freezers	~60-70	Basic industry, elec.	~10
Clothes washers	~30-40	Capital goods, fuels	15-20
Dryers	50	Capital goods, elec.	15-20
Dishwashers	30	Consumer goods, fuels	40-45
Transport		Consumer goods, elec.	~10
Passenger cars	~50-60	Food processing, fuels	25-30
Buses, trucks	~15-25	Food processing, elec.	~10
Electric traction	~15-25		
Aircraft	~50-60		

a - For appliances, the potential is relative to average new appliances

Source: Enquete Commission (1990)

Expressing the efficiency potential relative to the current (or recent) situation is useful, but somewhat unsatisfactory because this method does not reflect the dynamics of the real world, in which the stock is evolving and the roles of different end uses are changing. Expressing the future potential more realistically requires estimating the pace at which different types of new systems will enter the stock. An example of this 'dynamic' approach is found in a recent study of the technical potential for electricity-saving technologies in US buildings and industry (Faruqui et al. 1990). The authors estimated a high efficiency case constituting an optimistic scenario for the year 2000, and a low case that incorporates various practical constraints. The potential was expressed relative to a base case scenario that reflects an estimate of naturally-occurring improvements and the effects of mandated standards. As shown in Table 3-2, the estimated potential is 27-46% of the base-case consumption in the residential sector, 23-49% in the commercial sector, 24-38% in the industrial sector, and 24-44% overall. Each sector accounts for approximately one-third of the total savings. If the potential was expressed relative to *current* efficiencies, it would be greater than the above numbers indicate.

Table 3-2. The Technical Potential for Electricity-Saving Technologies in the US in Year 2000 (% reduction in base case consumption)

End Use	Low Case	High Case	% of Sector Use
Residential			
Space heating	32	55	19
Water heating	32	66	12
Central A/C	29	34	9
Room A/C	19	32	2
Dishwashers	5	26	2
Cooking	8	18	4
Refrigeration	22	48	17
Freezer	24	32	7
Other appliances	28	40	28
Total residential	27	46	100
Industrial			
Motor drives	29	45	68
Electrolytics	19	30	12
Process heating	8	13	10
Lighting	17	33	10
Total industrial	24	38	100
Commercial			
Heating	13	24	10
Cooling	30	70	20
Ventilation	30	50	10
Water heating	40	60	3
Cooking	20	30	2
Refrigeration	12	34	8
Lighting	22	56	32
Miscellaneous	18	36	14
Total commercial	23	49	100
Total	24	44	

Source: Faruqui et al. (1990)

The above study was somewhat conservative in that it looked only at technologies that were readily available nationwide. Development of high-efficiency technologies has been rapid in many electrical end uses. One recent study estimates that full adoption of leading-edge technologies would reduce US electricity use by 75% relative to 1986 efficiency levels (Lovins and Lovins 1991).

The *economic* potential is more difficult to estimate than the technical potential. One way in which energy-efficiency resources are similar to fossil fuel resources is that the total amount considered economically attractive depends on the price of alternative energy supply and the cost of 'harvesting' the resources. A useful way of depicting this relationship is with a *supply curve of conserved energy*. Figure 3-1 shows such a curve for electricity in the US residential sector. It consists of dozens of efficiency measures that were analyzed (by region where appropriate) in a very detailed study performed at Lawrence Berkeley Laboratory (Koomey et al. 1991). Each step of the curve represents the total electricity savings that would result in 2010 if the particular conservation measure was fully implemented wherever feasible. The savings are relative to a baseline that considers stock growth but assumes energy efficiencies frozen at 1990 levels.[12] Compared to the 1989 US average residential electricity price, measures that would save 40% of baseline electricity consumption in 2010 are cost-effective, assuming a discount rate of 7%.[13] About 25% of the savings are in water-heating end uses, 25% are in space heating and cooling, and 15% are in each of lighting and refrigeration. If electricity prices rise and/or the costs of the more expensive efficiency measures decline, the economic savings potential would increase.

The buildings sectors have received the most attention in studies because the costs and impacts of measures can be more accurately characterized there. Quantifying the economic potential in the manufacturing sector is more difficult. The savings and costs in existing factories are usually rather site-specific, and it is often not known how much manufacturers have already done. Estimating the impact of adopting new production technologies requires a thorough understanding of particular industries and their prospects. Studies usually focus on well-defined end uses such as motors or on a few electricity-intensive processes. The efficiency potential in non-electric end uses is usually estimated roughly by assuming that today's best practice for manufacturing various products becomes average practice by a certain time.

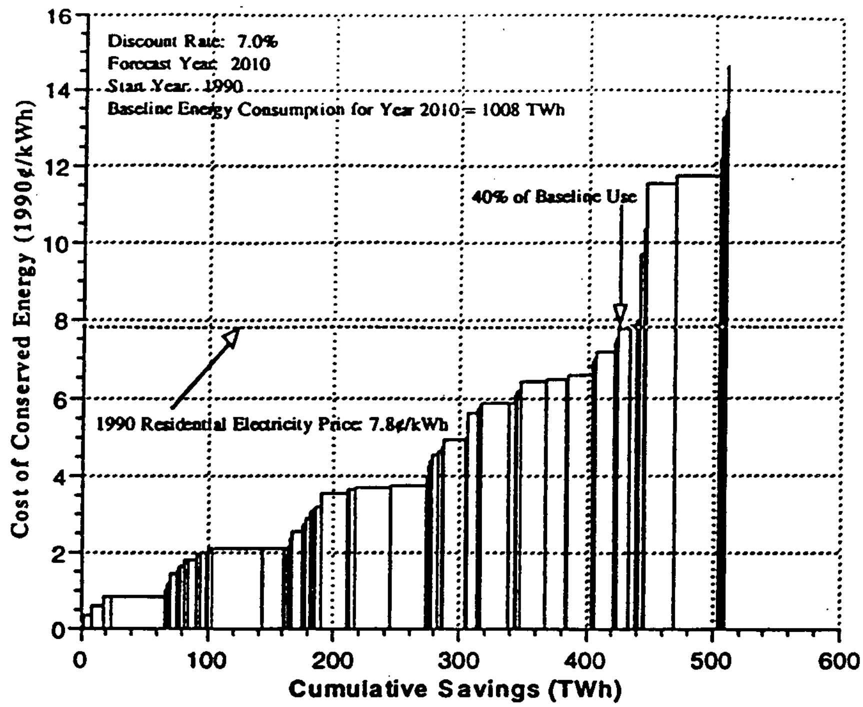
In transportation, the costs of making various efficiency improvements on vehicles are also somewhat uncertain, since most of the technologies are proprietary and not marketed separately from the vehicles. Moreover, most technologies affecting fuel economy affect other vehicle attributes as well, which complicates estimating the specific costs of improving fuel economy. For automobiles, the political debate over fuel economy standards in the US has brought a range of claims regarding how much efficiency could be improved, at what cost, and how fast. There is also controversy over whether certain technologies or design options would change the level of service that automobile users receive, or whether some manufacturers would have to abandon product lines before their normal replacement times. One recent study for the US estimated the maximum cost-effective level of new car fuel economy in 2000 (assuming 1987 levels of size and performance) at 40 mpg (6 l/100 km) (Ross et al. 1991). With various assumptions about new car fuel economy 'ramp-up' and penetration into the fleet, achieving this level would result in national fuel savings of 18% relative to a scenario in which new car fuel economy remains at its 1987 level (which may not be far from where the market might end up on its own). A recent report by the Office of Technology Assessment of the US Congress suggests that the above result may be somewhat optimistic, but concludes that improvement close to that level is probably feasible (US OTA 1991).

[12] The baseline case assumes that buildings and appliances existing in 1990 remain at 1990 efficiency levels (no retrofits), and all new homes and appliances that enter the stock remain at the efficiency of new systems in 1990. Thus, stock turnover improves average energy efficiencies in the base case. The future number of households and the market penetration of each type of equipment were forecast as part of the analysis.

[13] Reducing the discount rate to 3% would decrease the measure costs by about 30%, but since the CCE of the more expensive measures rises steeply past the 40% level of reduction, using a lower discount rate would not substantially change the size of the cost-effective potential.

Figure 3-1

Maximum Technical Potential Electricity Savings for U.S. Residences in 2010



How large is the overall economic efficiency potential across end uses and fuels? Any estimate must of necessity contain many assumptions about performance, costs, applicability, and other factors. A recent study by several national laboratories examined the question for the United States (Carlsmith et al. 1990). In each major sector, the analysts estimated how much efficiency improvement is likely to occur 'naturally' between 1990 and 2010 (assuming an official energy price forecast and no change in governmental regulations, tax policy, and incentive programs), and the potential for cost-effective improvements in efficiency.[14] The 'Where we are headed' scenario shows primary energy consumption in 2010 being 12% less than in a 'Frozen efficiency' scenario (Table 3-3). In the 'Cost-effective efficiency' case, primary energy use is 14% less than in 'Where we are headed' (and 24% less than the 'Frozen efficiency' case). Energy use in the 'Cost-effective efficiency' case is 10% higher than actual use in 1988.[15]

Table 3-3. US Primary Energy Use in 2010 in Three Energy Efficiency Cases (EJ)

Sector	Frozen efficiency	Where we are headed	Cost-effective efficiency
Buildings	42.0	39.2	33.8
Transportation	31.0	24.3	20.2
Industry	42.4	38.2	33.9
Total	115.4	101.7	87.9

Source: Carlsmith et al. (1990)

3.3.1. The Efficiency Potential in Developing Countries

We have already mentioned some of the opportunities for improving energy efficiency in the developing countries. A key difference between these countries and the industrial countries is that systems introduced in the future will play a dominant role in the stock (especially if one looks 20 or more years ahead).[16] Thus, much of the potential lies in making new systems better than they are or would be in a 'business as usual' case. Another difference is that estimates of the technical potential may vary considerably depending on the extent to which one takes practical constraints into account. For example, the potential to improve energy efficiency in the steel industry of China or the former USSR by incorporating state-of-the-art technology is in principle enormous; in practice, there are numerous constraints to achieving the full potential (as we discuss below). In some areas existing constraints can be overcome to a large degree, while in others it is more difficult. Whereas in the industrial countries the gap between the 'theoretical' technical potential and the 'practical' technical potential may be small, in developing and transitional countries it can be quite large.

[14] The cost-effectiveness calculations reflect a discount rate of 7% real. The scenario assumes that the most cost-effective technologies would be installed as new and replacement equipment is needed, and as new technologies become commercially available. The method used to estimate the economic potential in industry and in some parts of the transportation sector was more approximate.

[15] Part of the reason for growth in primary energy use is a substantial increase in the fraction of total final energy supplied by electricity compared to 1988.

[16] The importance of new systems also means that estimates of the efficiency potential in some future year are very sensitive to assumptions about stock growth and turnover.

Lack of data on energy end-use patterns and on characteristics of existing and new equipment have made it difficult to develop reliable estimates of the efficiency potential in developing and transitional countries. Reasonable estimates of the overall electricity efficiency potential have been made for a few developing countries, however. These analyses of necessity focus on those measures for which the costs and impacts can be estimated with some reliability. While uncertainties about future growth make the baseline more conjectural than in the case of the industrial countries, the savings estimates indicate that there is considerable potential in many areas.

For Brazil, a study of 20 measures in different sectors estimated an economic savings potential of 17% of baseline electricity use in 2000, and 24% in 2010 (Geller 1991). The measures found to have the largest savings potential are more efficient refrigerators, a set of low-cost measures in industry, motor-speed controls in industry, and more efficient fluorescent fixtures in the commercial sector. About 40% of the total savings potential is in industry.

A recent study of India looked at 27 measures in industry, buildings, and agriculture (Nadel et al. 1991b). It estimated that they could reduce electricity use in 2005 by approximately 20%. The largest kWh savings are in electric motors, high-efficiency pumpsets, and conversion from incandescant to fluorescent fixtures (Table 3-4). Even the most expensive of the measures has a lower cost per kWh saved than the short-run marginal cost of electricity production, and a lower cost per kW of reduced demand than the capital cost of new baseload generating capacity. Inclusion of additional measures or allowing more time for penetration would increase the savings potential.

Table 3-4. Potential Electricity Savings from Selected Efficiency Measures in India in 2005

Measure	% of 2005 Projected GWh Sales
Variable speed drives	2.22
Motor rewinding, etc.	2.04
High-effic. new pumpsets	1.81
Incand. to fluor. fixture	1.64
Agrig. pumpset rectification	1.59
Electronic ballast	1.49
Meter agricultural pumpsets	0.80
High efficiency motors	0.77
Two-speed motors	0.76
High-effic. refrigerator	0.73
Improved aluminum smelters	0.67
TLD lamp	0.66
Compact fluorescent lamp	0.66
Moderate-effic. refrig.	0.65
Optimize industrial pumps	0.62
Other measures	3.77
Total	20.88

Source: Nadel et al. (1991b)

3.3.2. The Long Run Efficiency Potential

The discussion in this chapter has referred mainly to technologies and techniques that are available now (perhaps not in all countries) or are likely to be commercialized soon. Given the way technologies disperse into the stock, it is these that can have the major impact over the next two decades.

Beyond the year 2010 (or potentially sooner), technologies and techniques still in various stages of research and development (and also those not even conceptualized yet) will have an effect. For example, prototype vehicles that incorporate advanced technologies and designs, including extensive use of plastics and light materials and innovative engines and transmissions, have been developed by many of the leading car manufacturers (Bleviss 1988). Among the vehicles designed for 4-5 passengers, fuel economy in city driving is in the 60-75 mpg range (3-4 l/100 km). Performance and size are generally slightly less than at present, but by no means poor. Even higher fuel economy might be possible if manufacturers 'tunnel through cost barriers' by utilizing advances in materials, switched-reluctance electric motors in each wheel (in place of a driveshaft), and other weight-saving possibilities (Lovins 1991).

A number of studies -- most of them conducted to evaluate the prospects for reducing or slowing the rise in greenhouse gas emissions -- have attempted to estimate the potential for energy efficiency improvement in the very long run. Such estimates are obviously a great deal more conjectural than more near-term estimates -- especially those that attempt to describe the potential world-wide. The more detailed among them consider the application of particular advanced technologies, while others rely on projected rates of efficiency improvement in different sectors or end uses.

Few cases studies have analyzed the very long-run potential in depth. A noteworthy effort by the US Department of Energy analyzed potential savings from increased energy conservation (mainly from end-use efficiency improvement) through 2030 using end-use models in each sector (US EIA 1990). In the reference case the ratio of final energy to GNP declines by 34% between 1990 and 2030 due to increased efficiency and structural change in the economy. Final energy demand in 2030 is 21% lower than that in a 'high conservation' case, and 30% lower in a 'very high' case. In the latter, the ratio of final energy to GNP in 2030 is 55% less than in 1990.

3.4. ACCELERATING INCREASE IN ENERGY EFFICIENCY

3.4.1. Barriers to Energy Efficiency

Within a given time period, some of the efficiency potential that is economic from a societal perspective will be realized in new and existing energy-using systems. This is likely to consist mainly of those measures that have the quickest payback, or that have other benefits besides energy savings. Many and perhaps most of the opportunities that are cost-effective from a social perspective will not be undertaken.[17] One reason for this, which has especially been a problem in the developing and transitional countries, is subsidized energy prices. Such subsidies are generally largest in the household sector, but also exist in transport and industry.

Even where energy prices are not artificially depressed, however, energy users pass up many opportunities that are socially cost-effective, and also many that seem to be privately economic given the criteria used for typical investments. Perhaps the primary reasons for this are lack of reliable information about the impact of potential investments or actions; the demand for a rapid payback (typically less than

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[17] The social perspective as used here does not consider externalities whose inclusion would raise the price of energy above its market level. If these are included -- as properly speaking they should be -- the gap between what the market is achieving and the societal 'optimum' would be even greater.

three years) for energy-efficiency investments; and the fact that energy costs are usually a small part of total household or business costs. Consumers and small businesses in particular often do not have sufficient interest in energy costs to take the time to consider efficiency measures. Even among large companies that have the technical staff to evaluate and implement energy-efficiency options, capital scarcity can be a problem, and investments with a long payback are usually not made unless they are part of some larger change, or have other benefits. A related barrier to higher energy efficiency is that energy users are typically more concerned with the initial cost of a technology than with life-cycle costs, so the higher first cost of many energy-efficient technologies inhibits their adoption. This is especially the case for low-income households and small businesses, where capital is scarce, and where the person who purchases a technology is not the one who has to bear the energy costs (as in many landlord/tenant situations).

While the barriers to higher energy efficiency are formidable, a variety of approaches have proven successful in accelerating efficiency improvement in the past two decades. These have focused on the producers and purchasers of new equipment and buildings, as well as the owners and managers of existing systems. Below we describe basic approaches that in principle can be implemented anywhere, though selection and design of strategies will vary among sectors and countries, depending on local conditions and needs.

3.4.2. Energy Pricing

Sending the right signal to the market through proper pricing of energy products is essential for accelerating energy efficiency improvement. For many energy products in much of the world, prices are not giving energy users very much motivation to purchase many of the higher-efficiency systems that are available, and producers of systems are thus not very motivated to incorporate efficiency-enhancing features in their products.

Energy pricing policy is the subject of much discussion and analysis. Generally speaking, 'proper pricing' means removing controls and subsidies that prevent prices from reaching market levels, and instituting marginal-cost pricing where it is not in effect already. Price controls may have worthy social aims, but it is increasingly recognized that they are not an efficient way to accomplish them. They encourage overconsumption of energy products, retard improvement of energy efficiency, and distort fuel choices. The subsidies are often a considerable drain on government budgets; the same funds could be used more effectively to assist energy users in improving energy efficiency, thereby lowering their energy bills. Marginal-cost pricing is important because energy users then face the cost of providing an additional unit of energy rather than the average cost, which is often lower. A related approach in the case of electricity is time-of-day pricing, which reflects the fact that the cost of supplying electricity varies over the course of a day.

A more controversial but important step involves internalization of environmental and social externalities into energy prices. One way of doing this is to require the actors involved in energy supply to reduce the environmental damage (or the risk of damage) caused along the supply pathway (and in waste disposal), which will presumably lead to higher production costs and prices. Another is to place a tax on energy products that reflects the environmental costs or risks associated with consumption of the product. In the context of limiting greenhouse gas emissions, a carbon tax is frequently discussed, and has even been imposed in Sweden.[18]

[18] The carbon tax in Sweden amounts (for gasoline) to about $0.10 per liter.

3.4.3. Promoting Energy Efficiency in New Technologies

Energy efficiency is only one of many features that are considered in decisions about purchase of new equipment or systems. While proper pricing of energy is important to increase purchasers' interest in energy efficiency, it does not overcome other barriers (especially the problem of higher first cost). The most effective way to encourage adoption of higher energy efficiency in new technologies is to focus on purchasers and producers. Resistance from the latter will be less if they believe there is interest in higher efficiency, even if it is 'artificially' stimulated.

Providing purchasers with reliable information can assist them in making decisions about energy efficiency and reduce the risk that contributes to rapid payback requirements. It is especially important for households and small businesses. Standardized testing or measuring by an independent party such as a government agency conveys more reliable information than claims from individual manufacturers. Labeling with energy-use information has been used for household appliances and automobiles, and is beginning to be used for new homes in the US. The experience with appliance labeling suggests that it has relatively little impact on consumers' decisions, but does seem to have some effect on what manufacturers choose to offer.

Lowering the initial cost of energy-efficient products with rebates and tax incentives, or spreading the cost through low-interest financing, can be effective methods of encouraging their purchase.[19] Rebates provided by utilities have been very successful in increasing demand for higher-efficiency appliances, lamps, and other products in North America. In many cases, the level of the rebate increases with energy efficiency. Incentives are most commonly given to energy users, but incentives for equipment retailers and payments to manufacturers (to subsidize the price of more efficient equipment) are also possible. Incentives and disincentives can be used together. For new cars, for example, a system of registration fees and rebates that vary according to rated fuel economy is possible, and was recently implemented in the Canadian Province of Ontario.[20] In countries where many of the vehicles are imported, a similar effect can be obtained with import duties that increase with engine size (or decrease with fuel economy).

3.4.3.1. Targetting producers of technologies

The producers of energy-using systems include manufacturers of equipment and those who design and construct buildings. Various methods can require or entice them to increase the level of energy efficiency that they incorporate in their products. Requirements in the form of energy efficiency standards can have a large impact in a short time because they affect an entire industry at once. Standards that specify a minimum efficiency level currently apply to a number of household appliances in the US, and are embodied in codes for new buildings in most northern European countries and North America. Regulations that specify a minimum average level of fuel economy for each manufacturer's cars and light trucks sold in a given year have been in effect since the late 1970s in the US (but have little impact at present). Efficiency standards are being considered for products such as lamps, lighting fixtures, and motors.

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[19] An objection that is sometimes raised to financial incentives is that some of the money is given to users who would have made a particular efficiency investment anyway. Even in these cases, however, the incentive may accelerate investment, which usually has some value. Moreover, it is possible to minimize the 'free rider' problem by limiting incentives to high-efficiency measures that would probably not be implemented (except by a few) without the incentive, or by varying the size of the incentive according to the level of efficiency.

[20] This policy can affect the size mix of new cars as well as the efficiency levels selected within each size class.

The effect of an efficiency standard depends on how strict it is, which in practice is affected by how much it will cost the targetted industry to respond (for retooling, for example). Since industry usually resists being pushed too far, standards initially may only eliminate the least efficient products. They can be gradually tightened, as has occurred with the US appliance standards. For refrigerators, the initial standard that took effect in 1990 was already fairly strict; only about half of the models that were marketed in 1989 could meet the standard (Figure 3-2). The updated standard that will take effect in 1993 requires a level of energy use approximately 30% less than the 1990 standard (Turiel et al. 1991). This level was not attained by any of the models in 1989; it is challenging but achievable.[21]

Compliance is an important issue for standards where there are many producers (such as for buildings). Voluntary efficiency improvement targets negotiated between government and equipment producers are an alternative approach to mandatory standards. This has been the preferred approach in Western Europe and Japan for automobiles and appliances. Targets may have greater effect if it is believed that non-attainment might lead to binding regulations. Regulations provide greater certainty than voluntary targets, but may take more time to implement. In situations where mandatory standards are difficult to implement for institutional or political reasons, utility incentive programs can create a *de facto* voluntary standard by specifying a minimum efficiency level to receive payments.

Minimum performance standards or guidelines often do not push the industry very hard. A variety of incentives can encourage designers and builders to go beyond the standard, or to produce energy-efficient buildings if there are no standards. Methods that have been used include payments to design teams, awards and publicity, and utility connection charges that vary according to building energy efficiency. Providing designers with technical assistance and information about advanced technologies and techniques is a complementary measure.

3.4.3.2. Pushing the efficiency frontier

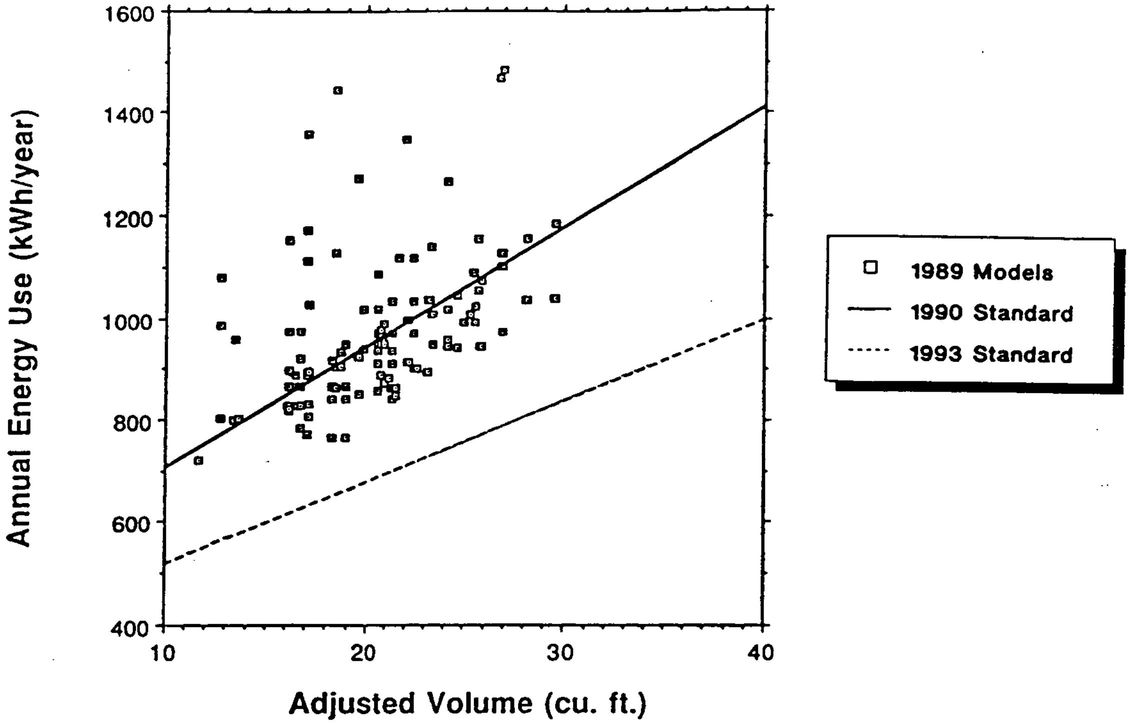
Supporting ongoing improvement in the energy efficiency of new equipment and buildings has two basic elements: (1) encouraging R&D that leads to new or improved methods of increasing efficiency; and (2) accelerating the movement of new technologies from the laboratory to the market. Industry R&D mainly focuses on technologies that appear commercially viable in the near or medium-term. Producers will put R&D resources into efficiency-enhancing options if they believe there will be a market for higher efficiency. Publicly-sponsored R&D is important for basic research that may lead to commercially viable results, as well as for ideas that are promising but too risky for the private sector to invest in. Demonstration of cutting-edge technologies and techniques can help to speed their acceptance in the market.

To accelerate the movement of new technologies from the laboratory to the market, it is necessary to engage the innovative impulses of producers while reducing their risk. In Sweden, the government has begun a program intended to stimulate production of more energy-efficient products by cultivating a market for them among major purchasers. The strategy is focused on a few key actors who account for a large share of the market for a given product, such as owners or administrators of large numbers of residential or commercial buildings. Working with these groups, technical specifications for the product desired, such as a refrigerator, lighting system, or ventilation system, are clearly spelled out so that other attributes are not sacrificed in order to save energy. Having helped organize a market, the government then opens a competition among suppliers for the technologies desired. A small subsidy is guaranteed so

[21] The 1993 standard is set very close to the societal economic 'optimum'. That is, it requires design options that result in the minimum total life-cycle cost, assuming a 7% discount rate and an official energy price forecast. This 'optimum' does not consider environmental externalities, but the analysis assumed that CFCs would not be used.

Figure 3-2

Refrigerator Energy Efficiency
The Role of Standards in the U.S.



that the first production will not be too costly to the buyers. In the longer run, of course, the technologies should be self-supporting. One result of the program to date is production of a fridge-freezer that will use 33% less electricity per liter than the current lowest model on the market.[22]

A program similar to the Swedish competition for refrigerators is being organized in the US by a consortium of utilities, government agencies, refrigerator manufacturers, and other interested parties. The 'Golden Carrot' program will provide incentives to manufacturers who develop and market refrigerators that use at least 25-30% less energy than is required by the 1993 Federal efficiency standard (which is considered rather strict), and use no CFCs. Manufacturers will compete for a 'winner-take-all' monetary payment on the basis of energy efficiency and the amount of incentive requested per unit. Funds will come from a consortium of electric utilities. Utilities will also offer rebates to customers, dealers, or manufacturers for the 'super-efficient' devices, as well as incentives for replacement of inefficient units with 'super-efficient' ones.[23]

3.4.4. Promoting Energy Efficiency in Existing Systems

The opportunities to encourage energy efficiency improvement in existing systems are generally more diffuse than in the case of new equipment. There are no producers to target, and a great many end users. Even so, many of the methods than can promote energy efficiency in new equipment can also work for existing systems. Even mandatory efficiency standards, such as requiring buildings to meet certain requirements when they are sold, are possible, and have been implemented in several US cities.

3.4.4.1. Encouraging retrofit

Raising awareness about energy-saving opportunities is especially important for households and small businesses. Providing general information through brochures and the like can be somewhat useful, but energy audits are a more specific and interactive approach for buildings and industrial plants. Experience has shown that audits are more likely to result in a substantial investment if followed up by further assistance. Providing financing may be helpful in cases where users lack capital, but even low-interest loans are often not a great enough inducement for many businesses and households. Grants or other incentives are likely to be more effective. Such inducements played an important role in encouraging retrofit of homes in the US and Western Europe. Installation or distribution of efficiency measures at no cost to the customer is a strategy that has been used by utilities for low-income households in the US and to promote compact fluorescent lamps.

The challenge in retrofit programs is to entice energy users to implement measures whose payback is longer than the 1-3 years that is common. While it is often possible to make further improvements at some later date (or to install measures in phases), in most cases it is more cost-effective to implement a comprehensive package all at once. Some type of subsidy is usually required to promote projects with long payback periods. Encouraging building owners to incorporate energy-saving measures when they undertake general renovation is especially important because installation costs can be much less in this

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[22] In another project, the government has organized major property owners to work with lighting system companies to implement advanced methods for reducing electricity use. The objective is not simply to replace existing equipment with more energy-efficient devices, but to incorporate new and improved lighting systems. In three pilot projects, reductions in electricity requirements for lighting of 50-65% were achieved. Similar efforts for industrial equipment and building shell retrofits have been announced.

[23] Products that do not win the competition, but are as energy-efficient as the winning bid, would be eligible for the rebates. The consortium is also trying to incorporate the purchasing power of federal agencies and public housing authorities.

situation. A recent Danish study estimated that the average simple payback period to achieve a 25% reduction in energy use for single-family homes built before 1979 was 17 years; but if the work is carried out when renovation and other improvements are made anyway (i.e., counting only material costs), the payback period decreases to 11 years (Energistyrelsen 1990).

Targetting large energy users such as major companies or government agencies is an especially attractive strategy because substantial energy savings can result from a few decisions made at a high level. Moreover, the resulting demand for energy-efficient products can have an effect on the larger market, potentially lowering costs for all purchasers (by moving products into mass production). In many developing countries, several dozen large companies may account for a large share of total commercial energy use. Requiring large companies to report their energy consumption and have audits performed appears to have had an effect in some countries, especially when combined with assistance and incentives. In a program initiated in Tunisia in 1986, for example, the public energy conservation agency paid half of the cost of required audits, prefeasibility studies, and recommended training programs (Philips 1990). Companies also received permission to accelerate the depreciation on conservation hardware investments, were eligible for low-interest loans, and could get an import tariff reduction for equipment not available locally.

Targetting large companies is also possible in the buildings sector. An example of this approach is the Green Lights Program of the US Environmental Protection Agency (EPA). This voluntary program enlists large corporations who agree to implement corporate-wide installations of energy-efficient lighting systems. EPA provides several types of program support, including a software package to help analyze options and a registry of utility rebates for energy-efficient lighting technologies. In addition, the program is involving manufacturers of lighting technologies, who agree to take part in an independent product testing and information program to validate vendor claims about product performance and enhance consumer confidence in the technologies, and electric utilities, who help recruit new corporate partners and market their own lighting retrofit programs. Along with saving energy, the program gives participating corporations an opportunity to present a 'green' public image.

As with new equipment, RD&D is needed to help push the efficiency frontier in the area of retrofits. Field tests of retrofits of integrated packages of advanced energy-saving technologies and techniques is important to measure the effects of component interactions on energy performance, economics, reliability, and end-user acceptance. A project designed to explore these issues in real buildings is the Advanced Customer Technology Test for Maximum Energy Efficiency of Pacific Gas and Electric Co. in northern California. In the initial pilot retrofit project, four of the firms involved created designs that are expected to save more than 70% of the current gas and electricity consumption and meet cost-effectiveness criteria. One lesson learned so far is that even relatively advanced designers need help in identifying and sorting through new technology options.

3.4.4.2. Other strategies

Encouraging improved operation and maintenance (O&M) of energy-using systems can complement retrofit programs and yield additional energy savings. The energy audit process often identifies opportunities in O&M along with possible hardware changes. Encouraging continuation of good O&M practices is difficult to do from the outside, but training programs and other technical assistance can help. Proper energy pricing is also important to encourage ongoing good practice. Hardware that contributes to improved O&M (such as energy management and control systems for buildings) can be encouraged with various incentives.

Addressing O&M is especially important in transportation, where there is little scope for making physical retrofits to vehicles. The main goal of strategies to encourage proper vehicle maintenance is to reduce exhaust emissions, but fuel economy can also be enhanced. Establishing or improving vehicle inspection and monitoring can have an especially large impact in developing countries, where vehicles are older and less likely to have advanced engine controls. For bus and truck operators, education and driver training can lead to more energy-efficient practices. In the OECD countries especially, speed limits on open highways are a possible (if unpopular) way to bring about more fuel-efficient vehicle operation.

For very old systems, an alternative to improving them is to encourage their retirement. In many cases, old systems are very inefficient and polluting, and often are marginally economic (or even not at all). The usual barrier to their retirement is lack of money to purchase new equipment. Incentives can help to overcome this. For example, some utilities in the US have offered customers money to turn in their old refrigerators.

3.4.5. Key Actors in Implementing Efficiency Strategies

Strategies such as energy pricing, efficiency regulations, and tax incentives require government involvement. Government at various levels (national, state, local) can also encourage energy efficiency through most of the other methods we have discussed: information programs, grants, training programs, support for RD&D. Government agencies in specific sectors (housing, transportation, industry, environmental protection) can do much to integrate energy efficiency with other concerns. In some cases, actors outside government may be more effective in accelerating efficiency improvement, or can complement governmental actions, but government leadership is crucial for setting a tone that efficiency is a high public priority.

3.4.5.1. Electric and gas utilities

Utilities can be a key vehicle for implementing efficiency strategies for the residential and service sectors, and can also play a role in manufacturing and agriculture. Utilities have access to funds, established relations with customers, and often can benefit financially from well-planned and executed programs. Electric utilities usually have more incentive to encourage end use efficiency than gas companies, but incentives can be structured for the latter as well.

'Demand-side management' (DSM) programs have come to play a major role in North America and are beginning to expand in Western Europe as well. DSM encompasses a wide range of activities that provide general information, energy audits, financial incentives, low-interest financing, direct installation of energy-efficient equipment at zero or low-cost to the customer, and technical assistance. A comprehensive review of DSM programs in the US (Nadel 1991) found that energy audits alone have relatively little impact, and implementation of audit recommendations is increased by the provision of follow-up services and financial incentives. Rebate programs can promote efficient equipment at a moderate cost to the utility, but they generally only reach a minority of customers and have not been very effective at promoting improvements involving the complex interactions of multiple pieces of equipment. Loan and 'performance contracting' programs (involving 'energy service companies') can be useful for customers who lack capital to finance conservation improvements. Direct installation programs can achieve high penetration rates and savings per customer, but generally at a higher cost to the utility (though not necessarily to society) than rebate and loan programs; they are most suitable for reaching low-income households and small commercial customers.

The experience shows that marketing strategies and technical support services have a large impact on program participation and savings. It is important to keep customers' needs in mind and tailor programs for particular market segments. Personal 'one-on-one' and community-based marketing strategies can be especially effective. Equipment dealers, contractors, and design professionals can be important allies in promoting programs.

To encourage utilities to fully exploit the economic potential for improving energy efficiency, it is important to compare DSM with supply-side options in an integrated manner. Under so-called 'integrated resource planning' (IRP), utilities consider improvements to customer energy efficiency as resource options, and are expected to 'purchase' end-use efficiency if the cost is lower than new supply. The application of IRP raises complex issues for utility planning (Hirst and Goldman 1991), but it is potentially a powerful method to increase energy efficiency.

3.4.5.2. Private sector actors

In addition to utilities, private companies can assist energy users in improving their efficiency. So-called 'energy service companies' (ESCOs) provide engineering and managerial expertise which helps customers to assess and implement energy efficiency improvements, and often arrange project financing. In the typical US arrangement, ESCOs assume much of the risk, since they usually receive a fee that is based on the actual energy savings achieved over a long period of time. ESCOs are especially important in the service sector, where customers usually have less expertise about energy efficiency than in manufacturing. ESCOs are coming to play a greater role in utility DSM programs in the US, particularly in 'DSM bidding' programs in which a utility solicits proposals from ESCOs to provide large amounts of energy savings (usually spread over many buildings) at a specified price.

Industry associations can play an important role in promoting energy efficiency among their members. Professional associations have established standards of minimum good practice for new buildings in the US and other countries. They can also play major roles in disseminating information on energy efficiency and in organizing training courses. Such associations can interact with government agencies in identifying priorities, provide important feedback about proposed policies, and assist in their implementation.

Finally, one should not forget that energy users themselves can take the initiative to make energy efficiency a high priority. This is true both in the private business sector and for households. Higher energy prices obviously contribute to such action, but the values that businesses and private citizens choose to embody in their actions can play a role and potentially influence others as well.

3.5. OTHER STRATEGIES TO CONSERVE ENERGY

Because it reduces energy use while leaving the level of service more or less unchanged (or even enhanced), improvement in energy efficiency is generally the most attractive and least controversial means of conserving energy, but it is not the only one. Policies and programs can affect decisions about the quantity or quality of service that is demanded in various end uses. In some areas these decisions (regarding temperature levels in buildings or the type of car purchased, for example) can play as large a role in shaping energy intensities as the level of energy efficiency. Policies can also affect the overall amount of activity in each sector (how much people travel, for example) and the mix of activities (the share of travel in automobiles). Policies that encourage recycling of energy-intensive materials decrease the amounts of such materials that need to be produced (and also reduce the energy intensity of production relative to using virgin material).

3.5.1. Energy Pricing

Over the long run, energy prices have relatively little long-run impact on overall activity in each sector (the per capita levels of travel or freight transport, for example), but they do affect the mix of activities (the sectoral structure). Low prices encourage energy-intensive activities. For example, historically low gasoline prices in the US have encouraged much greater reliance on the automobile for travel than in Western Europe and Japan.[24] In the manufacturing sector, energy-intensive industries usually play a greater role in countries with low energy prices (especially low electricity prices). Over the long run, removing price subsidies and instituting marginal-cost pricing for electricity can result in shifts in sectoral structure that conserve energy.[25] The effect of prices depends very much on the role that energy costs play in particular areas, and the importance of other factors. In the residential sector, prices have a small impact on decisions regarding whether to purchase energy-intensive equipment such as air conditioners and freezers.

Energy pricing can also affect decisions about the level of service in some end uses. In purchase of new equipment, they may have some effect on selection of features that are energy-intensive. Higher gasoline prices may encourage selection of smaller, less powerful cars, or smaller appliances. Energy prices are certainly not the decisive factor in these instances, but they may play a role. Higher energy prices will also encourage less or more careful use of space conditioning equipment and some other household appliances.

3.5.2. Energy Conservation in Transportation

The largest energy savings from changes in activity levels and sectoral structure are possible in passenger travel. Improving the operation of the transport system and reducing air pollution are the main motivation for urban transport strategies, but energy conservation can be an important result (especially for countries for whom oil imports are a burden).

Over the long run, land-use planning can reduce the need to travel by lessening the number and distance of trips. Policies that favor high-density housing and location of services closer to residences, transit centers, and work places result in shorter distances to many of the common destinations to which people travel in their daily lives. Land use planning can also encourage use of mass transit because it can be operated more efficiently and is easier for people to access when density is higher.[26] Careful land use planning is especially significant for developing countries, where cities are growing rapidly.

The major challenge in attaining reduced energy use (and emissions) in urban transport lies in designing strategies that discourage use of single-occupancy automobiles and encourage less energy-intensive modes. The problem is that once automobiles are acquired, they tend to be driven. People can usually travel more rapidly and in greater comfort in automobiles than in collective modes, and the variable private cost of using cars is often less than the cost of using other modes. Discouraging automobile

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[24] Other factors also play a role, including lower automobile prices, higher household income, lower density of urban areas, poorer mass transit service, and perhaps cultural factors as well.

[25] Raising prices to industry does not necessarily mean that the affected industries will be less able to compete internationally. The higher prices act as a spur to the industry to improve its energy efficiency and may contribute to decisions to upgrade production technology.

[26] Curitaba, Brazil provides a good example of how land use planning can promote mass transit (Lerner 1991). The city has five main arterial avenues that are mostly dedicated to express buses radiating from the city center. High density residential and commercial development is located along these avenues, and a system of local feeder buses connects to stations on the main lines. Automobile fuel use in Curitaba is significantly less than in other, similarly-sized cities in Brazil even though its automobile ownership rates are relatively high.

ownership through high taxation is an option that is used in many countries. Making drivers bear the true social cost of operating the automobile is important to change behavior. Policies to do this include congestion pricing of roads or bridges (in which tolls are higher during peak periods), road tolls, and parking pricing. More stringent methods of discouraging automobile use are also possible. Singapore has heavily restricted automobile use during peak hours through a combination of area licensing schemes, limitations on parking, steep road pricing, and mandatory carpooling (Ang 1991). Improving the service of collective modes is also important. High-occupancy vehicle lanes on roadways and designated lanes or separate guideways for buses on major routes can give them an important time advantage in peak periods. Transit services can also be improved by better integration of bus and rail systems through schedules and fares.

Policies can also affect automobile purchasing patterns with respect to size and power. Registration fees or import duties based on size have this affect. A system of fees and rebates based on fuel economy is also possible. Buyers of a car with above-average fuel economy would receive a rebate whose amount would vary depending on how far above average it is. The reverse would apply for cars of below-average fuel economy. A program of this nature is being implemented in the Canadian Province of Ontario. Vehicle emissions can also be part of the fee/rebate framework, as has been proposed in California.

3.6. CONSIDERATIONS FOR DEVELOPING COUNTRIES

The barriers to energy efficiency are much stronger in the developing countries than in the industrial countries (Reddy 1991). There is often a lack of awareness about opportunities and a shortage of technical expertise for evaluating and implementing them. Difficulty in obtaining energy-efficient products and services is often exacerbated by high import duties. Scarcity of capital and competing demands for it within businesses increase the tendency to place initial costs above life-cycle costs. Other problems include political instability or high rates of inflation that contribute to a very short-term focus and regulation of product prices that dampens manufacturers' interest in saving energy. In addition, poor quality of fuels and electric power supply often limits the viability of certain efficiency-enhancing measures, and leads to use of equipment that is relatively less efficient but can tolerate the energy inputs.

Given the barriers that exist, selection and design of policies and programs must carefully match local conditions. Barriers to the success of a particular policy must be foreseen, and complementary policies implemented to deal with them. Technical assistance and training are needed to increase the number of skilled energy auditors, energy management specialists, and building designers. There is a need to develop skills at a basic level (at universities and technical institutes) and among those already practicing in the field. Building skills in program design, implementation, and evaluation is also needed.

Utility involvement in improving electricity end-use efficiency through DSM programs is a promising approach for easing power shortages and reducing the power sector's capital demands. For example, studies conducted in Thailand estimate that at least 2,000 MW of power generating plants could be avoided over the next ten years through a variety of DSM programs (IIEC 1991). The estimated utility investment required to achieve this savings is about half as much as the capital expenditures needed for power plant construction to produce that amount of energy. How easily the potential can in fact be tapped remains to be seen, but the Thai government has committed to a program designed to save 225 MW of peak demand over the five years.[27]

[27] The first two years are to be devoted to planning and pilot projects to evaluate different energy-saving technologies and program strategies, with full-scale implementation thereafter. The World Bank/UNEP Global Environment Facility is providing funds to help support the program's initial phases.

Improving the link between indigenous R&D and commercialization of energy-efficient technologies is important. There is a need to increase collaboration among research institutions, commercial and industrial enterprises, and end-users, thereby increasing the responsiveness of the R&D community to market forces. One promising model designed to further this aim is the Program for Commercial Energy Research being implemented in India, which seeks to promote development of goal-oriented and market-responsive technological innovations in the Indian power sector through financial assistance to consortia of manufacturers, research institutions, and end-users (Jhirad 1990). Encouraging joint-venture research linked to eventual commercialization between indigenous and foreign firms is another attractive approach.

Sectoral strategies with benefits that go beyond energy conservation are especially important in developing countries. These include transportation system management and improving highway conditions and the quality of fuels. For freight transport, integrated planning of industrial sites with construction of rail or water transport infrastructure can contribute to greater use of these less energy-intensive modes. Improving the quality of electric power supply is an important step. Because of the large voltage fluctuations that are common in many countries, certain technologies that can increase the efficiency of motors, compressors, lighting systems, and other electrical equipment are not used, or equipment is oversized so that it will provide adequate power when voltage is low. Voltage fluctuation also decreases the lifetime of many types of equipment, reducing the period over which energy savings can pay back the initial extra investment in energy efficiency.

Some of the above considerations also apply in the Former East Bloc. Removal or reduction of energy-price subsidies will help to stir interest in more energy-efficient technologies and practices, but where managers have historically paid little attention to energy, or are unfamiliar with concepts such as life-cycle cost, the impact may be slow to develop. Similarly, policies that require products that are not widely available and/or skills and services that are not well-developed may have little impact at first. Policies can create incentives for the local market to deliver those products and services, but technical or financial assistance are needed to accelerate the process.

3.7. THE IMPACT OF ENERGY CONSERVATION STRATEGIES: OECD SCENARIOS

We have used our data base on energy use in the industrial countries to construct two scenarios that illustrate the potential impact by 2010 of strong energy conservation policies and programs. The scenarios use OECD-average energy intensities in some 25 different end uses or subsectors, but we have considered trends and potentials in different regions in constructing them. We treat electric and non-electric uses separately, which allows us to estimate the impact on primary energy use. Each scenario embodies the same growth in activity and structural change as the scenario described in Chapter 2, with slight differences as described below.[28] We present that scenario here as 'Trends'; it is not a 'frozen efficiency' baseline but rather an attempt to project where market forces and modest efficiency policies might lead. Appendix B contains more discussion of the assumptions in the scenarios.

The scenario called 'Efficiency Push' envisions a future in which full adoption of marginal-cost pricing and internalization of some environmental externalities boosts real energy prices to users by 25-40% relative to 'Trends.' (These increases should occur by 1995 if their full effect is to be felt by 2010.)

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[28] In actuality, economic growth and the associated investment and stock turnover will affect the degree of efficiency improvement that occurs in the future. Faster economic growth leads to more investment and stock turnover, so efficiencies tend to improve faster. The efficiency improvements described in the scenarios are plausible with the assumed rates of economic growth, but more improvement might occur 'naturally' with higher growth.

Governments also step up the role of energy-efficiency policies, with particular emphasis on automobiles and retrofit of existing buildings. No major technological breakthroughs are assumed, however. Most intensities decrease between 1985 and 2010 at approximately the same rate as they did between 1972 and 1985. Exceptions are air travel, which decreases more slowly, and truck freight, which decreases faster than in the past. For many end uses, the average intensity levels in 2010 are near the lowest of new systems in 1989. There is also moderate improvement (more than in 'Trends') in the efficiency of electricity supply.

The 'Extra Effort' scenario depicts what might be attained if energy prices rose significantly, if a very strong effort was made to improve new energy-using technologies, particularly for motor vehicles, and if a comprehensive program of retrofitting buildings and factories was undertaken as well. Energy prices are 50-100% higher than in 'Trends', as there is more aggressive internalization of externalities associated with local environmental problems related to energy production and use, as well as those associated with greenhouse-gas emissions. National and international consensus to greatly improve the efficiency of new and existing systems is reached in the mid-1990s, leading to rapid response from transnational manufacturers, national and local energy supply authorities, and other actors. Energy-efficiency R&D is pursued in earnest, leading to cost reductions. In addition to much more efficient technology, this scenario embodies a modest shift toward smaller cars. The rate of decline in intensities resembles that which occurred in the 1979-1983 period, when energy prices and programs stimulated much action to save energy. Average intensities in 2010 lie below the lowest of new systems on the market in 1989, but are close to the levels achieved by the best products expected to be available by the mid-1990s, or at levels represented by prototypes. There is also some shift in travel from automobiles to collective modes. The increase in electricity supply efficiency also accelerates.

The energy intensities of key end uses in each scenario (relative to 1985 levels) are shown in Figure 3-3, along with the associated reduction in the energy/GDP ratio. Whereas in 'Trends' the intensity reductions relative to 1985 are mostly in the 15-25% range, 'Efficiency Push' results in reductions of 35-50%.[29] Intensities in the 'Extra Effort' scenario are 50-75% less than 1985 levels. The intensities of automobile travel and home heating in particular fall considerably. In 'Extra Effort', the energy/GDP ratio is about 60% lower than in 1985.

Figure 3-4 depicts total OECD primary energy use for the five sectors studied in 1985 and in each 2010 scenario. The improvements in 'Efficiency Push' yield a reduction of 22% relative to 'Trends', and demand is about the same as it was in 1989 (which was 7% higher than in 1985). In the 'Extra Effort' scenario, energy use is 44% less than in 'Trends', and is nearly 30% less than the actual use in 1989.

In reality, the reduction in energy demand in the 'Efficiency' and 'Extra Effort' scenarios would be somewhat less than described above. The reason is that lower demand from energy conservation would tend to depress energy prices. Unless prices are kept up by government taxation, the reduction would tend to lower the rate of price-induced efficiency increase and also discourage energy-saving behavior. The size of this feedback effect is subject to some debate among energy economists.

We have not performed an economic evaluation of the efficiency improvements embodied in the scenarios. Roughly speaking, however, we believe that the efficiencies in the 'Efficiency Push' scenario are cost-effective from a social perspective based on projected market prices. The efficiency levels in the

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[29] As discussed in Chapter 2, the 'Trends' scenario reflects our judgment about energy-efficiency improvements that are likely to occur if energy prices evolve as currently expected, and if policies and programs now in place or under development are reasonably effective. In many cases, the stock-average intensities in 2010 are near the average values for new technologies in 1990.

Figure 3-3

OECD Energy Intensities 2010 Scenarios

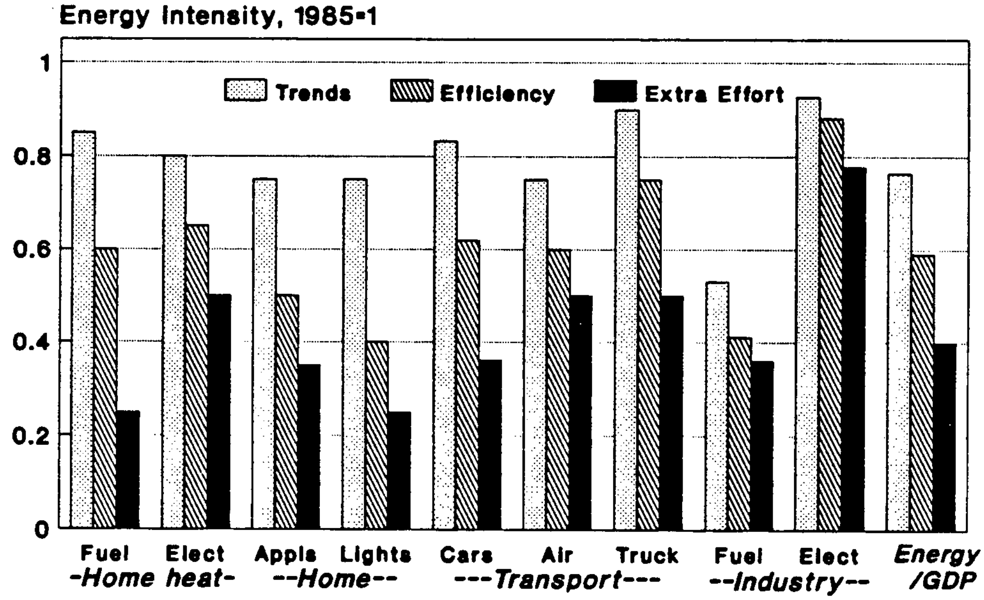
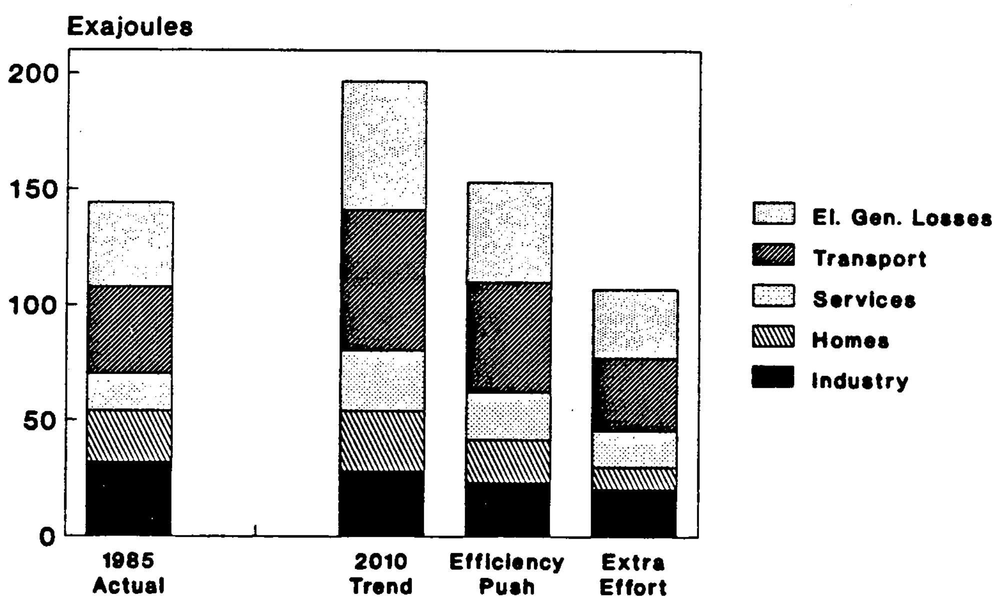


Figure 3-4

OECD Primary Energy Use 1985 Actual and 2010 Scenarios



'Extra Effort' scenario may be cost-effective in some cases, and many, if not most of them would probably be so if energy prices incorporated the environmental externalities associated with energy supply and use, or if R&D lowered costs of implementation.

One way of judging how realistic the intensity declines described in the 'Efficiency Push' and 'Extra Effort' scenarios are is to compare the rates of change to historical experience. The average decline in the weighted average of the energy intensities is 2.0%/year in "Efficiency Push", slightly less than the 2.3%/year achieved between 1972 and 1985. (To express the combined effect of the various intensity changes, we weighted each intensity according to 1985 energy use patterns.) In 'Vigorous Effort', average energy intensity declines by 3.6%/year, close to the rate experienced in many countries during the period 1979-1982, when energy prices rose sharply and various policies were implemented. Sustaining such a rate over 20 years would require a major and concentrated effort. It would not take an enormous amount of technological innovation, but would require great effort to accelerate the market penetration of highly energy-efficient technologies and practices.

3.8. CONCLUSION

The potential to improve energy efficiency in existing and new systems is considerable in all sectors and all parts of the world. The degree of improvement that is cost-effective from a societal perspective varies. In the industrialized countries, reductions in energy intensities of 30-50% relative to current levels are technically achievable and probably economic as well, considering life-cycle costs and a social discount rate. The potential in the developing and Former East Bloc countries is more uncertain and depends on how easily modern technologies can be acquired, but could well be of a similar magnitude.

As stocks of energy-using capital turn over and energy users make improvements on long-lived systems, energy efficiency will gradually increase. But a variety of barriers cause the 'natural' adoption of higher energy efficiency to be much less than it could be, and less than is economically attractive for society. These barriers are especially large in the developing and Former East Bloc countries, and scarcity of capital and technical expertise adds to the problem. Removal of energy price subsidies and existence of a competitive business environment will encourage efficiency improvement, but public policies and programs are needed to realize more of the efficiency potential. Other energy conservation strategies can also have important effects, especially in transportation.

An energy strategy that places a high priority on improving energy efficiency and conserving energy in other ways can slow the pace of growth in energy use, or even reduce consumption in the industrialized countries. In so doing, it can lessen the environmental problems associated with energy supply and use and enhance economic productivity at the same time.

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Chapter 4
Changes in Energy Supply: Prospects and Opportunities*

Strategies to encourage energy conservation through improved efficiency and other means can reduce growth in energy use considerably from what it would be otherwise. But increasing population and rising living standards in the developing countries, along with the considerable barriers to improving efficiency that exist for them, make it unlikely that world energy use in 2020 would be less than it is today. Holding growth below the 40-60% envisioned in conventional views of the global energy future is certainly feasible, especially if the greenhouse problem prompts strong action on an international level. But even in a very optimistic view of how easily the energy conservation potential can be realized, there will still be very large (and increasing) amounts of energy supplied and used. In order to reduce the problems that are associated with the supply and use of energy, which include local and regional environmental impacts, the troubling prospect of the greenhouse effect, and threats to international relations, changes in energy supply are needed.

It is generally agreed that the energy situation of today is not resource constrained. There are ample resources of fossil fuels for decades or even centuries. Renewable energy, in principle, also presents a virtually unlimited physical resource. If unconventional fossil and other resources such as oil shale, tar sands, or uranium from seawater are considered, energy resources are in effect unlimited. The issue is whether we can use them without incurring serious negative environmental impacts.

There are numerous ways of controlling the impacts or reducing the risks of energy mining, transport, and conversion into final products. They include technological solutions as well as change in practices that reduce impacts or risks. The same can be said with respect to the impacts and risks presented by energy end use. Since most of these impacts derive from combustion byproducts, the policy responses generally fall into the domain of air pollution control, but some of them do involve energy supply considerations, such as switching to fuels or technologies that are less polluting.

Evaluating options in the realm of energy supply is complicated, as measures that help in one area (such as using nuclear power rather than fossil fuels to reduce CO_2 emissions) often present problems in another (the risks of nuclear accidents and nuclear weapons proliferation). Comparing different kinds of costs and risks and addressing intergenerational issues is difficult. Moreover, many if not most of the ways of controlling impacts increase the monetary costs of energy, which presents a particular problem for the developing and transitional countries.

In this chapter, we focus on several ways in which changes in energy supply can help solve the problems we have described. One involves improving efficiency in supply of final energy products, particularly electricity. Another and more challenging way involves provoking changes in the energy mix toward sources that have lower overall costs or risks. Of course, the latter depend on the technologies that are employed to convert and utilize particular energy sources. Thus, we also consider the potential for technological (or institutional) changes that can reduce the negative impacts or monetary costs associated with different energy sources. The focus here, as in the rest of this book, is on changes that can be implemented in the short to medium term; we do not cover options that may become viable in the longer term, such as hydrogen, superconductivity, or advanced solar energy technologies.

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* The discussion of nuclear and renewable energy, as well as some sections of the discussion concerning natural gas, have been adapted from Chapter 5 of *Energy Policies and the Greenhouse Effect. Volume One: Policy Appraisal*, by Michael Grubb of The Royal Institute of International Affairs, England, with the permission of the author. Lars Kristoferson of the Stockholm Environment Institute also contributed to the chapter.

4.1. IMPROVING EFFICIENCY IN ENERGY SUPPLY

Many of the energy products used by society result from some degree of processing or transformation of other energy sources, which generally entails a loss of usable energy. Energy may also be lost in delivery of the product to end users, as occurs with electricity and district heat. The proportion of energy lost ranges from very little (natural gas) to very much (electricity). Some reduction in losses is possible in petroleum refining and district heating systems, but the largest opportunities, many of which have very short payback times, lie in electricity supply.[1]

Improving Powerplant Efficiency. The conventional steam powerplant burning fossil fuels is a mature technology that achieves an energy efficiency (net) of 35-40% if well maintained and operated. In many industrialized countries, there is modest room for improving the efficiency of existing power plants (the savings may be just enough to balance the additional energy required by pollution control technologies, however). In the developing countries, efficiencies as low as 25% are not uncommon in older plants.[2] Powerplant rehabilitation can result in sizable efficiency improvement, but it must be followed up with good operational and managerial procedures. Improving fuel quality (especially for coal) can also contribute to higher generating efficiency in some countries (such as China and India). Rehabilitation can also result in substantial energy savings and environmental benefits in the formerly-planned economies.

Use of new technologies in existing powerplants (through 'repowering') and in new plants offers much potential for efficiency gain in all countries. Turbines have attracted renewed attention as new technologies and advanced materials (mostly resulting from R&D for improved jet engines) have improved their efficiency considerably. New designs offer much greater efficiency than those typical of conventional combustion turbines (less than 25%). A particularly promising technology (still in pilot stage) is the intercooled steam-injected gas turbine, which may be able to reach an average efficiency of 48% at a competitive cost (Williams and Larson 1990). Adding a steam turbine to a combustion turbine to form a combined-cycle powerplant is a relatively new approach that is becoming more popular. Combined-cycle efficiencies are already over 50% and research aimed at higher turbine inlet temperature may make 60% efficiency possible by the turn of the century. Advanced technologies promise to also allow for more clean and efficient use of coal (using gasification) and oil (Grubb and Walker 1992). Gas-fueled combined-cycle units may be especially attractive for developing countries because of their low capital cost and small unit size.

Reducing Transmission and Distribution Losses. Over the medium-term, the potential for reducing electricity transmission and distribution (T&D) losses exists mainly in the developing countries. While T&D losses should normally be below 10% of generation, in many developing countries they are over 20% (US AID 1988). The technical solutions for reducing high T&D losses are straightforward and do not require any advanced technologies. One of the main causes of high losses, low power factor in primary distribution lines, can be easily remedied through installation of capacitors. The payback period for T&D improvements can be very short in many cases.

Cogeneration. By substituting the 'waste' heat that is produced in thermal electricity generation for heat that would otherwise be provided by direct burning of fuel, cogeneration can result in energy

[1] One can also reduce losses in production and transportation of primary energy products. In the context of global warming, reducing the amount of methane released in oil, gas, and coal production and in gas transportation and storage is an important strategy.

[2] The majority of thermal powerplants in developing countries operate at lower-than-design capacity and efficiency, and the amount of time they are unavailable for operation is far greater than in the industrialized countries. The higher down-time results in increased reliance on units that are usually used for peaking power, which have lower efficiency than normal base-load plants.

savings on the order of 25% (relative to separate electricity generation and heat production in boilers).[3] Cogeneration can be large-scale, as when heat from powerplants is used in district heating systems, medium-scale, as in systems used at large industrial plants, or small-scale, as in systems used at smaller factories and buildings.

Expanded use of large-scale cogeneration is mainly of interest in regions where heating needs and urban density allow for economic viability. It faces two key obstacles. One is the long payback period and other problems arising from its capital-intensive, infrastructural nature. The other is the lack of incentives for electric utilities to sell heat. Successful expansion will require an integrated approach and public finance.

The potential for medium and small-scale cogeneration is far larger and extends throughout the world. It is already common in industries that have large electricity and heat loads (such as petroleum refining and chemicals). Recent years have seen institutional and technical developments that greatly expand the potential for cogeneration. Policies that require utilities to buy independent power at avoided cost have contributed significantly to rapid growth in cogeneration in the US, and are being implemented in other countries are well. Technology development has also expanded the range of applications for cogeneration. Conventional cogeneration equipment converts only 10-15% of the energy into electricity and requires large and fairly steady heat loads to be economic. New systems can deliver higher generation efficiency through use of automatic process control, topping turbines, and better motors. A promising new technology is the steam-injected gas turbine, which has a flexible electricity-to-heat ratio up to 40%. Combined with fair rates for selling power to the grid, the greater production of electricity allowed by this technology could greatly enhance the economics and applicability of cogeneration.

4.2. CHANGING ENERGY SOURCES AND IMPROVING TECHNOLOGIES

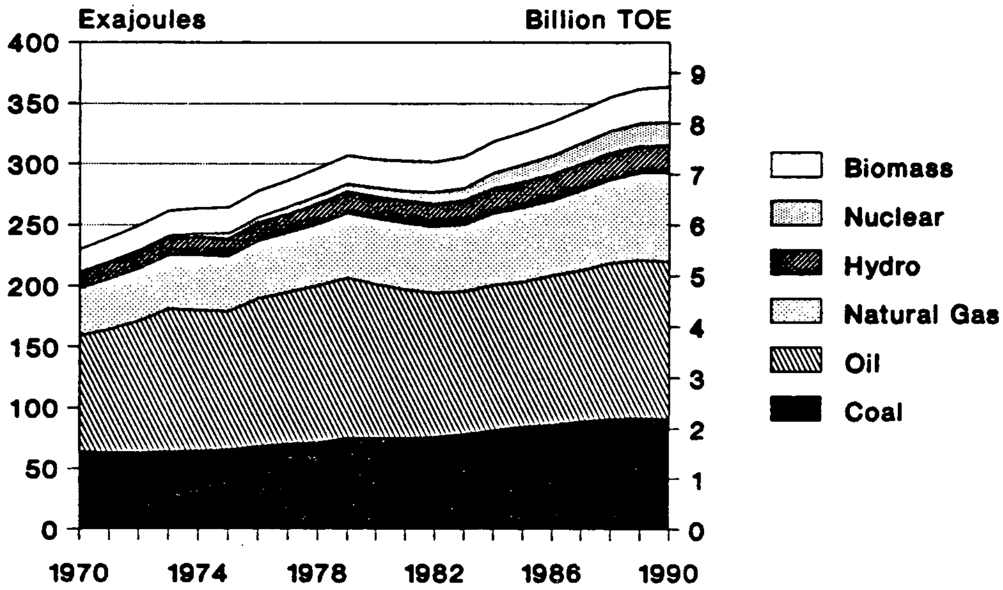
The world has seen considerable change in the global energy mix since 1970 (Figure 4-1). Oil has declined in share from 41% to 36%, coal has fallen from 28% to 25%, while natural gas has grown from 17% to 20%. Absolute consumption has increased in all cases, however. Nuclear energy has seen rapid growth, and the share of hydroelectric production has risen modestly. These changes resulted from shifting prices among competing fuels, development of new energy resources in many countries, government energy and environmental policies, and changes in the structure of end use.

While all of these forces will continue to shape the energy mix, the conventional wisdom envisions relatively modest changes from the current energy supply mix over the next 20 years. This view is illustrated in Figure 4-2, which shows the recent international energy outlook of the US Department of Energy (US EIA 1991). The share of oil continues to decline, but at a slower rate than in the past. The share of gas rises slightly, while coal remains stable. The role of nuclear energy does not grow. This projection reflects the consensus understanding of energy resource prospects, the range of future energy demand, and the resulting evolution of energy prices. It is a guess, but not an unfounded one. Even if energy demand were to grow less rapidly than in conventional views, the world of 2010 would be faced with greater impacts from energy supply and use than exist today, and would be on a path of rising CO_2 emissions. Local, regional, and global environmental issues provide reason for provoking change in the supply mix and for improving technologies. Below we give an overview of opportunities and prospects for different energy sources.

[3] In some cases, high-temperature waste heat from industrial processes is used to generate electricity.

Figure 4-1

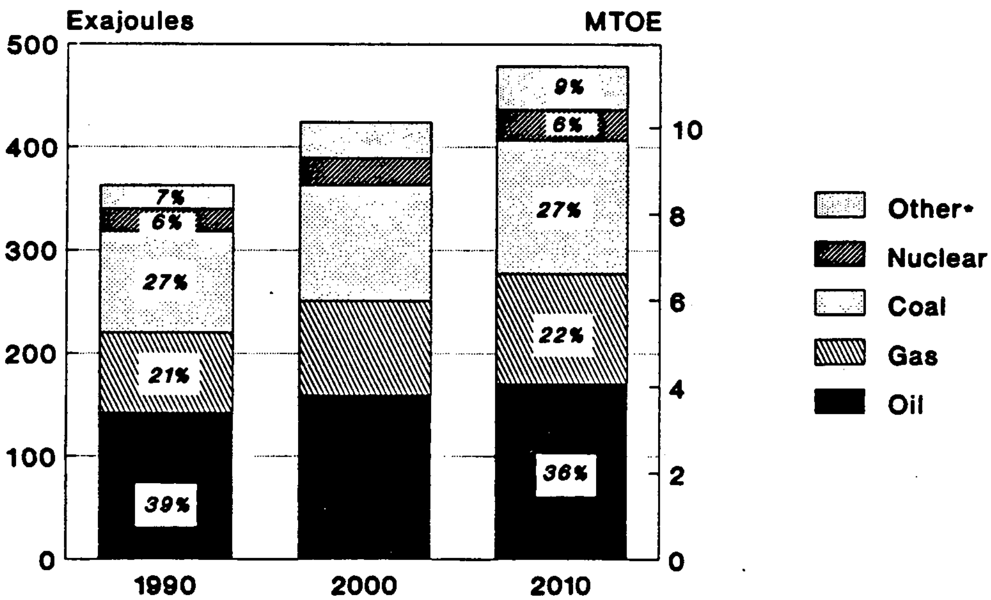
World Primary Energy Use By Source, 1970-1990



Sources: BP, IEA & LBL

Figure 4-2

World Energy Outlook, 1990-2010



Source: U.S. Dept. of Energy (EIA 1991)
Base case projection
• Does not include biomass

4.2.1. Displacing and Cleaning Coal

With some notable exceptions outside the industrial countries (especially China and India), coal has been largely displaced as an end-use fuel. But it has come to be a favored energy source for electricity generation in much of the world, especially where nuclear power is no longer (or never was) viable. The main virtue of coal is its low (and stable) price relative to other fuels. From an environmental and public health standpoint, however, coal is arguably the least attractive of conventional energy resources. Mining coal usually has major ecological impacts (and occupational hazards), and coal burning with conventional technology releases air pollutants associated with local and regional problems. These problems can be mitigated to a degree, depending on how much resources are devoted to such efforts. They are naturally most severe in poorer countries like China, India, and Poland. The other main environmental drawback of coal, its high carbon content per unit of energy, is far more difficult to deal with, and casts coal in the role of villain with respect to the greenhouse effect. Coal contains around 1.8 times more carbon per unit of energy than natural gas and around 1.3 times more than oil.[4]

Despite its environmental drawbacks, displacing coal will not be easy, especially in countries where it is the main indigenous energy resource. China, already the world's largest consumer of coal, plans to increase its coal use 40% by the year 2000. India also envisions major increases, as do other developing countries. Even in the industrial countries, the difficulites in curbing coal are likely to be high due to social factors, vested interests, and the inertia of the technological infrastructure.

Because of coal's abundance and low price, much attention has been given to development of technologies that can reduce the air pollution associated with its use. These include technologies for achieving a higher degree of emission removal from flue gas and for controlling NO_x emissions in combustion, as well as alternative combustion systems such as fluidized-bed combustion and the integrated gasification combined-cycle process. These technologies can make coal more attractive with respect to local and regional air pollution, and some also improve the efficiency of its use, but removing and disposing the large amounts of CO_2 generated through coal combustion remains a daunting problem. Various schemes for CO_2 'scrubbing' and disposal appear technically feasible, but none have been tried as yet. The increase in cost could remove much of the price advantage that makes coal attractive in the first place, and the limited practical options for disposing of CO_2 may constrain application even if the technical problems of removing CO_2 can be overcome. If today's best coal technology was used worldwide, however, CO_2 emissions from coal combustion would be reduced by at least 30%.

4.2.2. Increasing the Role of Gas

Gas is enjoying a wave of popularity. Relative to coal and oil, it has smaller impacts in production and transport, is cleaner in use, can be burned with high efficiency in electricity generation and in many end-use applications, and contains less CO_2 per unit energy. In principle, gas could substitute for other energy sources in all sectors and in most of the world. Its main disadvantages are the need to build extensive infrastructure to distribute it and, in many cases, its higher price.

One reason for optimism about gas is that the global resource is clearly much larger than was once thought. Proven gas reserves, which are roughly sixty times the current global consumption, have doubled in the past decade. The estimated potential resource is twice that amount, and some believe that

[4] The relative CO_2 emissions per unit of energy delivered depend on the combustion technologies employed. Most coal combustion technologies are less energy-efficient than comparable oil and gas technologies, in part because of energy used by pollution control equipment. Coal mining also results in emissions of methane, which is a short-lived but potent greenhouse gas. The global emissions are estimated to be roughly comparable to those from natural gas drilling, venting, and transmission.

there are very large unconventional gas resources which might be economically exploited. The problem is that gas resources are not evenly distributed. Proven reserves are heavily concentrated in the former USSR and the Middle East, so the eventual global role of gas will depend on the development of pipeline networks from these areas and on the use of more expensive LNG transport. But pipeline networks are vulnerable, and it is far from clear how politically stable some of the main gas resource regions will be over the coming decades. Consequently, the gas world of 2030 (or perhaps sooner) could look suspiciously like the oil world of 1970. Unless major new resources are discovered within the industrialized countries, large price rises and volatility may constrain the long-term role that gas can play. While gas is clearly poised to play an important part in the future global fuel mix, and thereby help in limiting CO_2 emissions, it is not a greenhouse panacea because its use on a grand scale would still result in substantial increases in carbon emissions. Care would also have to be taken to minimise methane emissions.

4.2.3. Displacing Oil

There are good reasons why the world is so dependent on oil. It is relatively easy to transport and convenient to use. It is liquid, yet has high energy density, features that make it especially attractive as a portable fuel for powering vehicles. There are also good reasons for displacing oil in the energy mix, however. From a global perspective, substitution (by anything but coal) would help slow greenhouse problems, though replacement with gas would have a relatively small effect. Restraining growth in oil use through substitution can decrease the degree of dependence on volatile oil-exporting regions, and thereby perhaps help prevent conflict. From the perspective of many developing and formerly-planned economies, displacing oil can reduce the burden that oil imports place on foreign exchange resources. From a local perspective, substituting alternative fuels for petroleum products in urban transportation can help alleviate air pollution problems.

Despite the above reasons, displacement of oil over the next 20 years is likely to be fairly limited, given the probable evolution of international oil prices. Most observers envision an increase in prices between now and 2010 ranging from nearly zero at the low end to around 50% at the high end. Barring major political changes in the Middle East, the lower end may be more likely, as expansion of relatively low-cost oil production in that region could keep prices from rising substantially. Some in the oil industry believe that enhanced oil recovery could keep prices in the $20-40 per barrel range until around 2030 (Chevron 1990).

As prices rise in the long run, oil use may be increasingly confined to transport (and petrochemicals). Even with prices substantially higher than today's, displacing it in transport to a significant degree may prove difficult (though restraint in demand is certainly feasible through improved fuel economy and other transportation management measures). Compressed Natural Gas (CNG) and electric vehicles are both viable possibilities, but even with improvement in technology their performance in terms of power and range is unlikely to be as good as most gasoline-powered cars. In terms of carbon emissions, CNG is at most 20% better than gasoline, and electric vehicles charged from thermal power systems may be better or worse depending on the fuel mix in generation and the efficiency of the competing cars. Liquid fuels from biomass, electric vehicles charged from nuclear or renewable sources, and hydrogen from various sources could make a larger impact, but may have difficulty competing with oil in terms of price.[5] This, and the probable lower performance of many alternatively-fueled vehicles, means that trying to force societies away from gasoline cars may not be easy. The situation concerning aircraft and heavy goods vehicles, where power density is a still more important factor, is even more difficult.

[5] Liquid fuels derived from coal (such as methanol) may have advantages over gasoline in terms of local air pollution (although this is a matter of debate), but would be much worse with respect to CO_2 emissions.

4.2.4. Nuclear Power: The Debate Goes On

No other energy source evokes such heated disagreement as nuclear power. It has been hailed as a cost-effective, clean, and (if properly handled) safe power source by its supporters, and condemned as uneconomic and dangerous by its critics. After a period of rapid growth in installed capacity in the 1970s, its fortunes began to wane in most industrialized countries in the 1980s. New orders evaporated, and the Chernobyl disaster seemed to seal its fate as publically unacceptable. Even in Japan, which was considered one of its safest bastions, it began to come under growing criticism. In recent years, however, concerns over the greenhouse effect have sparked renewed interest in the nuclear option.

What are the prospects and issues facing a nuclear revival? The problems break down into two major areas. The first lies in the realm of technology and economics; the second concerns safety and public confidence. Though the two are linked, safety concerns have been far from the only factors behind the long story of cost overruns and poor performance in many countries. While experience in some countries (e.g. France, Japan, Sweden) has demonstrated that nuclear power can be a technical success given the right conditions, it is still unclear whether it has been or will be economic when all costs are taken into account, especially if private sector criteria are used. What has become clear is that nuclear power requires an extraordinary degree of centralised commitment combined with very good management to make it work well.

A passive public, or an ability to push through developments against popular opposition, emerged as another key requirement for large nuclear programs. Public confidence still poses an obstacle to a nuclear revival.[6] The fear of major accidents is probably the greatest single cause of public concern. In principle, enough precautions can be introduced to make such accidents virtually impossible. The questions are not only how this affects the economics, but how reliably humans can apply such precautions in practice. While it is true that most of the world's nuclear powerplants are far safer than was Chernobyl, the disaster there, combined with other accidents in the 1980s, has certainly not contributed to public confidence.

Dealing with nuclear waste is another concern. The industry believes, probably correctly, that it can handle the problem without significant risk if it can have access to the best sites and processes. But the best sites remain elusive for a mixture of technical and political reasons, and the waste is steadily accumulating in storage tanks above ground, vulnerable and in some cases leaking. Still more deep-rooted problems underlie proliferation concerns. Nuclear power is not essential for developing nuclear weapons, but it offers a ready path to obtaining the basic know-how and materials. Major studies conclude that the international safeguards regime cannot be expected with confidence to police forever the line between energy and weapons, and several countries -- outside the Non-Proliferation Treaty but nevertheless with some foreign assistance -- are now suspected of having obtained nuclear weapons under the cover of nuclear power (Spector 1987).

Given these problems, the task of gaining acceptability for nuclear power seems a huge one in most countries. The greenhouse effect might conceivably give it another chance, but a further major accident, or use of a nuclear weapon derived from nuclear power, would probably spell the end in most countries. One possible avenue is to rely on massive electricity imports from the few areas which, for one reason or another, are able to proceed with nuclear technology. Though this pattern has already emerged in Europe to some extent with the progression of French exports, the drawbacks of taking such an option to

[6] This is true not only in the industrialized countries, but in some developing countries and certainly in the formerly-planned economies. In the latter, there is little support for nuclear power at official or public levels, and many existing plants may be shut down as the situation permits.

extremes are obvious: it creates dependence usually on a single foreign source, which could be vulnerable to accidents of technology or politics. Another path is to turn to alternative and perhaps more attractive nuclear systems. Some parts of the nuclear industry are considering smaller-scale 'passive' reactors, designed so that they cannot melt down even if there is a complete loss of coolant. Development and demonstration will inevitably be a long path, but this might meet many of the concerns, and the smaller scale might in the long run prove better commercially as well. However, others in the industry doubt the wisdom of this route, because it would divert economic and political resources from established technology, and might be seen to carry an implication that existing systems are not safe. In any case, it is clear that developing a new generation of 'inherently safe' nuclear reactors would need substantial long-term commitment by both industry and governments worldwide.

Dealing with the problems of weapons proliferation and possible terrorist use of nuclear materials poses yet another challenge. 'Diversion-resistant' nuclear power would probably require abandoning reprocessing of spent fuel (which generates considerable quantities of plutonium) and managing nuclear fuel through safeguarded international centers (Williams and Feiveson 1990). The former makes good sense on several counts, but faces some political obstacles; the latter would require major restructuring of the nuclear industry.

In summary, nuclear power, despite its vast theoretical potential, is unpopular, often costly, and in many respects now appears unattractive and insecure as a basis for long-term electricity supply. Attempting to push for a large-scale revival of the technology as it stands would be politically and perhaps financially costly, and is probably impossible in many countries. Some of the problems could be avoided by a large-scale restructuring of the nuclear industry, based on new reactor designs, international safeguards, and an abandonment of reprocessing, but it is not clear if the industry has the will or the resources for such a strategy. Attempts to expand nuclear power in most countries would probably require major political and financial support from governments, for returns which are uncertain.

4.2.5. Renewable Energy: How Real are the Prospects?

The alternative to fossil fuels and nuclear energy hailed by the environmental community and some researchers is renewable energy. In the very long run in particular, many believe that renewable energy 'should form the foundation of the global energy structure during the 21st century' (WCED 1987). Renewable energy covers a wide range of energy sources that have little in common except that they derive from energy flows rather than concentrated geologic energy stocks. It includes hydropower, wind energy, solar radiation, and biomass, as well as other sources. Geothermal energy, though actually not a renewable source, is usually included for the sake of convenience. The attractiveness of renewables is not so much their flow nature (which in certain respects is a drawback), but rather the low impact that is often associated with their use, and the fact that resources are widely distributed.[7]

The conventional attitude towards the prospects for and importance of renewable energy is that in the short to medium time horizon relevant to the real world of industrial and political policy formation and investment, non-hydro renewable sources are essentially irrelevant: that for the foreseeable future

[7] The quality of low impact does not, however, generally apply to the renewable resources that are most commonly used today: large-scale hydropower and traditional biomass in developing countries. Large-scale hydropower is non-polluting but has major ecological impacts and has also had considerable social impact in many developing countries due to dislocation of people. Biomass as traditionally used in the developing countries is probably responsible for serious health problems in many areas (Smith 1987, Ellegard 1992). Indoor air-pollution from biomass stoves could be considerably mitigated with improved technology, but widespread dissemination of such stoves has proved difficult.

their contribution will remain marginal. In this view, there are three primary obstacles to large-scale contributions from renewable sources: technical limitations including high cost and other problems such as reliability; the difficulty of using sources which fluctuate with natural cycles; and limits on the available energy taking into account realistic constraints on siting. In reality, the scale and importance of these obstacles are questionable.

Avenues for major technical improvements exist in many renewable technologies. A number of these could be of local and perhaps national importance in some countries, and three stand out as having a large global potential if successfully developed: photovoltaics (PV, or solar cells); modernized biomass systems for producing electricity or liquid fuels; and schemes for extracting energy from underground hot dry rocks (HDR geothermal). The global potential from wind energy is also very large. The economic prospects for modernized, sustainable biomass systems based on short rotation forestry now seem good for electricity and probably liquid fuels as well. Overall PV costs would have to reduce by a factor of 2-3 to start making it commercially competitive on grid systems, but there are clear technical avenues suggesting that these targets could be reached during the 1990s. HDR geothermal is much more uncertain technically but cannot be ruled out. Also, wind energy is expected to improve further, reducing its costs by 10-40% over the coming decade and making it competitive for power generation in a wide range of coastal and upland regions.

The underlying reasons for optimism are simple: the technologies are still developing rapidly; the technical avenues to lower costs in many cases are already visible; substantial cost reductions are inevitable from mass production alone; in detail there are still a wide range of options to be explored; and relatively little RD&D expenditure has been directed toward them to date (Figure 4-3). In total, it seems that few if any individual renewable technologies have received more than about one-thousandth of the total public expenditure on thermal nuclear power RD&D, with the possible exception of PV (Grubb 1990).

Most of the major renewable technologies produce electricity, the value of which is relatively high and seems unlikely to decline. As the technologies develop further the economics could become quite favourable, especially if there are substantial carbon taxes and/or stricter regulation of other fossil fuel impacts. Technically there are also promising routes into transport, either directly through biofuels such as ethanol or indirectly through electricity. The latter could involve either hydrogen generated from PV in deserts (Ogden and Williams 1989), or electric vehicles charged directly from PV (probably with a combination of cells on cars and recharging/battery exchange points at homes and garages). When these options might compete with oil is uncertain, however.

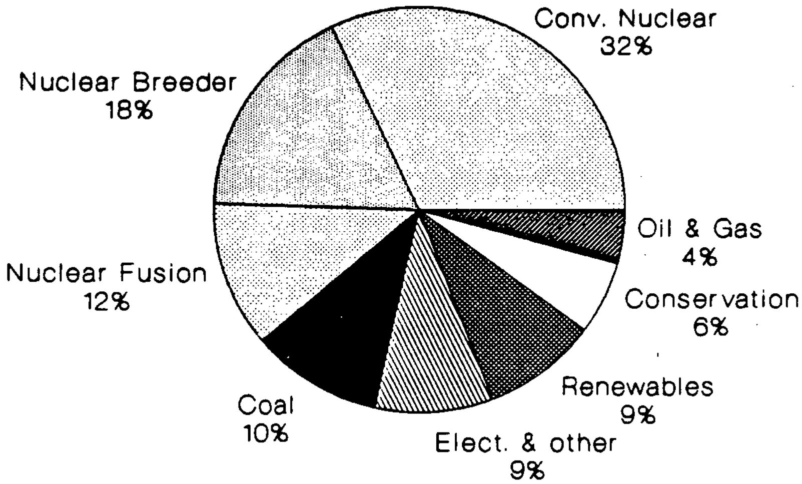
The concern about the variability of many renewable sources is largely misplaced. Biomass and hydro sources represent stored energy, and geothermal is also relatively constant. As for the variable renewables, studies suggest that large integrated power systems could absorb over half their energy from windpower in combination with other variable sources, without either storage or hydro power, before economic penalties would necessarily become prohibitive (Grubb 1988). The limits on PV may be either lesser or greater depending on the nature of the system. In all cases, access to large hydro capacities (which contain natural storage), the greater diversity afforded by large-scale system interconnection, and the use of modern generation and control systems could increase the extent to which power systems could economically integrate variable power sources.

The third concern is that, although in principle some renewables offer a large resource, practical siting and other constraints will greatly limit their realistic contribution. Without more experience this is a somewhat open question. Onshore wind and PV might be deployed in huge arrays in remote deserted areas, but in more populous regions, wind is usually best deployed in small arrays of a dozen or so machines spread over a few acres of farmland or hillside, generating 1-10 MW. Several hundred or even thousand windfarms in a country would be quite visible but, to judge from current experience, not

Figure 4-3

IEA Government Expenditures 1977-1988
Energy Research and Development

Total Expenditure: 119 Billion US $ ('88)



Source: IEA (1989)

necessarily objectionable. Biomass electricity would tend to work best with units of perhaps 5-50 MW sited in the center of the associated forest areas. PV could be deployed mounted on poles in patterns similar to those of windfarms, but cells could also be integrated in the surface glazing or tiles of new buildings as a convenient way of minimizing mounting costs.

How large is the potential for renewables, assuming reasonable technology development but taking into account various regional and systemic constraints? An assessment of the long-run potential in the US, conducted by a team of national laboratories estimated that renewables (including large hydro) could provide around 30 EJ (or 24% of projected primary energy use) in 2020 if RD&D were intensified (SERI et al. 1990). Close to half of this total contribution comes from biomass.

The potential in other countries may be more or less, depending on the magnitude of available resources and the nature of technical developments. Long-distance transport (and international trade) of renewable-derived energy may be possible in some cases, but most use of renewables is likely to occur reasonably close to the point of production. If one divides the world into areas of high energy demand density (comprising Europe and Asia outside the former USSR) and low density (comprising all the rest), the following conclusions seem plausible:

- The 'confident' renewables of hydro, biomass wastes, geothermal aquifers, solar water heating in sunny areas, solar space heating in colder areas, and wind in windy ones, can make useful contributions to national supplies in a variety of regions and stages of development, but they can dominate supplies only in a few minor cases (excluding traditional biomass use in poor countries).
- Major further development of wind energy would greatly increase the importance of this source but would not change the above broad conclusion, except that it might then make large contributions to electricity supply in the Americas, Australasia, Africa, and the former USSR. If offshore deployment of wind or waves proves feasible, these could make moderate to large contributions to electricity in many coastal countries.
- Successfully modernized biomass could in principle meet a large proportion of primary demand in the low demand density regions of the world, excepting very dry areas, but it is limited on a global scale.
- Photovoltaics could easily meet demand to within the constraints of the power system in the low demand density regions. To meet projected demand in the high density regions, PV would have to cover a few percent of the land area. This would take it beyond any conceivable degree of building surface mounting. The main constraints, however, would be the rapidly deteriorating economics in colder and cloudier climates, and the constraints of power systems.
- Successful development of PV-derived hydrogen or methanol would provide the physical potential for an international fuels industry, centered on desert regions, which could in principle meet the total global requirements for liquid fuels projected for the middle of next century. Clearly, this would require a whole new infrastructure of supply, trade and end-use equipment which would take many decades to develop, and it would be dependent on key desert regions. These fuels could not compete economically with the extraction cost of oil and gas resources, but they might enter at the margin if oil and gas prices rise in the long term as most analysts predict, or if these fossil sources are otherwise constrained for environmental or energy supply/security reasons.
- Hot Dry Rock geothermal is a largely unknown quantity in terms of both technology and resource potential, but it could be very large in some areas and its geographical availability would be uncorrelated with any of the true renewables.

A recent extensive and detailed global study of renewable energy concludes that by the year 2050 renewable sources could supply the majority of global electricity requirements (with most of the rest coming from gas) and a large fraction of transport fuels. The study projects technology developments such that an energy system based largely on renewables would not be significantly more expensive than one based mostly on fossil fuels and nuclear power to provide the equivalent amount of energy (Johansson et al. 1992).

In summary, the prospects for large-scale contributions from renewable sources, though uncertain, appear good. At the very least, the possibility of some major renewables becoming competitive cannot be rejected with confidence. Renewables may well be more significant than most energy specialists currently believe. If current trends continue, however, the commercialization and penetration of renewable technologies will be relatively slow, and most are unlikely to emerge on a large scale until conventional supplies start running up against further price rises and/or various environmental and logistical constraints. These might include the political reactions to dramatic climatic events at some point in the future, resulting in rapid and drastic measures to penalize carbon and promote alternatives -- the 1970s syndrome of crash programs. This would be an unnecessarily costly, painful and relatively ineffective way of bringing alternatives in. Renewables face some serious institutional obstacles which will have to be addressed if this prospect is to be avoided, and their potential is to be realized.

4.3. ISSUES FOR DEVELOPING COUNTRIES

Energy supply prospects vary around the developing world depending on natural resource endowments. In part due to foreign exchange constraints, future energy supply is likely to be based on indigenous resources to the extent possible. Traditional use of biomass will probably be important for at least the next several decades in the rural areas of Asia and Africa, but the transition to other fuels is occurring rapidly in larger Asian cities. For China and, to a lesser extent India, the two largest LDC energy consumers, coal will continue to dominate the commercial energy mix. For oil-exporting countries, development of other energy resources for local use will continue so that export earnings can be maximized. For many countries, imported coal may be an attractive option for power generation, especially if coal prices are depressed by carbon-abatement policies adopted by the industrial countries.

While resource availability and cost will dominate energy supply decisions, local environmental issues may play a growing role. For the most part, the result will be increasing use of better pollution control technology rather than changes in the energy mix. Advances in 'clean coal' technologies would be very important for China, India, and some other countries. Fluidized-bed combustion technologies promise higher efficiency and lower environmental impacts, particularly for the low-grade and dirty solid fuels which are now used in large quantities. In many cities, air pollution concerns may contribute to greater use of gas-based transport fuels (as has already occurred in South Korea). The desire to limit oil imports may also give a boost to alternative transport fuels. One issue that seems likely to be of growing importance is opposition to large hydroelectric projects by the people that would be negatively impacted by them. Such opposition, which is already a major factor in some countries, could force greater use of other energy sources for electricity generation.

One promising option for power generation is combined-cycle technology fueled with natural gas. It offers lower cost (capital and total) than other fossil fuel generating sources or typical hydro projects, high thermal efficiency, less air pollution than oil or coal, modular installation, and short construction time. While the operating record to date of combined-cycle units in developing countries has not been good, various steps can be taken to improve operations. A recent World Bank study found that some 25 developing countries have sufficient gas reserves for a relatively large combined-cycle development that could satisfy their power requirements during a long period (about 20 years) beyond the year 2000

(Moore and Crousillat 1991).

Expanding use of indigenous natural gas is attractive for environmental and other reasons in other sectors as well. Accelerating exploration for gas and development of infrastructure for producing and transporting it is an important priority. In many cases, the trans-national companies that have the necessary expertise and capital are not interested in gas development because of the difficulty in exporting it for hard currency. In regions where there is a premium placed on use of LNG for environmental reasons (such as East Asia), the export problem is less severe, but the local resource is often not large enough to warrant the attention of foreign companies. Assistance from international organizations such as multilateral lending agencies and growth in world demand for LNG will help to deliver gas for local use.

Greenhouse concerns are unlikely to play much of a role in LDC energy supply decisions in the next 10-20 years unless the industrialized countries provide expanded assistance for development of low-carbon resources. The developing countries face somewhat of a dilemma in this regard. Local opposition may constrain expansion of hydropower; high capital cost and public opinion make a major role for nuclear power unlikely; and natural gas faces the obstacles described above. As alternatives to the fossil fuels, that leaves renewables. Renewable sources that can play a modest role over the next 10-20 years include geothermal energy, small-scale hydro, agricultural residues, low-temperature solar heating, and specialized applications of PV and wind. Ethanol from biomass could be attractive for some sugarcane growing countries, and appears to have gained a stable place in the Brazilian energy picture.

In the longer run, the potential for a much greater role for renewables certainly exists, but large-scale expansion is unlikely until technical development further reduces costs and conventional fuel prices are reformed to remove subsidies. Most renewable technologies are relatively capital-intensive, a major drawback for developing countries. In addition, questions of reliability and maintenance need to be resolved before widespread use can occur. Decentralized electricity generation based on renewables is often attractive on paper, but maintenance, parts replacement, and especially capital cost are important issues, and the variability of sources such as wind and PV raises costs for isolated applications which are not incurred in integrated systems. An important breakthrough for the developing countries would be a major reduction in the cost of PV, which because of its low maintenance requirements and modular nature is especially attractive.[8]

Modernized use of biomass offers a considerable potential to extract much more useful energy from current bioenergy supplies, especially from forestry and agricultural residues. Fuelwood plantations are another potential supply source. Applications that are especially promising are the generation of electricity from sugarcane bagasse and electricity production using advanced gas turbines fired by gasified biomass from various feedstocks. While the overall potential is enormous, the enhancement of biomass availability on a sustainable basis will require careful long-term planning and development (Hall 1991, Pasztor and Kristoferson 1991).

In the power sector, shortage of capital for new capacity means that improving the existing system must be a high priority. As mentioned earlier, there is much potential to improve energy efficiency (and plant availability) in electricity generation and to reduce T&D losses. Expansion of cogeneration is also possible, but institutional issues concerning sale of power to the utility must be dealt with if the potential is to be realized. In general, institutional changes in the power sector (including expanded use of private power generation) and reform of electricity pricing can do much to improve performance, reduce costs, and allow greater use of available energy resources and cleaner technologies.

[8] PV and wind energy are already finding very useful niches in developing countries, especially in health services and communications (Kristoferson and Bokalders 1991).

4.4. CONCLUSION

Even with considerable progress in improving energy efficiency, the scale of future energy use is likely to bring growing environmental impacts and risks unless major changes in energy supply are accomplished. Indeed, changes are needed now to reduce the local environmental costs associated with energy supply, especially in the developing and transitional countries. During the last decade or two, energy R&D has already made equipment and systems available that are much more efficient and clean than what is presently generally installed. Application of already existing technology can provide substantial efficiency and environmental improvements in the short to medium term, but creative financial and political solutions will be needed here, particularly as regards technology cooperation with the developing and transitional countries. Of course, this should not be taken as an argument to diminish current energy R&D programs. On the contrary, they are still too limited in scope and often not focused on the most promising alternatives. It will always be necessary to continue the evolutionary process and to look for new and presently underdeveloped technologies. In the longer term, environmental and sustainability criteria will demand radical changes in the energy system and the choice of energy technologies. Such a transition will require new solutions and cannot be realized without substantial long-term energy research activities.

In much of the world, local environmental concerns will encourage gas, discourage coal (or make it cleaner), and probably bring modest penetration of alternative transport fuels. The greenhouse problem seems unlikely to play a major role in shaping energy supply in the next decade, but if evidence to confirm today's scientific consensus regarding the greenhouse effect accumulates, major changes may be set in motion. Modest carbon taxes or other schemes adopted by the industrialized countries would give an additional boost to use of gas and help many renewable sources gain market share. While gas is attractive on several counts, it will be ultimately constrained by the concentration of resources and infrastructural requirements. Nuclear energy could make a comeback with new technology, but this will be a slow process and building public confidence could prove difficult. Further technology development and institutional changes could greatly expand the role of renewables, and there are signs that this role could be larger than is foreseen in conventional projections of future energy supply. Increased RD&D is needed to support renewables and other promising technologies that can help meet future energy needs without imposing intolerable impacts and risks.

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Chapter 5
World Energy:
Building a Sustainable Future

As the 20th century draws to a close, both individual countries and the world community face a number of challenging problems related to the supply and use of energy. These include local and regional environmental impacts, the prospect of global climate and sea level change associated with the greenhouse effect, and threats to international relations in connection with oil supply or nuclear proliferation. For developing countries, the financial costs of providing energy to provide basic needs and fuel economic development pose an additional burden.

From a global perspective, lack of energy resources or technologies to make use of them is not the problem—though concentration of the most desirable resources and access to modern technology are important issues. Nor is the high price of energy products a major concern. Adjusted for inflation, international oil prices are higher than they were in 1970, but below the levels that prevailed for most of the 1970s, and the outlook is for only modest rise over the next two decades.[1]

Part of the problem is in fact that the price of energy is too low: it does not reflect the full *cost* to society (present and future) of supplying and using energy. Indeed, the gap between the price of energy and the costs connected with its use may well be growing. Quantifying these costs is difficult, but some of them, especially those related to local environmental problems, are becoming increasingly evident. Others are more uncertain, and may be felt more strongly in the future than at present. Foremost among these is the threat posed by the greenhouse effect. If it turns out to be as serious as the majority of scientists believe, major changes in the energy system may be needed, yet the current energy-price situation reinforces the inertia of present patterns.

The gap between energy prices and the full cost of energy supply and use is of concern because it means that the benefits derived from energy use may not be commensurate with the costs which such use imposes on society. It contributes to reliance on energy souces with low monetary but high environmental costs, to expansion or development of energy-intensive activity patterns, and to inefficient energy use, and retards development and adoption of new energy-saving techniques. The momentum towards higher energy efficiency that was built in the past has slowed markedly, as described in Chapter 2. Along with the growth in the sheer magnitude of energy-using human activity that is occurring in the world today, the slowing of efficiency improvement is pushing energy use upward at a troubling rate.

Narrowing the energy price-cost gap should be a key element of energy strategies for the 1990s and beyond. Governments should take strong steps to:

- **Adjust energy prices to reflect the full costs of energy use.**

Eliminating subsidies on energy prices and special treatment for particular energy sources is a first step, with care taken to cushion the impact on those who are truly harmed by doing so. Environmental costs should be gradually internalized into prices through both regulation and taxation, beginning with those costs that are most clear and agreed upon. Uncertainty in quantifying costs and incorporating the risk element into energy prices is inevitable, but is not a reason to put off some degree of internalization. For costs that are global in nature, such as those connected to the greenhouse effect, the wealthy countries that

[1] The cost of oil imports is certainly a problem for many developing countries, but this has more to do with their overall lack of foreign exchange than the price of oil.

are most able to afford internalization must lead the way. Even there, both energy suppliers and users are likely to resist adjustments that raise prices substantially. Developing a consensus within the business community regarding the magnitude and timing of changes that would be acceptable is important.

Adjusting energy prices will have positive effects on the supply and demand sides. For energy sources that have large 'externalities', such as coal, it will spur efforts to develop and implement cleaner technologies. It will benefit sources that have relatively high monetary costs but low environmental costs, such as most renewables. For energy users, proper pricing will affect fuel choices and influence decisions with respect to the efficiency of new equipment, retrofit of existing systems, as well as how people use equipment. The shift in the market will encourage producers of equipment to place greater emphasis on efficiency.

While reform of energy pricing is critical to give technology producers and users proper signals for investment and management decisions, higher prices will not by themselves overcome the institutional and behavioral barriers that cause private decisions to diverge from the societal interest. Such barriers influence the energy supply mix, making it more difficult for unconventional or small-scale sources to make inroads. They are especially problematic in hindering improvement in energy efficiency. Because of barriers such as lack of reliable information, uncertainty about performance, and lack of interest because energy costs are relatively insignificant, many investments in efficiency that cost less than comparable investments in energy supply are foregone. To remedy this problem and better represent societal interests, governments should:

- **Help overcome barriers to more efficient energy use.**

Apart from pricing reform, a variety of policies and programs implemented by government at various levels can help to accelerate efficiency improvement. Providing information through energy audit programs and energy labeling of new equipment can help energy users to evaluate efficiency options. Efficiency standards or agreements with equipment manufacturers are important because they affect the entire market in the near-term. For devices that are distributed world-wide by trans-national manufacturers, such as home appliances, international agreements can potentially have a major impact in a short time. For new and existing systems, low-cost financing, grants and tax incentives, and other means can encourage improvements in efficiency.

Successfully overcoming the barriers to higher energy efficiency requires development of programs designed for specific users and locations. Policies should complement one another and work in the same direction. Minimum efficiency standards or agreements can 'raise the market floor' for new products, but they are likely to encounter problems if they attempt to push too far beyond where energy prices are leading the market. In addition, standards may not 'raise the market ceiling' very much, and do little to push the efficiency frontier. To accomplish these goals, incentives and other market-development strategies are needed. Policies that constrain progress in energy efficiency, such as high import duties that inhibit use of energy-efficient equipment, should also be adjusted. Last but not least, trying to accelerate efficiency improvement without addressing pricing problems may lead to limited success.

Government is not the only actor that can help accelerate improvement in energy efficiency. Industry and professional associations can promote energy efficiency among their members and advise and complement government policies and programs. It is also critical to take advantage of the relationship between energy supply companies and their customers. Electric utilities in particular are in a position to balance investment in new supply with improvements in end-use efficiency. Working with customers to improve their energy efficiency can bring financial advantages to utilities, but there are various financial and institutional barriers to their aggressive involvement in such activities. Thus, government policies should:

- **Encourage utilities to promote energy efficiency.**

A growing number of utility demand-side management (DSM) programs in the US and Europe are enticing and helping customers to improve their energy efficiency. In some cases, utilities are marketing efficiency measures as aggressively as they once marketed electricity. DSM programs are beginning to be implemented in some developing countries as well. Many DSM programs can save energy at less than short-run operating costs, and can also be financially attractive in the medium- and long-run due to deferment of capital expenditure for new supply. Despite these advantages, a reduction in revenues in the short run may occur and discourage utilities from aggressively pursuing efficiency options. In addition, the institutional history of most utilities, and the experience of its management and personnel, are heavily weighted on the supply side, so there is often a reluctance to engage in demand-side activities.

Ways of overcoming this reluctance vary depending on the nature of the utility industry in each country. Where utilities are state-owned, which is still the case in most of the world, a clear political mandate from a high level may be effective. Where they are privately-owned, or in the process of being privatized, incentives connected to rates are needed. The goal should be to get utilities to see themselves as comprehensive 'energy service companies' rather than simply as energy supply companies. For DSM programs to take root and flourish, it is necessary to establish a planning framework in which they are compared to supply-side investments to cost-effectively meet customer energy-service needs. Such 'integrated resource planning' is gradually becoming more common in the US, and some utilities are relying heavily on DSM resources to meet future needs.

Programs executed by government, utilities, and other actors increase the interest of energy users in energy efficiency and thereby encourage producers of energy-using equipment to incorporate higher energy efficiency in their products, and to devote resources to develop and improve new methods. But it is also important to:

- **Push the efficiency frontier through RD&D and other measures.**

Increasing support for Research, Development, and Demonstration (RD&D) is important for encouraging ongoing progress in energy efficiency. Government activity should be concentrated in areas where the incentives for and availability of private investment are limited, which typically means sponsoring R&D on concepts and technologies that are too risky or whose payoff may be too long-range for the private sector. Energy-efficiency R&D should be seen as a component of general R&D policy designed to enhance national productivity and competitiveness. For commercialization of R&D results, it is important to involve prospective users in all stages of the process, from formulation to demonstration. Collaborative, cost-shared research between government and industry has proven successful in many cases. Government can also play a role in stimulating private sector R&D through tax incentives and other means. Such support should not be viewed as a substitute for government-sponsored R&D, however, which provides a technology base on which industry can build new products.

The movement of new technologies from R&D into the market can be accelerated by reducing the risk that producers face. Apart from offering rebates or subsidies to lower the price of advanced products, government can work with large purchasers to organize a market for advanced products, as Sweden is doing for refrigerators and some other systems. Or utilities can pool resources to offer a large incentive to entice producers to push the efficiency frontier, as is occurring in the US for refrigerators. Equipment producers must be fully involved in programs designed to accelerate the commercialization of advanced energy-efficiency technologies.

Whether focusing on existing, new, or cutting-edge systems, well-designed and executed government and utility programs can play a major role in accelerating improvement in energy efficiency.

However, the degree of success that they realize depends on the larger environment in which energy users operate, and the extent to which programs relate to the concerns of users. Programs will produce the most results with the least cost if fundamental barriers to energy efficiency are addressed at the same time. Moreover, programs are not a substitute for changes in the way that the multitude of private energy users make decisions that affect energy efficiency. To receive the greatest impact from programs, and to encourage the maximum amount of 'natural' energy efficiency improvement, it is important to:

- **Address the context in which energy efficiency decisions take place.**

Understanding particular contexts and the motivations of the various actors is critical for success of programs and policies. For example, dealing with the components of energy-efficient homes without considering the housing process—the housing market and financing, urban planning, the construction industry, occupant or buyer tastes —may lead to plans for efficient homes for which there are neither builders nor buyers. Programs and policies will be most effective -- and have greater institutional longevity -- if they are integrated into overall sectoral strategies. Evidence for this can be found in the high level of energy efficiency in Swedish housing or Japanese industry. In both cases, energy efficiency was seen as part of sound housing and industrial policy, and promoted as much for other reasons as for saving energy.

Efficiency-enhancing actions that also provide other benefits to energy users, or give equipment producers additional selling points, are much more likely to be greeted favorably than those that only save energy. For industry, the main incentive for improving energy efficiency is to increase productivity generally. The experience of the industrial countries shows that competition among firms operating in a market economy leads to continuous efforts to improve productivity. In countries in which domestic and/or international competition have historically been stifled, the trend toward encouraging competition will be a major force for improving energy efficiency. One must beware the idea that simply allowing market forces to operate will quickly lead to major gains in energy efficiency, however. Competition may be slow to develop, and there are many obstacles to efficiency improvement. Where energy prices have been heavily subsidized, the development of skills and technologies to improve energy efficiency has been stifled. Problems with basic infrastructure and the quality of energy products also constrain energy efficiency improvement in many developing and transitional countries and must be addressed.

In developing and transitional countries, the financial and human resources that can be devoted to energy efficiency are limited. Other problems may be equally or more pressing. Low energy efficiency is like a small leak that is not quite large enough to make a boat sink: to some extent, dealing with it can be postponed, and often is if resources to fix the leak (or buy a better boat) are scarce. To make the best use of available resources, it is important to carefully balance supply and demand-side investments and adjust policies that hinder energy efficiency, such as high import duties. Where stocks are growing rapidly, or much of the old stock will be replaced, targetting new equipment is a key strategy. Various internal reforms, especially with respect to energy pricing and trade policy, can do much to accelerate efficiency improvement. Each country must design and implement policies that are best suited to its situation, but the industrialized countries can do a great deal to:

- **Assist developing and transitional countries in improving energy efficiency.**

Training of various kinds (technical, engineering, program planning and management) is needed to provide a foundation for ongoing energy efficency efforts. Developing easily accessible information networks on technologies and programs is an inexpensive step that can yield much benefit. While not all lessons are transferable, the experience in the industrialized countries with energy efficiency policies and programs can help developing and transitional countries avoid mistakes than can waste scarce resources. Governments in industrialized countries can assist in analysis and implementation of efficiency standards and other programs, and can encourage links between utilities. They can also help companies with energy efficiency products or skills to identify opportunities in developing and transitional countries, potentially leading to joint ventures of mutual benefit. Policies and programs that help firms to acquire modern technology (through credits and other forms of innovative financing) and learn new practices are especially important.

International development banks can be a key source of financing for energy efficiency, but it is necessary to package efficiency projects together to create projects large enough to qualify for loans. In addition, loan funds need to be supplemented with grants that support program planning and implementation. 'Model efficiency programs' can serve as examples for other countries. Various agencies within the United Nations organization can provide assistance in many areas, including support for better information flow among developing countries.

In addition to direct assistance, the industrialized countries can indirectly support energy efficiency in the rest of the world through their own energy efficiency initiatives. In many end uses, policies and programs that encourage development of energy-efficient technologies can have a profound effect worldwide. Investment and technology transfer by private companies (through joint ventures, for example) can also play a major role in improving energy efficiency (and productivity) in developing and transitional countries. Other means of accelerating the transfer of energy-efficient technologies should also be pursued.

In developing and other countries as well, even the best of programs, implemented in the most favorable setting, face limits to the rate at which efficiency improvement can be accelerated. Where more efficient technologies and practices offer multiple benefits, the pace of adoption will be greater, but that is not always the case. And there is always a 'learning curve' associated with new technologies and practices. Policies and programs are especially important in the early stages of market penetration, but overcoming inertia can take both time and effort. Even when a new technology or practice has become more familiar and begins to gain momentum of its own, enticing the market to adopt payback periods that reflect social rather than private criteria can be difficult. These concerns do not mean that policies and programs cannot accomplish a great deal. But it is important to recognize that efficiency alone may not restrain energy demand to the degree desired for environmental and other reasons. Thus, it is also important to:

- **Adopt other strategies that conserve energy and provide other benefits.**

The area with the greatest potential for combining energy saving with other benefits is passenger travel. In the long run, urban land-use planning can lessen the number and distance of trips and support use of public transit. Improving public transit service can restrain automobile use and help to discourage automobile ownership. Accomplishing the latter is difficult but important, because once purchased, automobiles tend to get used for many trips. Such use reduces public transit ridership, often leading to deterioration in service which further encourages automobile use. Developing and transitional countries are in a position to prevent this spiral that is already well-advanced in many industrialized countries, but it will take strong public policies, including high taxation of automobiles and gasoline, as well as investment in public transit. Reducing reliance on the automobile in the industrialized countries is a formidable challenge, but may be required to improve urban air and living quality. Policies that shape land use and travel mode choice will be implemented primarily for non-energy reasons, but the potential to reduce oil use provides an additional motivation for them. The same is true of policies that shape mode choice in freight transport.

Changes in behavior and lifestyle in travel and other areas -- or avoiding energy-intensive patterns early on in the case of developing countries -- can bring considerable energy savings. To the extent that efforts to conserve energy through efficiency improvement and other means are successful, they will depress energy prices somewhat. The impact on different energy sources will of course depend on which fuels are conserved the most, but the dampening effect on prices will encourage consumption to some extent. Thus, the feedback between demand and price creates limits to how much can be accomplished through energy conservation alone. For this and other reasons, it is critical to develop a supply system that provides the needed energy without imposing the costs that would result from simply expanding, or slightly improving, the system that exists today. An important step in this direction is to:

- **Improve efficiency and reduce pollution in energy supply.**

In the developing countries in particular, realizing the considerable potential for reducing losses in existing powerplants and transmission and distribution networks will require financial and technical assistance from the industrialized countries, as well as improvements in utility management and operations are needed. Throughout the world, advanced power generation technologies offer much potential for higher efficiency. Increasing the use of cogeneration can save fuel, facilitate the utilization of energy resources that might otherwise remain untapped, and provide an additional source of electricity to the grid. Realizing its full potential requires institutional changes regarding sale of power to the grid.

For reducing the environmental impacts of energy supply in the short and medium term, application of already available technology can provide major gains, especially in developing and transitional countries. RD&D is important to adapt existing technologies to new applications and to reduce costs, as well as to develop new techniques. This is especially important for coal, which because of its availability and cost will be a primary fuel for power generation in much of the developing world.

Improving the environmental characteristics of fossil fuel technologies is important because these fuels will probably continue to play a major role for several decades at least. If the greenhouse effect turns out to be as serious as most scientists believe, however, it will be necessary to:

- **Move toward a lower-carbon energy supply mix.**

Changes in the energy supply mix will be encouraged in the right direction if environmental and other costs are reflected in energy prices. Such moves will favor use of natural gas, which is clearly poised to play a greater role in the global energy mix. Its substitution for oil and coal will reduce local impacts and restrain carbon emissions. Helping developing and transitional countries to exploit and use their natural gas resources is a high priority. In the long run, however, concentration of gas resources and infrastructure requirements are likely to constrain the role that gas can play, and its use would still contribute to the greenhouse effect.

Nuclear power is attractive from a global-warming perspective, but remains problematic on other counts. Developing a new generation of safer nuclear reactors and proliferation-resistant fuel cycles is an option to consider. Renewable energy sources are the other main candidate on which to base a lower-carbon energy supply mix, and there is evidence that a supply system based heavily on renewables may be both technically feasible and economically viable. An advantage of renewables is that most countries have an existing or potential abundance of one type or another, but renewables face serious institutional obstacles which need to be addressed. To help realize their potential, governments should:

- **Increase support for development and use of renewable energy.**

Renewables have received far less public RD&D expenditure than other energy sources, yet many renewable energy technologies are closer to being commercially viable than is commonly believed. Greater

RD&D will help the private sector to realize the opportunities for technical improvements which exist in many cases. Energy pricing that internalizes environmental costs is also important to encourage renewable technology development and market penetration.

To develop an energy path that is sustainable in the long run, major efforts will be needed to reduce energy demand through energy efficiency and other means and to build an energy supply system that poses fewer environmental and other problems. Even if great progress is made in both of these areas, however, it is not at all clear that the impacts connected with energy supply and use will be tolerable if the human population grows in accordance with current projections. In the near and medium term, population growth in the industrial countries, slow as it is, contributes the most to global energy-environment problems, since the per capita energy use in these societies is so much higher than in the developing countries. In the longer run, however, the high rate of growth in the developing countries, combined with increase in per capita energy use, will have an enormous impact globally as well as locally. Thus, it critical to:

- **Promote population restraint worldwide.**

While technological innovation will allow higher standards of living with less impact per person, restraining population growth will permit breathing room to develop and disseminate new techniques. Without such restraint, many of the benefits from energy-efficiency and supply-side efforts will be overwhelmed by the impact of greater numbers of people. By assisting the development process itself, energy efficiency improvement will contribute to slower population growth in the developing world, but many other actions are also needed.

Considerations about population growth are an important reminder that solutions to energy problems must involve more than simply technological change. Whether on the supply side or the demand side, problems related to energy are closely connected to broader issues of economic and social development and international equity. How the built environment, transportation and communications infrastructures, and agriculture and industrial sectors of economies evolve means as much, if not more, to energy demand and energy efficiency as the characteristics of individual technologies. This is especially important in the developing and transitional countries, where much of the future energy-using infrastructure is still to be built. Similarly, the problems associated with energy supply and use are interlinked with challenges in other areas. Fortunately, many solutions are also interconnected. It is essential to move beyond a narrow focus on technologies to discover the synergisms between solutions in different areas, and to strengthen them where possible. While each country must take responsibility to put its own house in order, greater international cooperation will be needed to ensure that the global home is a livable one for future generations.

Appendix A
Data Sources

Our analysis of past trends and future prospects for energy use is primarily based on work done over the past decade by the authors and their colleagues in the International Energy Studies (IES) Group. We rely on data gathered from various sources in each country rather than international publications, as experience has shown that the latter are often not reliable or sufficiently detailed or documented. Our sources include official statistics and surveys, private data and surveys, and reports from local insitutions or academic groups. Official data include figures published by government ministeries, transport and housing authorities, and the central bureaux of statistics. Private data include surveys of household equipment commissioned on a regular basis by energy suppliers, as well as energy consumption data from suppliers.

Our analysis of the industrial countries draws from a number of past and ongoing studies that have assembled detailed time-series data bases on energy use and related factors in manufacturing, passenger travel, freight transport, the residential sector, and the services sector for nine countries: the US, Japan, West Germany, France, Italy, the UK, Norway, Sweden, and Denmark. An important focus of our effort is data on the characteristics and structure of each sector. These include the types of homes, heating systems, and electric appliances; the types of motor vehicles and their usage; the levels of passenger travel and freight activity; and levels of output in the major sectors of manufacturing. To these "structural" data we join energy use by fuel for the main subsectors or purposes. In disaggregating energy use, assumptions are required to separate household energy consumption into end-uses, or to separate the use of road, rail, and marine fuels into the various travel and freight modes. We often use a "bottom-up" approach which entails combining data on energy-using stocks with estimates of average energy use for various purposes (either our own or those of in-country experts). The data sources for the OECD countries are described in the forthcoming book by the authors (with Richard Howarth and Ruth Steiner) mentioned in the Preface.

The analysis of energy use in the former USSR draws on a recent study by Schipper and Cooper (1991). Data are mostly from sources within the former Soviet Union: published data from various ministeries; energy studies in the open literature; and a wealth of unpublished data provided by the Energy Research Institute (Moscow), the Siberian Energy Institute (Irkutsk), and the All-Union Institute for Technical Problems of the Fuel-Energy Complex (VNIIKTEP), an arm of the the Soviet State Economic Planning Agency (GOSPLAN). Additionally, we used information from a series of studies led by M. Sagers of the U.S. Bureau of the Census. The methods used to disaggregate energy use are described in the report cited above.

For the LDC analysis, a key source is a time-series data base on sectoral energy use and related factors for 13 countries that has been organized by the IES Group. The countries (China, India, Indonesia, Malaysia, Pakistan, the Philippines, South Korea, Taiwan, Thailand, Argentina, Brazil, Mexico, and Venezuela) together account for about 70% of total LDC energy use (and a somewhat higher share of total commercial energy use). Although these data are not as detailed as those for the OECD countries, they present trends in a comparable format. Past analysis using these data is given in Sathaye et al. (1987). We also use results from studies conducted by institutions in various countries, as referenced in Chapters 2 and 3.

The data on world primary energy use presented in the first section of Chapter 2 are primarily based on BP (1991). The data on biomass energy use are mainly from the IEA (1989, 1990), which relies on UN/FAO statistics. Estimates of biomass energy use in the LDCs are very uncertain. The authors have made some modifications based on Meyers and Leach (1989) which result in much higher use than the IEA indicates. One recent study (Hall 1991) estimates that total use is some 50% greater than these revised values.

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Appendix B
Scenarios of OECD Energy Use in 2010

The scenarios described in Chapters 2 and 3 are based on the historical data base that we have developed for the US, Japan, and seven European countries. They are built from patterns of energy use in 1985 for approximately 25 different end uses. We have assumed that the end-use pattern that we have estimated for the average of these nine countries applies to the entire OECD. Since the nine countries account for about 85% of total OECD energy use, this is a reasonable assumption. The values presented below are expressed for the OECD-average, but in many cases they are based on separate considerations of the US, Japan, and Europe-7.

Activity and Structural Change

Each scenario embodies the same increase in activity levels and the same structural change, except for some small differences (as described below). The growth in aggregate activity in each sector in 1985-2010 and the impact of structural change are shown in Table B-1. The activity growth in industry and services is based on growth in GDP, which is assumed to average 2.8%/year. Industry (mostly composed of manufacturing) grows more slowly than GDP, while services grows faster. Activity growth in travel (p-km) and freight transport (t-km) are based on the growth estimated for each mode. In travel, the number of automobiles per 1000 people grows from 400 to 480, and average km per vehicle rises 10%. Km per vehicle increases somewhat less in the 'Vigorous Effort' scenario in response to higher fuel prices and policies to encourage mass transit; this has a slight effect on the structure of travel. The load factor for cars remains at 1.5. Domestic air travel increases by 2.5 times over its 1985 level. In freight transport, truck t-km grows at the same rate as industrial GDP. Activity in the residential sector (population) grows at 0.6%/year.

Structural change toward less energy-intensive manufacturing is assumed to have somewhat less effect than in 1972-85. The impact on fuel use is -0.5%/year, compared with 0.9%/year in 1972-85. The structure effect in travel is mainly the result of air travel growing faster than other modes. Growth in the share of automobiles plays a role in Europe and Japan. The structure effect in freight transport is the result of truck t-km growing faster than the total.

Structural effects in the residential sector were estimated in some detail. Heated area per capita grows by 35%; area heated by fuel grows 90% as much, as electricity assumes a rising share. Fuel and electric cooking and water heating grow with population times an adjustment factor to account for the effect of declining household size (the inverse square root of household size); a shift from fuel to electricity also occurs. Lighting grows with house floor area. Appliance ownership increases per capita electricity use by 50% (compared to nearly 100% during the 1972-1985 period).

In the service sector, the area heated by fuel grows at 90% of value added (VA), while area heated by electricity grows 25% faster. We assume that virtually all fuel is for heating. For electrical end uses, penetration of cooling and ventilation is 1.25 times more rapid than VA, lighting grows the same as VA, and other services grow 10% faster.

Table B-1. Change in OECD Energy Use Due to Activity and Structural Parameters, 1985-2010 (avg. annual rates of change)

Sector	Activity	Structure
Industry	2.4	-0.4
Fuels	-	-0.5
Electricity	-	-0.1
Travel	3.1	0.2
Freight transport	2.4	0.3
Residential	0.6	1.2
- Fuels: heat	-	-0.4
- hw, cooking	-	-0.2
Electricity	-	1.8
- appliances	-	1.6
- heat, hw, cooking	-	2.1
- lights	-	1.2
Services	3.1	-0.1
Fuel (heat/hw)	-	-0.4
Electricity	-	0.4
- Heat, hw	-	0.9
- Lights	-	0.0
- Cooling, vent.	-	0.9
- Other	-	0.4
Total[a]	-	-
Energy	2.4	0.1
Fuels	2.4	0
Electricity	2.1	0.8
Primary Energy	2.3	0.3
GDP	2.8	
Population	0.6	

[a]Activity and structure weighted by end-use shares of 1985 energy use.

Energy Intensities: How the Scenarios Differ

Over the next 20 years, most energy intensities in the OECD countries will decline as new capital stock replaces the old and as improvements are made to buildings and industrial facilities. The extent of decline will depend on many factors, including economic growth, energy prices, technological developments, and government policies. The scenarios reflect our judgement of how energy intensities might respond to different "boundary conditions." The conditions in each scenario, and the basic method by which intensities were estimated, were described in Chapter 3. Here we discuss some of the changes in more detail.

The average annual rates of change in key energy intensities in each scenario are shown in Table B-2. For comparison, historical rates achieved between 1972 and 1985 are also shown. For most sectors, the rates shown were calculated based on the intensities derived for 2010. For manufacturing, the estimated rates of change were the basis of intensity decline, and the intensity values for 2010 were calculated based on those rates.

Table B-2. Average Rate of Decline in OECD Energy Intensities (%/year)

Sector	1972-1985 Actual	1985-2010 Scenarios Trends	Efficiency Push	Vigorous Effort
Industry (energy/VA)				
Fuels	3.7	2.5	3.0	4.0
Electricity	0.5	0.3	0.5	1.0
Travel (energy/p-km)				
Cars[a]	2.2	1.0	2.0	4.1
Air	3.9	1.2	2.0	2.8
Freight transport (energy/t-km)				
Trucks	(-)0.4	0.4	1.1	2.7
Residential (energy/capita)				
Fuels: heat, hw, cooking	1.8	0.6	2.0	5.4
Electricity: appliances	1.2	0.9	1.7	2.8
- appliances	1.2	0.9	1.7	2.8
- heat, hw, cooking	1.7	1.2	2.8	4.2
- lights	0.8	1.2	3.7	5.5
Services (energy/VA)[b]				
Fuels	2.7	0.6	2.0	3.1
Electricity	1.2	0.7	1.7	2.7
Weighted total[c]				
Energy	2.3	1.1	2.0	3.6
Fuels	2.5	1.2	2.1	3.8
Electricity	0.8	0.5	1.4	2.4
Primary energy				
Primary/final elec	3.24	2.92	2.85	2.77
Energy	2.1	1.0	2.0	3.6

[a] Energy/km
[b] The estimated impact of changes in the space heating energy mix and in the penetration of electrical equipment has been removed from aggregate fuels and electricity intensity. The values given represent end-use intensities.
[c] Intensities are weighted by end-use shares of 1985 final energy use.

Industry. Energy intensities in manufacturing, measured as energy per unit of value-added, have declined for many decades due to technological change. The rate of decline in fuel intensity in "Trends" (2.5%/year) is slower than what occured in the 1972-85 period (3.7%/year). We expect continuation of the trend of technological innovation, but the slower growth in fuel prices results in less emphasis on energy saving. Fuel intensity falls by 3.0%/year in "Efficiency Push" as manufacturers respond to higher energy prices; the pace is more rapid (4.0%/year) in "Vigorous Effort," since the price rise is much greater.

Electricity intensity declines by 0.3%/year in "Trends." There is increasing use of electricity in many applications, but higher efficiency still results in a net decline in intensity. The drop of 0.5%/year in "Efficiency Push" is comparable to the historic trend from 1972-1985. In "Vigorous Effort," the rate of decline is twice that of 1972-85, reflecting the impact of higher prices, utility DSM programs, and strong standards for electric motors.

There is relatively modest decline in intensity relative to "Trends" in the "Efficiency Push" scenario. The reason is that the primary force of intensity reduction is ongoing technological change that is relatively independent of energy prices. There is also more limited scope for efficiency policies and programs in manufacturing, relative to other sectors.

Transportation. We focus on three subsectors—automobiles, air travel and truck freight—which together account for over 75% of OECD transportation energy use. While reductions in intensities of other travel and freight modes are likely to occur, they are not very significant in the overall picture.

In "Trends," automobile fuel intensity declines from 10 l/100 km (24 mpg) in 1985 to about 8.5 l/100 km (28 mpg) in 2010. Most of the change occurs in the United States.[1] The slow improvement reflects trends in recent years in new car fuel economy, as well as the effect of increased traffic congestion. In "Efficiency Push," intensity declines to 6.9 l/100 km (35 mpg). Higher fuel prices play a role, as do regulations or agreements that cause automobile producers to focus more effort on fuel efficiency. This level is somewhat better than the on-road figure for Italy in 1988, which implies that cars will be somewhat smaller and less powerful than those being sold today, or that the share of diesels will increase. In "Vigorous Effort," automobiles use only 4-5 l/100km (48-60 mpg), roughly the level of the most efficient small cars sold in 1990. In this scenario we assume a shift toward smaller cars as a result of higher gasoline prices and policies, as well as technological improvements that help commercialize the fuel-saving features now found only on lightweight prototypes. Reaching this level of fuel economy would require clear agreement among political leaders, citizen groups, and automobile manufacturers so that efficiency goals have wide support.

The intensity of air travel declines at 1.2%/year in "Trends," much less than the 3.9% rate of decline during the 1972-1985 period. This reflects the slowing of intensity reduction in recent years, a slower rate of improvement in load factors, and somewhat less turnover and retrofit of aircraft. In "Efficiency Push," intensity declines more rapidly as airlines respond to higher prices; the rate is only half of its historical rate, but intensity in 2010 is nonetheless 40% lower than in 1985. This scenario reflects replacement of almost all existing aircraft by models with the lowest intensities available in 1990. In "Vigorous Effort," the intensity declines at close to 3%/year as a result of significant penetration of propfan aircraft.

The intensity of truck freight declines at 0.4%/year in "Trends." The historic upward trend in intensity in the United States reverses as various technologies penetrate the fleet and operations improve. In "Efficiency Push," intensity declines at 1.1%/year as higher fuel prices provoke careful effort to improve both trucks and freight operations. In "Vigorous Effort," there is much faster decline (2.7%/year), reflecting widespread use of advanced technologies made available through accelerated R&D.

Residential Sector. The 'Trends' scenario envisions a continued but slow pace of retrofitting of existing homes. Entrance of new homes into the stock also contributes to decline in average heating intensity, although the 2010 value remains above the 1987 average for *new* homes. (In Japan, indoor comfort levels are increasing; consequently, space heating intensity is higher in 2010 than 1987 in

[1] Changes in the U.S. figure significantly in the OECD average, since the U.S. accounts for about 57% of OECD automobile fuel use. In considering the scenario intensity levels, one must bear in mind that actual on-the-road intensity is some 20% higher than test intensity.

'Trends'.) Overall, intensity of fuel use for space heating, water heating, and cooking declines by 0.6%/year (compared to 1.8%/year in 1972-85). In "Efficiency Push," stepped-up retrofit activity and programs that target new homes cause fuel intensity to fall by 2.0%/year, about the same rate as between 1972 and 1985. In "Vigorous Effort," much higher prices and strong programs cause a large reduction in heating intensity relative to "Efficiency Push" in Europe and the U.S. The average heating intensity in 2010 is well below the level of new homes in 1987 in the U.S. and Europe. Space heating intensity in new homes falls close to the levels now found in Scandinavia. More careful energy management in the home, induced by higher fuel prices, is facilitated by advanced control systems.

For electric appliances, the average intensity in 2010 in "Trends" is comparable to that of new appliances in 1988. The decline is driven mainly by the current U.S. efficiency standards and other programs now in place in Europe. In "Efficiency Push," stronger policies and programs, especially in Europe, cause the average intensity to fall to near the level of the present market lowest (which is about half the level of the average new appliance in 1987). "Vigorous Effort" includes programs to push the efficiency frontier in new appliances and to encourage market uptake of these devices. The average intensity of appliances in 2010 is well below the lowest intensity of products available in 1990. "Vigorous Effort" also embodies considerable reduction in energy intensity of lighting as compact fluorescent lamps come into widespread use. Utility DSM programs play a major role in accelerating the efficiency of electric end uses.

Service Sector. In the "Trends" scenario, fuel intensity declines by only 0.6%/year. The decline is much slower than in the 1972-1985 period (2.7%), which reflects some saturation of the retrofit potential and the slow penetration of new buildings.[2] Electricity intensity decreases by 0.7%/year, also less than in the past. In "Efficiency Push," higher prices cause fuel intensity to decline at 2.0%/year. Electricity intensity falls at a rate of 1.7%/year, in part due to the increasing attention given to the service sector by utility DSM programs. In "Vigorous Effort," fuel intensity declines at 3.1%/year as retrofit activity becomes more ambitious. Electricity intensity falls considerably as strong DSM programs and other efforts push the market penetration of cutting-edge technologies. A large share of new buildings soon incorporate energy-saving designs and technologies that are found in the most efficient new buildings today.

[2] The fuel and electricity intensities incorporate adjustments to remove the effects of structural change described earlier. These effects have been roughly estimated for the historical period in order to make the scenario values comparable. Thus, the intensity changes in 1972-85 described here are less than those described in the historical analysis in Chapter 2. The actual values were -3.6%/year for fuel intensity and +1.3%/year for electricity intensity.

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