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ABSTRACT

The post-World War II era is commonly described as the age of oil. Petroleum has fueled the industrialization process and has helped to raise living standards around the globe. At the same time, the current era has been referred to as the age of efficiency. Since 1973, it is estimated that the world saved far more energy through improved efficiency than it has gained from all new energy sources. This document deals with some of the possibilities for energy efficiency, particularly as it relates to environmental quality. It includes sections which deal with: (1) energy-wise buildings; (2) transportation challenges; (3) new potentials for industry; (4) research; (5) prices, taxes, and standards; (6) institutionalizing efficiency; and (7) the limits to energy growth. (TW)

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Building on Success: The Age of Energy Efficiency

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Introduction

The postwar era is commonly described as the age of oil. Petroleum fueled the engines of industrialization and helped raise living standards around the globe. By similar logic, the current era is the age of energy efficiency. Since 1973, the world has saved far more energy through improved efficiency than it has gained from all new sources. The energy savings of the industrial market economies alone exceed the combined energy use of Africa, Latin America, and South Asia.[1]

Most market-oriented industrial economies have improved their energy efficiency by between 15 and 30 percent in the past 15 years—a period that witnessed almost no net increase in energy supplies. Efficiency now displaces $250 billion worth of oil, gas, coal, and nuclear power annually in industrial market countries. These energy efficiency improvements are the world's single largest step in reducing dependence on imported oil.[2]

The energy efficiency revolution is not proceeding smoothly, however. Government officials and industry leaders still concentrate on expanding supplies of oil, coal, and nuclear power while neglecting less expensive energy efficiency options. Most societies are still riddled with institutional obstacles to efficiency improvements. New technologies are not being commercialized as quickly as they could be. And buildings and transportation systems still waste billions of dollars worth of energy each year.

Since the oil shocks of the seventies, energy policymakers have been gradually awakening to the potential of energy efficiency, and introducing policy changes to encourage its development. A 1987 report of the International Energy Agency contains a simple but remarkable statement. "Investment in energy conservation at the margin provides a better return than investment in energy supply."[3]

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Dozens of other studies agree with this central conclusion. Energy efficiency is now a key ingredient of economic success. If the United States used energy as efficiently as Japan does, for instance, it would lower the national fuel bill by $200 billion. Growing recognition of efficiency's importance was reflected in the early eighties by energy efficiency research programs, utility efforts to weatherize homes, and mandatory efficiency standards for home appliances and automobiles.[4]

Today, however, this progress is being undermined by a period of low energy prices, and an accompanying spirit of complacency. At $18 per barrel, the real price of oil in early 1988 was lower than at any time since the 1973 oil embargo—75 percent below the peak levels of 1981. Both government and private energy efficiency programs have been scaled back. Energy efficiency is not considered the priority that it was in the early eighties.[5]

Official statistics for 1987 show continuing but slower improvement in efficiency. It is still too early to estimate the full impact of recent cutbacks in efficiency investments, but it is almost certain that the momentum achieved in the early eighties will soon dissipate.

Countries that do retreat from their energy efficiency programs will likely regret it. Even at today's prices, many efficiency improvements are solid investments in economic competitiveness, costing only a fraction as much as new energy supplies. Energy prices are destined to resume their upward march, inefficient economies will then pay a heavy price.

If energy efficiency is an economic opportunity for the nineties, it is little less than an environmental necessity. Improved efficiency means that less fuels are burned, reducing urban air pollution as well as acid rain. Improved energy efficiency is vital to any long-range effort to solve air pollution problems, particularly in the heavily polluted cities of Eastern Europe and the Third World. It is also the only means available to significantly reduce carbon dioxide emissions from fossil fuel combustion that threaten to permanently alter the earth's climate.

In the years ahead, innovative and sustained efforts are required on the part of the world's consumers, industries, and governments to achieve economic gains through energy efficiency. If the challenge is met, industrial countries could use energy efficiency to hold level or even reduce energy consumption. In the Third World, efficiency is almost certainly a precondition of sustained improvement in living standards. Improved energy efficiency is by itself no panacea, but it is essential to solving many of the world's most profound problems, from Third World debt and trade imbalances to acid rain.

The Efficiency Revolution

When the Ford Foundation completed its landmark study of the U.S. energy future in 1974, it presented three scenarios. One curve was identified as the "historical growth scenario" and projected national energy use doubling between 1970 and 1987. The lowest consumption forecast, considered radical at the time, still assumed an almost 20-percent increase in energy use. Since that report was published, the U.S. economy has expanded by over 35 percent but energy use has actually fallen.[6]

Only rarely have so many forecasters been so dead wrong. Indeed, analysts not only underestimated the potential for greater efficiency, they overestimated the world's ability to live with the side effects of high levels of energy use. They assumed, for example, that world energy consumption could more than double by the year 2000 without debilitating price increases. The Organization of Petroleum-Exporting Countries (OPEC) was expected to be pumping at least three times as much oil as it now does, unhindered by tanker wars or a revolutionary regime in Teheran. Nuclear power was believed capable of supplying at least five times as much energy as it does today, unaffected by billion-dollar cost overruns or accidents in Pennsylvania or the Ukraine.[7]

As circumstances changed, energy use patterns changed with them. Between 1973 and 1985, the energy intensities of all industrial market countries fell. (See Table 1.) However, the improvement varied

Table 1: Energy Intensity of Selected National Economies, 1973–85

Country	1973	1979	1983	1985	Change, 1973–85
	(megajoules per 1980 dollar of GNP)				(percent)
Australia	21.6	23.0	22.1	20.3	−6
Canada	38.3	38.8	36.5	36.0	−6
Greece[1]	17.1	18.5	18.9	19.8	+16
Italy	18.5	17.1	15.3	14.9	−19
Japan	18.9	16.7	13.5	13.1	−31
Netherlands	19.8	18.9	15.8	16.2	−18
Turkey	28.4	24.2	25.7	25.2	−11
United Kingdom	19.8	18.0	15.8	15.8	−20
United States	35.6	32.9	28.8	27.5	−23
West Germany	17.1	16.2	14.0	14.0	−18

[1]Energy intensity increased as a result of a move toward energy-intensive industries such as metal processing.

Source: International Energy Agency, *Energy Conservation in IEA Countries* (Paris: Organisation for Economic Co-operation and Development, 1987).

widely—from about 6 percent in Australia and Canada, to 18 percent in West Germany, and 23 percent in the United States. Japan's efficiency improved by 31 percent, remarkable since it already had one of the world's most efficient economies. It continued to widen its lead during the early eighties.[8]

National differences can make gross energy-intensity figures like those in Table 1 seem misleading. A country with a large energy-intensive steel industry (like Poland) or a large automobile- and truck-based transportation network (like Canada) almost always appears relatively energy intensive. However, changes in energy intensity often do reflect real efficiency improvements. Process and equipment advances make the average Japanese paper plant or steel mill 30–50 percent more efficient than it was a decade ago. A new American

"In 1986, the United States used 10 percent of its gross national product to pay the national fuel bill, but Japan used only 4 percent."

office building has about the same lighting levels and temperatures as older ones but uses less than half as much electricity. Even large luxury cars now get 20–25 miles per gallon, comparable to much smaller cars built in the mid-seventies.[9]

In 1986, the United States used 10 percent of its gross national product to pay the national fuel bill, but Japan used only 4 percent. The difference was $200 billion that the United States did not have available to invest in other areas. As a result, the average Japanese product has an automatic cost advantage of about 5 percent in the U.S. market. Japan is not only richer for its efficiency, it has also positioned itself to dominate the world market for many high-efficiency technologies.[10]

Energy efficiency data for centrally planned countries are more difficult to obtain, but available evidence indicates that these nations are lagging behind in the efficiency revolution. The Soviet Union has not bettered its record at all since the early seventies, and remains the least energy-efficient industrial economy. Without the discipline of market prices, Soviet industrial managers look at energy bills as just another cost to pass on to consumers. Many families still open windows to regulate the temperature in their poorly built and unmetered apartments.[11]

An energy efficiency gap has also opened among developing nations. Newly industrializing economies, such as those of Taiwan, South Korea, and Brazil, have begun to incorporate state-of-the-art industrial machines and processes, encouraged by a broad array of energy efficiency standards and financial incentives. But most of the Third World falls further and further behind the industrial world. Many nations are in the early, energy-intensive phases of industrialization, and also subsidize energy prices. But their inefficiency penalizes them severely in increasingly competitive international markets.

In the seventies, many analysts mistakenly assumed that energy efficiency improvements of 20–30 percent could be achieved only through wholesale reordering of societies. Yet, such improvements have come largely unnoticed, the result of subtle shifts in the economy and technological advances, rather than lower thermostat settings or redesigned transportation systems. Higher energy prices have spurred engineers, managers, and consumers to make operational changes and apply a backlog of new technologies. Indeed, ever since industrialization began, societies' energy efficiency has been improving in fits and starts as new technologies were developed, a trend that was accelerated when energy prices soared. And approximately one-third of the wholesale decline in national energy intensities during the past 15 years is due to structural economic shifts away from heavy industry and toward the service sector.[12]

Energy efficiency is not simply "conservation," with its Spartan connotations of lowered thermostats and restricted driving. While it is influenced by such behavioral patterns, it is more fundamentally a function of industrial and urban structures and of the technologies employed in buildings, factories, cars, and trucks. Energy efficiency is about getting the same, or better, services from less energy by substituting ingenuity for brute force. After all, people want light and heat, not electricity and gas.

Energy efficiency seems intangible compared to energy sources like coal and oil, and perhaps that explains its relative neglect by policymakers. Unlike the energy supply industry, efficiency is thoroughly decentralized, involving every individual energy consumer. Its economic impact is proportionate to its broad distribution.

Efficiency improvements have been most impressive in industry. Energy-intensive industries like chemicals have improved remarkably. Similarly, high fuel costs have pushed the commercial aviation industry to invest heavily in wide-body aircraft, improved jet turbines, and lighter materials, increasing fuel efficiency by about half. Buildings, which actually have the most efficiency potential, have improved slowly due to the fragmented nature of the industry and the slow replacement rate of buildings compared with automobiles or industrial equipment.[13]

Some governments have encouraged efficiency by enacting standards for buildings and automobiles, by making tax credits and subsidies

"Energy efficiency is about getting the same, or better, services from less energy by substituting ingenuity for brute force."

available, and by creating institutions to open new avenues of investment. Some utilities in the United States, for example, are now being rewarded by regulators for putting money into the efficiency of their customers' buildings.[14]

Cost-effective investment in energy efficiency hinges on a concept known as "least-cost planning." Adopted by utility regulators in a growing number of American states, least-cost planning puts investments in energy supply and energy efficiency on an equal footing. Whenever an investment in increased efficiency is more economical than one in energy supply, it is given priority. Several studies show that such an approach could lead to additional energy efficiency improvements worth tens of billions of dollars. Of course, many other considerations must be weighed in making energy investments, such as reliability, ease of maintenance, and unpredictable human tastes. Nonetheless, when applied with flexibility, least-cost planning can be used effectively by government agencies, corporations, and consumers to help rationalize the energy economy.[15]

While the economic case for energy efficiency has faded a bit in recent years, powerful new arguments for it have emerged. Fossil fuels are the main source of the air pollution now choking rural areas and cities alike. Even in the United States, which has relatively stringent air pollution standards, sulfur dioxide and carbon monoxide emissions are down less than 20 percent since 1975. Nitrogen oxide emissions are actually up 5 percent. Many American cities still do not comply with air quality standards laid down more than a decade ago. In most other countries, air pollution continues to increase, particularly in the coal-rich regions of Eastern Europe and China. The incidence of respiratory and cardiac disease is growing rapidly in these areas, as is damage to lakes and forests. Despite strong evidence that air pollution is killing the forests of central Europe, the European Community has been able to agree only on relatively weak standards for emissions reduction, and most East European governments have yet to act.[16]

Energy efficiency can be a new weapon in the air pollution wars, complementing flue-gas scrubbers and catalytic converters. Czechoslovakia, East Germany, Poland, and others could stem the damage to their forests by improving their industrial energy efficiency. Rome could attack the cause of much of the population's respiratory disease and slow the deterioration of its ancient ruins by doubling the fuel efficiency of its cars. A 1987 study by the American Council for an Energy-Efficient Economy concludes that increased efficiency could help widen the scope and improve the cost-effectiveness of acid rain control programs.[17]

Rising levels of carbon dioxide are irrevocably altering the world's climate, and could well make the world warmer 50 years from now than at any time in human history, according to scientists. The main cause of this phenomenon is fossil fuel combustion, which adds 5.4 billion tons of carbon to the atmosphere each year, more than one ton for each person on the planet. The full implications of such a warming are not fully understood, but they could well include serious disruptions in agriculture and the flooding of densely populated coastal areas. Governments throughout the world have not only been slow to respond to the climate problem and other environmental threats, they are actively pursuing energy policies that aggravate them.[18]

Over the next two decades, efficiency will have to play the largest role in reducing carbon output. Later, as technologies mature, the transition to renewable energy must begin in earnest. A successful effort to improve worldwide efficiency by 2 percent annually would keep carbon dioxide concentrations to 463 parts per million in 2075. The world's climate would still be at least 1 degree Celsius warmer than today, but the most catastrophic climatic effects would probably be avoided. However, achieving such a rate of improvement in energy efficiency over a period of decades will require major policy changes around the world.[19]

In a world facing chronic air pollution problems and the threat of climate change, improved energy efficiency has become as much a necessity as an opportunity. Yet with oil prices close to an all-time low, the energy efficiency revolution could fizzle as quickly as it started. Simple government mandates cannot maintain the momentum toward improved efficiency. Nonetheless, in buildings, transportation, and industry, innovative government and private programs

"With oil prices close to an all-time low, the energy efficiency revolution could fizzle as quickly as it started."

can keep the efficiency revolution moving. Political leadership, so far lacking in most countries, may be the most important ingredient.

Energy-Wise Buildings

Winston Churchill once said "We shape our buildings and afterwards our buildings shape us." We have become an indoor breed, spending most of our lives inside the walls we build. We now also spend a substantial share of world energy resources heating, cooling, and lighting buildings: In 1985, buildings in the industrial market economies used the equivalent of 16.7 million barrels of oil per day, almost equal to the production of OPEC that year. The economic and environmental implications of energy consumption on that scale are enormous. Indeed, today Churchill might say "We shape our buildings and afterwards our buildings shape our world."[20]

In industrial market economies, energy goes to buildings, industry, and transportation in almost equal parts. Centrally planned economies and many developing countries, on the other hand, devote over half their commercial energy to industry. In Eastern Europe and the Soviet Union, despite the prevalence of theoretically efficient apartment buildings and district heating, buildings tend to be leaky and poorly insulated.[21]

Structures in developing countries present starkly different images. In the countryside, buildings are Spartan, fuelwood is the dominant energy source, and the essential energy questions are those of meeting bare needs. Because fuelwood use is currently so inefficient, total energy consumption measured in units of heat is rather high, while the services that energy supplies are minimal.

Cities across the Third World house a swelling urban underclass, which uses fuelwood, charcoal, or more expensive fuels as changing prices dictate. Meanwhile, members of a relatively wealthy elite consume energy with the same profligacy as their industrial-country counterparts. For this modern sector, which consumes the bulk of national commercial energy, high-efficiency technologies are crucial.

Indeed, better air conditioners make even more sense in Manila than in Manhattan.[22]

In industrial market countries, an ever-growing stock of buildings has used an almost constant amount of energy since the early seventies. Efficiency has filled the gap. Buildings in these countries use 25 percent less energy per person than they did in 1973, saving the equivalent of 3.8 million barrels of oil every day—more than the output of the North Sea. Gains to date, however, pale beside what new technologies could offer. It is possible to save 40 percent or more of the energy used in existing buildings—and over 70 percent in new ones.[23]

Already, Swedish homes are twice as well insulated as those in northern Minnesota and considerably better insulated than houses in other parts of Europe. Homes in Stockholm, for instance, are 6 degrees Celsius warmer in the winter than houses in London but actually use a quarter less energy. Sweden is unique. It made the commitment to improve energy efficiency over two centuries ago when a severe fuelwood shortage led a royal commission to initiate a national campaign for improved woodstoves. The Swedes have placed a premium on energy efficiency ever since.[24]

"Retrofitting," renovating to save energy, has proved itself to be an excellent investment. In over 40,000 retrofits monitored by U.S. utilities since the mid-seventies, energy consumption fell by a quarter, and homeowners got a 23-percent annual return on their investment. Larger savings are technically feasible and economically justified. In a study for Austin, Texas, Amory Lovins and his colleagues at Rocky Mountain Institute calculated that existing homes in Austin could save 63 percent of their electricity by employing a carefully chosen package of readily available technologies. (See Table 2.) The retrofits would cost between $1,700 and $2,400 apiece, but energy savings would repay that sum within about three years.[25]

Unfortunately, many retrofits are poorly conceived and executed, resulting in energy savings far below the economic potential. The U.S. government's low income weatherization program has generally

Table 2: Estimated Average Electricity Savings Potential for a Typical House in Austin, Texas

	Electricity (kilowatt-hours per year)
Electricity Use before Retrofit	14,113
Retrofit Savings[1]:	
Compact fluorescent lights	1,686
Double-glazed windows with film	1,578
Efficient refrigerator and freezer	1,300
Upgrade air conditioner	1,227
Roof insulation	1,227
Hot water efficiency[2]	575
Plug air leaks	529
Improved TV and minor appliances	381
Total Retrofit Savings	8,852[3]
Electricity Use after Retrofit	5,261

[1]Major household appliances such as air conditioners and refrigerators are assumed to be replaced with efficient models only when they wear out.
[2]Tank and pipe insulation, advanced showerheads, etc.
[3]Savings for all measures differ from sum of individual savings (8,503 kWh/y) because of interactions between measures.

Source: Rocky Mountain Institute, *Advanced Electricity-Saving Technologies and the South Texas Project* (Old Snowmass, Colo.: 1986).

achieved only 15 percent reductions in energy use because it ignored many effective techniques. Market failures can also reduce the effectiveness of retrofits. Home and building owners have shorter timetables than energy suppliers, and so consumers pass over efficiency measures with two-year payback periods while buying energy from plants with 20-year paybacks. In addition, consumers often lack full information on the economic merits of retrofits or the capital to carry them out. In rental housing, often the least efficient type, landlords pass electricity and gas bills on to tenants, and so have no incentive to finance retrofits, tenants meanwhile have little interest in paying for improvements to someone else's property.[26]

Boosting efficiency in new residences is also crucial. Energy efficiency is cheapest when built in from the start, so the efficiency potential in new buildings far exceeds that in existing ones. While average U.S. homes consume 160 kilojoules of heating energy per square meter of floor space per degree-day, new Swedish houses use just 65. Recently built superefficient homes in Minnesota average 51 kilojoules, and some individual units in Sweden go as low as 18. Rocky Mountain Institute's headquarters reduces this figure to essentially zero in a climate that gets as cold as −44 degrees Celsius.[27]

The key to these savings is "superinsulation". doubling the normal insulation and building an airtight liner into the walls. In fact, superinsulated houses are so airtight that they require mechanical ventilation to remove indoor air pollutants. Heat radiating from people, stoves, and appliances warms the house, requiring little auxiliary heating. In summer, superinsulation also keeps warm air out.[28]

Superinsulation adds about 5 percent to building costs, but the energy savings, along with the reduced heating and cooling system costs, cover the extra expense in around five years. There are now more than 20,000 superinsulated homes in North America, with perhaps 5,000 more built every year. But this is not even 1 percent of new housing construction. Homebuyers tend to discount operating costs, so builders put their efforts into cosmetic selling points rather than efficiency. As one expert in energy-wise housing put it, when American homebuyers must choose between better insulation and a Jacuzzi whirlpool bath, "the Jacuzzi wins out most of the time."[29]

Commercial buildings—offices, hospitals, schools, and stores—use less energy than residences in most countries, but their energy consumption is growing more rapidly. Efficiency investments in these structures tend to be inexpensive, but owners still tend to overlook many opportunities. Since 1973, closer attention to heating, cooling, and lighting efficiency has cut energy consumption in new U.S. office buildings from the extraordinarily wasteful level of 5.7 million kilojoules per square meter of floor space per year to 3.0. Commercial buildings in Sweden now average under 1.7, and the government enforces a maximum standard of 1.1 for new buildings. If all U.S. commercial buildings were that efficient, total U.S. energy consumption would drop 9 percent.[30]

Survey data for new office buildings in the United States show no correlation between energy efficiency and construction costs, suggesting that efficiency improvements have been virtually free so far. Savings from smaller cooling and heating systems offset the cost of added insulation and window glazing. The Oregon-based Bonneville Power Administration estimates that further improvements of 30 percent increase construction costs less than 1 percent. Energy savings from efficiency investments during construction are almost pure profit.[31]

The most important feature of efficient new commercial buildings is "intelligence." In existing structures, inflexible energy systems that do not respond to outdoor temperatures often waste energy cooling air in winter and warming it in summer. "Smart buildings" monitor both outdoor and indoor temperatures, sunlight, and the location of people—sending heat, cooled air, and light where they are most needed. Analysts at Lawrence Berkeley Laboratory calculate that Los Angeles homes could halve their air-conditioning bills just by changing the controls on air conditioners to measure outdoor temperatures and substitute ventilation for cooling when possible.[32]

One intriguing technique now attracting attention in the commercial building market is called "thermal storage," which holds heat or cold for later use. Some new office buildings in Sweden so effectively store heat from people and equipment that they use virtually no auxiliary heating, even in the middle of winter. And in Reno, Nevada, some buildings now operate through the summer without air conditioning, using cool night air to chill large chambers of water that keep indoor temperatures comfortable during the day.[33]

Many of the technologies used in efficient new commercial buildings are so cost-effective they are worth installing in existing buildings as well. As in residential buildings, retrofit savings in the United States average 25 percent, but most retrofits fall far short of the economic potential. The Rocky Mountain Institute's study of Austin, Texas, identified potential savings in commercial buildings of 1.8 billion kilowatt-hours per year, 73 percent of the buildings' current annual electricity use. Realizing these savings would cost less than operating most power plants. This finding—perhaps incredible at first—has been substantially corroborated by an expert panel advising the Boston Edison Company.[34]

Windows are also crucial to building energy efficiency. As much energy leaks through American windows every year as flows through the Alaskan pipeline. Special heat-reflecting film that doubles windows' insulation value by letting in light without letting out heat is now being marketed. Further window improvements can be realized by creating a vacuum between the two parts of a double-pane window, insulating in the same way as thermos bottles. In the future, that space could be filled with "aerogel," a microscopic glass foam that insulates like styrofoam but looks like normal glass. One firm is already combining heat-reflecting film with insulating-gas fillings to produce cost-effective windows that insulate as well as an ordinary wall.[35]

Planting trees is an effective way to cool buildings in warm climates. Trees provide shade from solar radiation, and in sufficient numbers can lower the summer temperatures of entire cities. The great agglomerations of concrete in cities keep urban temperatures well above those in the surrounding countryside, but water evaporating from vegetation ameliorates these "heat islands." In Phoenix, Arizona, 250,000 new trees could idle a power plant-worth of air conditioners.[36]

Furnaces, air conditioners, appliances, and lights are also ripe for savings. Heating and cooling are the dominant energy uses in buildings, taking up well over half of total consumption. Conventional gas furnaces send a quarter of their heat up the chimney. But new condensing furnaces reabsorb much of that heat by cooling and condens-

"As much energy leaks through American windows every year as flows through the Alaskan pipeline."

ing exhaust gases. They cut fuel use by 28 percent, reduce air pollution, and make chimneys obsolete, requiring only small, plastic exhaust vents.[37]

Electric heat pumps that heat in winter and cool in summer are making inroads in home heating markets long dominated by oil and gas. Unfortunately, even the best heat pumps have a lower overall efficiency than gas-fired systems, because two-thirds of the energy needed to produce electricity is wasted at the power plant. Heat pump clothes dryers can be twice as efficient as conventional designs. Similarly, several heat pump water heaters now on the market use half the power of conventional units. Howard Geller of the American Council for an Energy-Efficient Economy calculates that installing these in all American homes with electric water heaters would eliminate the need for 15 large power plants.[38]

Integrating heating and cooling equipment offers even greater advances. Refrigerators and air conditioners, for instance, produce as much heat as cold air—heat that can be redirected to hot water tanks. Water heaters can also be integrated into furnaces, increasing efficiency dramatically.[39]

Appliance technology is advancing as well. The average refrigerator-freezer in an American home consumes 1,500 kilowatt-hours of electricity every year. The average new model does the same job with 1,100, and the best model on the market, a Whirlpool, takes only 750. But further gains are possible: A Danish prototype consumes 530, and a Californian custom model runs on 240. One study suggests that the number could cost-effectively drop as low as 200 kilowatt-hours per year.[40] Similar stories could be told of most other appliances. (See Table 3.)

Geller estimates that installing the 750 kilowatt-hour Whirlpool model in every American home and apartment could idle twelve 1,000-megawatt coal plants. Indeed, each year the average American refrigerator burns almost exactly as much coal as could be packed inside it. Improving efficiency to the current cost-effective maximum would mean cutting coal use to less than a freezer compartment-full.[41]

Table 3: United States: Energy Efficiency Improvements and Potential for Residential Appliances and Equipment, 1985

Product	Average of Those in Use	New Model Average	Best Commercial Model	Estimated Cost-Effective Potential[1]	Potential Savings[2]
		(kilowatt-hours/year)			(percent)
Refrigerator	1,500	1,100	750	200–400	87
Central Air Conditioner	3,600	2,900	1,800	900–1,200	75
Electric Water Heater	4,000	3,500	1,600	1,000–1,500	75
Electric Range	800	750	700	400–500	50
		(therms/year)			(percent)
Gas Furnace	730	620	480	300–480	59
Gas Water Heater	270	250	200	100–150	63
Gas Range	70	50	40	25–30	64

[1]Potential efficiency by mid nineties if further cost-effective improvements already under study are made.
[2]Percent reduction in energy consumption from average of those in use to best cost-effective potential.

Source: Howard S. Geller, "Energy Efficient Appliances. Performance Issues and Policy Options," *IEEE Technology and Society Magazine*, March 1986.

Efficient appliances generally have higher price tags, but the lower energy bills more than cover the difference. In 1986, the best refrigerator on the market cost $60 extra. But that investment was effectively repaid in two years, a 46-percent annual rate of return.[42]

A powerful measure of the economic merit of efficiency gains is called the "cost of saved energy." Every kilowatt-hour of electricity an American homeowner buys from a utility costs 7.8¢ on average, but every kilowatt-hour saved by switching from an inefficient refrigerator to the more expensive Whirlpool costs the consumer less than 2¢. These cost-of-saved-energy figures allow energy planners to compare efficiency investments with new supply options on a least-cost basis.[43]

Lighting, which accounts for 25 percent of U.S. electricity use, offers some of the most economical savings now available. Arthur Rosenfeld of Lawrence Berkeley Laboratory believes that 40 large U.S. power plants could be given early retirement simply by fully applying available, cost-effective lighting technology.[44]

Compact, screw-in fluorescent bulbs with special "warm light" coatings are trickling onto the market to replace traditional incandescent bulbs. One 18-watt fluorescent provides the light of a 75-watt incandescent and lasts ten times as long. The purchase price is high, but the cost of saved energy is generally under 2¢ per kilowatt-hour. They have an environmental bonus as well: Over their useful lives, 18-watt light bulbs each keep 180 kilograms of coal in the ground and 130 kilograms of carbon out of the atmosphere.[45]

The most widely sold minifluorescent bulbs are somewhat bulky, not yet fitting into all standard fixtures, but engineers are improving them. However, consumer sensitivity to purchase prices presents an obstacle to their acceptance. If utilities or energy efficiency companies were to invest in efficient lighting in homes and offices, and split the savings with occupants, compact fluorescents could sweep the market. Southern California Edison has already given away 450,000 to low income ratepayers, displacing 8 megawatts of generating capacity. The cost per saved kilowatt-hour is less than operating the nuclear power plant at San Onofre.[46]

Researchers are also making great improvements to full-sized tubes used in commercial buildings. High-frequency electronic ballasts (the devices in fluorescent fixtures that control the electrical current in the tube) cut energy use by 20–40 percent. High-frequency ballasts are now commercially available and, because they are so economically attractive (with a cost of saved energy around 2¢ per kilowatt-hour), could capture half of sales by the mid-nineties.[47]

A package of measures already on the market, including better controls, reflectors, and spacing, as well as improved bulbs and ballasts, can reduce lighting energy required in commercial buildings by over half. One office in Green Bay, Wisconsin, recently cut lighting energy consumption by 72 percent without even employing several cost-effective technologies. Advanced technical developments such as super-high frequency ballasts are within a decade of maturity.[48]

Microelectronic sensors that measure sunlight and sense people entering and leaving rooms can cut energy use for lights in half yet again. Furthermore, every improvement in lighting efficiency lowers the generation of waste heat and therefore saves on air conditioning. The California Energy Commission calculates that in a typical Fresno office, every 100-watt savings on lighting means an additional 38-watt savings on air conditioning.[49]

Ever since Thomas Edison, the light bulb has symbolized electricity—indeed, in much of Latin America the words are used almost interchangeably. Cutting lighting energy use in industrial and developing countries by half could serve as a test case for institutionalizing least-cost energy planning. Part of a global response to the mounting economic and environmental ramifications of fossil fuel dependence might grow from the simple slogan "Better light bulbs."

Providing buyers with full information may require energy ratings for new buildings and equipment along the lines of the automobile mileage ratings now common in many countries. Consumer sensitivity to initial costs can be overcome through special energy-saving financing. The diverging interests of tenants and landlords justify a variety of measures to encourage efficiency investments. And reforms in the construction industry could ensure that maximum efficiency is built in from the start. Ultimately, building practices shape energy demand for most of a century, power plants and oil wells last less than half as long.

"The United States uses fully 63 percent of its oil in transportation, more than it produces."

The Transportation Challenge

Transportation is now the largest and most rapidly growing drain on the world's oil reserves. The United States uses fully 63 percent of its oil in transportation, more than the country produces. Worse, as growing auto sales confirm, much of the world appears set on replicating this unhealthy condition. Already, passenger cars consume one of every six barrels of oil. Meanwhile, transportation emissions have become a force of nature, adding more than 700 million tons of carbon to the atmosphere annually. Indeed, the average American car pumps its own weight in carbon into the atmosphere each year.[50]

The crux of the transportation energy predicament is heavy reliance on the automobile, which was hardly lessened by the oil pri... rises of the seventies. It has led to neglect of railroads and bus service, half-hearted efforts at mass transit, and indifference to energy in urban design. Suburban sprawl, the product of private auto ownership, now makes the car indisp nsable. Auto bound American cities use more than twice as much gasoline per pe son as some cities in Europe, and ten times as much as industrial Asian cities where walking is the norm.[51]

Urban design decisions made today will affect the world's energy needs for decades. Vast amounts of energy can be saved by channelling urban growth so that jobs, stores, and residences are concentrated in city cores and along mass transit corridors. Rapidly growing cities, especially those in developing countries, are particularly well placed to capitalize on these savings. Of course, the world's cities cannot be restructured overnight, and there are scores of considerations beyond oil requirements that must shape urban development. But designs that optimize convenience and a sense of community also tend to be energy efficient. Reduced commuting distances save citizens precious time, as does offering an array of stores, services, theatres, and parks within each community.

Public transportation can offer additional savings. Trains, buses, van pools, and public cars require a quarter as much fuel to move each passenger a kilometer as private cars do—if they are well used. But they are only effective if they serve an area's needs appropriately. Today, van pools and light rail systems are generally more practical than expensive subways.[52]

Both a carrot and a stick are required to move societies toward more energy-wise transport systems. A first priority might be to eliminate some of the hidden subsidies to automobile travel. Drivers almost never pay the full cost of their cars, including road building and maintenance, traffic congestion, noise, air pollution, and danger to pedestrians. In many cities, traffic congestion makes traveling hectic and time-consuming, exacting millions of dollars in uncounted economic losses.

Hong Kong has considered an ingenious approach to making drivers pay their way. Officials planned to turn the entire city into a high-tech network of toll roads equipped with interconnected computer sensors that would read electronic tags installed in cars and record travel. At the end of the month, each car owner was to be billed for road use. As with modern telephone systems, drivers would have been billed at variable rates. Rush-hour driving in town might cost a dollar a kilometer, while night travel in outlying areas might cost only a dime. Hong Kong's plan was scrapped at the last minute due to legitimate concerns over privacy rights. A central computer with a full record of every car's travel would be easy to abuse. But anonymous systems being studied in the United Kingdom could resolve this problem.[53]

With or without successful programs to stem the tide of auto-dependence, improving auto fuel economy must be a top priority. Worldwide, the average fuel efficiency of new cars has improved greatly since 1973, but progress has been uneven. New cars now average between 25 and 33 miles per gallon (MPG) in most countries, compared with the 1973 range from 13 MPG in the United States to 28 MPG in Italy. (See Table 4.) New American cars have improved most dramatically, nearly doubling their fuel economy since 1973, but they still have not closed the efficiency gap with Europe and Japan. The more dramatic improvements in the United States were a result of the transition to smaller cars with front wheel drive. But in other coun-

Table 4: Urban Fuel Efficiency of New Passenger Cars, Selected Countries, 1973 and 1985[1]

Country	1973	1985	Change
	(miles per gallon)		(percent)
Denmark	26[2]	33	+27
West Germany	23	31	+35
Italy[3]	28	30	+ 7
Japan	23	30	+30
United Kingdom	21	31	+48
United States[4]	13	25	+92

[1]These figures are not equally reliable, only U.S. figures are sales-weighted to reflect numbers of each model sold.
[2]1975.
[3]Average of all cars in use, not new cars.
[4]Composite urban-highway figure. Figures for city driving would be somewhat lower.

Source: International Energy Agency, *Energy Conservation in IEA Countries* (Paris. Organisation for Economic Co-operation and Development, 1987).

tries, where cars were already smaller than in the United States, the introduction of a variety of new technologies allowed gains of up to 50 percent.[54]

In Europe and Japan, drivers are now shifting *away* from small cars, wiping out some of the savings achieved through technical efficiency gains. Increased traffic congestion in most of the world's cities has also reduced the impact of technical progress. Stop-and-start traffic in London reportedly yields average speeds of just 8 miles per hour.[55]

The first round of efforts to boost efficiency, which began in the mid-seventies, has now peaked. There are even some signs of backsliding. In the United States, the fuel economy of new domestic cars actually fell slightly in 1987 due to falling oil prices. However, new automotive technologies offer a host of opportunites for continuing to improve fuel efficiency.

Gains in fuel economy usually come piecemeal. Auto weight can be trimmed by incorporating more aluminum, new alloys of steel, recently developed engineering-grade plastics, and space-age ceramics. Aerodynamic drag can be reduced by streamlining the body. Engines can be modified or completely redesigned to make fuller use of the energy released in combustion. Improved transmissions can match efficient engine speeds with drive power needs. Efficient air conditioners and other accessories allow reductions in engine size and auto weight. Microelectronics can fine-tune engine and transmission operation and revolutionize steering.

Several innovative fuel-efficient automobile models are already on the road, achieving over 50 MPG. (See Table 5.) Most are Japanese. The 54-MPG Honda CRX, a two-seater that runs like a sports car, has plastic body panels, aluminum parts, good aerodynamics, and a special lean-burning engine. The Suzuki Sprint engine is constructed largely of aluminum, and the Mitsubishi Mirage can turn extra cylinders on and off as needed. The Honda City has a hybrid manual-automatic transmission that in effect gives the car seven gears, keeping engine speed closer to the optimum.[56]

Subaru has replaced the gear box entirely in its tiny Justy, opting instead for a "continuously variable transmission" (CVT). In CVTs, a belt transfers engine power to the drive shaft as it runs around two self-adjusting pulleys, giving the car an unlimited number of gears. Subaru found that this technology improved fuel efficiency by 20 percent over a three-speed automatic and by 10 percent over a five-speed manual transmission.[57]

Prototype models have fuel economy levels far surpassing anything on the market. Volkswagen's E80 uses a state-of-the-art, turbocharged "direct injection" diesel engine, a technology at least 15 percent more efficient than traditional diesels. Volkswagen also added an innovative energy storage device that transfers energy to a flywheel as the car decelerates. The engine can then actually turn off while the car is standing still. The flywheel powers the accessories until the accelerator is again pressed, when the engine restarts.[58]

Table 5: Fuel Efficiency of Selected Four-Passenger Automobiles, 1987

Model	Fuel	Composite Fuel Efficiency (miles per gallon)
In Production		
Peugeot 205	gasoline	42
Ford Escort	diesel	53
Honda City	gasoline	53[1]
Suzuki Sprint	gasoline	57
Prototypes		
Volvo LCP 2000	diesel	71
Peugeot ECO 2000	gasoline	73
Volkswagen E80	diesel	85
Toyota AXV	diesel	98
Renault VESTA	gasoline	124

[1]City driving; composite urban-highway figure would be higher.

Source: Deborah Bleviss, *The New Oil Crisis and Fuel Economy Technologies. Preparing the Light Transportation Industry for the 1990's* (New York: Quorum Press, in press), Renault VESTA from Dan McCosh, "Automotive Newsfront," *Popular Science*, December 1987.

The most innovative prototype is Volvo's aerodynamic LCP 2000. The LCP weighs half as much as the average American car due to extensive use of lightweight materials, and has an advanced diesel engine that can accommodate alternative fuels. Furthermore, Volvo engineers plan to install a CVT and a flywheel energy storage system to boost mileage by an additional 20 MPG. The LCP 2000 also withstands impacts more severe than many production vehicles, meets air pollution standards, has better acceleration than the average new American car, and could be mass-produced at about the same cost as today's subcompacts. Unfortunately, Volvo has no plans to market this car.[59]

Toyota's prototype AXV is another standout, complementing an advanced diesel engine with a continuously variable transmission. It is spacious enough for use as a family car—a remarkable achievement considering its estimated fuel economy of 98 MPG. Renault may hold the record for fuel economy in a prototype, however, having completed initial testing on its 124-MPG four-passenger VESTA in late 1987.[60]

Other technologies could also reshape future autos, bringing about even greater savings. Improved aerodynamics and weight reduction promise the most gains today, but transmission advances are also rapidly maturing. New engines that may take over in the long run include lean-burn- and stratified-charge models, and those made of ceramics. Energy lost to friction can be drastically curtailed by replacing liquid lubricating oil with solid and gaseous lubricants, such as ceramic ball bearings, and self-lubricating metal composites. In the future, a membrane that filters nitrogen out of intake air could markedly increase oxygen concentrations in the combustion chamber, boosting efficiency. The membrane, selected by the Japanese government as an automotive research priority, would also reduce emissions of nitrogen oxides, a major urban air pollutant.[61]

Diesels are the most efficient engines to date, but their future is clouded by their air pollution problems. Although they emit less carbon monoxide and hydrocarbons than gasoline engines, diesels issue more nitrogen oxides and particulate matter. Both Mercedes Benz and Volkswagen have developed technologies to bring their diesels into compliance with California's particulate standards—the strictest in the world. Nevertheless, if these diesels were widely used, they would still result in some deterioration in air quality. Experts believe that clean diesels can be developed. However, it may prove easier to achieve the same efficiency improvements in nondiesel technologies.[62]

There can be little argument about the technical potential for extraordinarily efficient automobiles, but automakers know that fuel economy is a relatively low priority for most consumers at today's lower fuel prices. Many have cut back their efforts to improve fuel efficiency

"Europe and Japan now set the pace in developing new fuel-saving technologies, while the United States falls further and further behind."

while focusing on fancy electronics and other amenities that they believe will please customers. However, fuel efficiency need not come at the expense of other important features. High-efficiency models can be safe, reliable, affordable, and even "sporty," as the Honda CRX and the Volvo LCP demonstrate.

When efficient technologies are integrated into vehicles that are mass-produced, they may not raise the cost of production at all. Advanced materials like plastics require fewer welds and parts, and therefore cost less to manufacture. The U.S. Office of Technology Assessment estimated in 1982 that if fuel economy innovations were fully integrated into the normal cycle of turnover in plant and equipment, it would cost an additional $50–90 per automobile in the United States to bring most cars into the 38–53 MPG range by 1990. By 2000, cars could average 51–78 MPG for an additional $120–330 apiece (in 1980 dollars)—less than the cost of a high-quality car stereo. If those figures are accurate, it costs only 20¢ to save a gallon of gasoline through improved fuel economy.[63]

Despite the modest cost of improving fuel efficiency, the market alone is unlikely to boost efficiency sufficiently to head off growing oil dependence and greenhouse warming. Even at current European fuel prices of around $2 per gallon, consumers have little to gain by buying a car with fuel economy above 35 MPG because at that level the cost of fuel is small relative to other operating expenses such as maintenance, insurance, and taxes. Societies' interests in energy security and environmental protection, however, call for higher fuel economy, justifying government incentives of the sort discussed later in this paper.[64]

Europe and Japan now set the pace in developing new fuel-saving technologies, while the United States falls further and further behind. By late 1987 the three leading American carmakers had dismantled much of their research programs on smaller, more fuel-efficient cars. In Japan, meanwhile, advanced fuel economy technologies continue to move steadily into production.[65]

Other forms of transportation have also benefited from efficiency improvements. Railroads save energy through better control systems and wider use of lightweight materials. Large trucks have improved aerodynamics and tires. Pick-up trucks have advanced technically almost as rapidly as cars, but in the United States the resulting fuel savings have been cancelled out by a rush of car drivers trading in their cars for trucks. Fashion is rarely efficient.[66]

Airplanes are increasingly important energy consumers as air travel grows rapidly in many parts of the world. Between 1973 and 1984, the amount of fuel American jets used to carry each passenger a kilometer decreased by 70 percent, partly as a result of the transition to wide-body jets and growing numbers of passengers on each flight. Boeing's most recent models, the 757 and 767, with their improved engines, streamlined aerodynamics, computer controls, and extensive use of lightweight materials, use at least a third less fuel than their predecessors, the 727 and 707. Jets planned for the nineties are projected to cut fuel use by another 30 percent. Even more advanced technologies are under investigation for the turn of the century.[67]

Propeller planes could soon make a comeback, thanks in part to research at the U.S. National Aeronautics and Space Administration in the seventies. Turboprop engines use a jet to power a pair of multi-bladed propellers that spin in opposite directions. The result is a 20-percent fuel saving compared to the best 1987-model engine. By the turn of the century, "laminar flow" aerodynamics may reduce drag and fuel use by an additional 30 percent. Normally, jets carry a layer of turbulent air against the skin—as if the airplane were covered with thick shag rug. Engineers hope to suck the turbulence through razor-thin slits into a duct system in the wings. But insects pose problems: They tend to clog the slits.[68]

It is ironic that just as the technical potential to improve transportation fuel efficiency has soared, worldwide momentum toward lower dependence on oil-based transportation has stalled. Major efforts to commercialize new technologies and to steer urban development in a fuel efficient direction are essential. The stability of the world oil market and the air quality of the world's cities now ride on these efforts.

New Potential for Industry

In most countries, industry has led the way in improving energy efficiency. Overall, the energy intensity of the industrial sector in countries that belong to the Organisation for Economic Co-operation and Development (OECD) has fallen a remarkable 30 percent since 1973. About one-third of this shift is due to structural economic changes. Denmark and Japan made unprecedented gains, with 7-percent annual savings between 1979 and 1984. In the United States, industrial energy use in 1986 was actually 17 percent lower than in 1973, despite a 17-percent increase in industrial production during the period. In some nations, including the United States, industry is no longer the largest energy user.[69]

Marc Ross, a physicist at the University of Michigan, has suggested that the lowered energy intensity of U.S. industry has two causes. About 45 percent, he estimates, is attributable to structural shifts in the economy toward the production of less energy-intensive products. Production of steel and cement, for example, has fallen, while electronic gadgets proliferate, and some energy-intensive raw materials are now imported from newly industrializing countries. But 55 percent of the improvement can be traced to new, more-efficient equipment and processes. In many industries, managers have aggressively reduced energy consumption to preserve their profit margins.[70]

Industry's use of oil has fallen particularly rapidly, petroleum has become a specialty fuel. Almost half the oil American industry consumes now serves as raw material rather than fuel. Use of natural gas and coal has also declined, and even the utilities' loudly trumpeted "electrification of industry" has fallen flat: Electricity intensity has leveled off as efficiency gains consistently offset the introduction of electrical processes such as electric arc furnaces and robotics.[71]

Even after these advances, industry still uses 37 percent of the total primary energy supply of the industrial market economies, and as much as 60–70 percent in many developing nations. North American industry is still much more energy-intensive than the industries of Europe and Japan, and recent declines in oil prices may lull some industries into complacence, delaying additional improvements.[72]

The lion's share of industrial efficiency improvements in the United States so far have been in petroleum refining, chemicals, cement, metals, paper, glass, and clay—energy-intensive industries where competition required change. Other, less energy-intensive industries now use a growing share of industrial energy. Studies show that many companies continue to pass up efficiency investments with short payback periods, while investing aggressively in means of boosting market share.[73]

Training managers to identify and appraise ways to increase energy efficiency should be a high priority for corporate and national planners. Considering the potential to raise efficiency can make a large difference when companies are adding new equipment; it can affect a plant's energy use for decades. Many companies have appointed senior energy program managers with responsibility in this area and offer bonuses tied to success in lowering energy costs. Japan, which has significantly reduced industrial energy use, requires by law that companies with high energy consumption designate full-time energy managers.

A few widely used technologies hold immense potential for savings. In the United States, fully 95 percent of industrial electricity goes for electromechanical drives, electrolysis, and heating. (See Table 6.) Electromechanical drives, ubiquitous in industrial processes, can be improved in many ways, including the use of electronic speed controls that cut power needs by up to 50 percent. Sales of these devices have more than tripled in the United States since 1976, and can be expanded further. The Electric Power Research Institute estimates that variable speed drives alone are sufficient to offset the additional electricity likely to be used by all 27 new electricity-using industrial technologies projected to be introduced between 1980 and 2000.[74]

Production of chemicals is now the largest use of industrial energy in many countries, accounting for 22 percent in the United States. Im-

Table 6: United States: New Technologies and Industrial Electricity Use

Electric Use	Share of Industrial Electricity[1]	Selected Technologies to Improve Efficiency[2]	Probable Trend in Electric Intensity
	(percent)		
Electromechanical Drives	70	Efficient motors Adjustable speed drives Cogeneration	Down
Electrolysis	15	Improved cell efficiency Chloride process Membrane separation Electrochemical synthesis	Down
Electroheat	10	Plasma applications Electroslag casting Heating with: laser, electron beam, infrared, microwave. Ultraviolet curing	Up
Other	5	Robotics Improved space heating/cooling	Down

[1]As of 1983.
[2]Technologies likely to be widely employed by 2000.

Source: Adam Kahane and Ray Squitieri, "Electricity Use in Manufacturing," in Annual Reviews, Inc., *Annual Review of Energy*, Vol. 12 (Palo Alto, Calif.: 1987).

proved processing techniques and heat recovery devices helped reduce the energy intensity of the U.S. chemical industry by 34 percent between 1972 and 1985. The cement industry is also a major and growing energy user, although efficiency improvements are under way. Most notably, more widespread use of a dry production process will cut energy requirements greatly.[75]

The steel industry, once the universal symbol of industrialization, has declined in importance but remains a significant user of energy As total steel use has fallen, the industry has shut down its older, less efficient plants. In industrial countries, traditional open-hearth furnaces have largely been replaced by more-efficient basic oxygen furnaces and electric arc furnaces that recycle scrap steel and cut energy needs by half. Energy consumption in existing steel plants is being trimmed through the use of continuous casting, in which steel is formed directly into the desired shape, reducing waste.[76]

One of the greatest opportunities for improving industrial energy efficiency lies in cogeneration—the combined production of heat and electricity. By installing a small boiler and electric generator within a plant, the waste heat of electricity generation is made available for industrial processes. Such systems are hardly new, they were widely used early in this century, but most were abandoned in the rush to build central power plants. In the United States, cogeneration reached a low of 10,476 megawatts in 1979, in Europe, it is still widely used in urban district heating systems.[77]

Industrial cogeneration has grown explosively in the United States due to the Public Utility Regulatory Policies Act of 1978, intended to allow industry to sell power to utilities at a fair market price. As of 1985, total U.S. cogeneration had reached about 13,000 megawatts, but that number will grow rapidly in the next few years, as hundreds of new facilities are finished. More than 47,000 megawatts of planned cogeneration—with as much generating capacity as 47 large nuclear plants and a market value over $40 billion—were registered with the Federal Energy Regulatory Commission (FERC) as of October 1, 1987.[78]

"One of the greatest opportunities for improving industrial energy efficiency lies in cogeneration."

In fiscal year 1987 alone, about 13,000 megawatts of projects were registered. The cogeneration industry now includes most of the engineering and manufacturing firms that once served the utility industry, and is also well established financially, with extensive ties to leading U.S. banks and institutional investors. Cogeneration projects range in size from 300,000-kilowatt facilities that serve petrochemical plants, to 20-kilowatt units in fast-food restaurants and apartment complexes. Manufacturers soon plan to make systems as small as 3–5 kilowatts, suitable for residential use. Some of the largest users include the oil industry, which taps such systems to produce steam for enhanced oil recovery; the chemical industry, which can use petroleum by-products as fuel, the food-processing industry, which has large heat requirements; and the pulp and paper industry, which burns wood wastes.[79]

In the early eighties, conventional wisdom held that cogeneration would never make more than a small dent in centralized electric power systems. Today, however, as technologies advance, the potential uses for cogeneration have broadened to include a range of commercial and industrial facilities such as hospitals and hotels. Applied Energy Services, a cogeneration company, estimates that by the year 2000, the U.S. market could surpass that for nuclear power, reaching 100,000 megawatts—15 percent of the U.S power supply. The long-term potential is even greater.[80]

Cogeneration could face some problems, however. About half the new U.S. projects rely on natural gas, a fuel that will probably not remain as inexpensive as it is today, and coal accounts for another 30 percent of planned U.S. cogeneration, which will add to the carbon dioxide buildup in the atmosphere. However, many cogeneration projects will displace less-efficient central power plants fired by gas and coal. Industries that were once burning gas for process heat may now be using only slightly more gas and meeting all their electricity needs as well. Studies have shown that by using cogeneration, many factories can raise total plant energy efficiency from 50–70 percent to 70–90 percent. Nonetheless, with the rapid growth in cogeneration, its effect on total fuel requirements and on air pollutants and carbon dioxide needs careful consideration before major commitments are made.[81]

Industry as a whole is on a path to substantially decreased energy and materials intensity, rendering past projections obsolete. The world's largest economies appear to be in the midst of a structural shift away from the processing of basic materials, a shift that is caused only in small part by higher energy prices. Growing affluence, saturation of the market for energy-intensive materials, and the emergence of new high-technology products are helping to usher in this new era. On balance, most industrial market countries are unlikely to use as much industrial energy in the year 2000 as they did a quarter-century earlier.[82]

Although this is good news for the global environment, and for the economies of many nations, these benefits could well be offset by growing energy requirements in developing and centrally planned countries. Many Third World industries suffer from a damaging combination of subsidized energy prices, limited access to energy-efficient technologies, and poor management. None of these can be overcome without policy changes and more effective transfer of new technologies to the Third World.

Programs to improve the efficiency of basic industries in countries such as Kenya and South Korea have been quite successful, indicating the potential. Studies in India have found that efficiency can be improved in existing industries by 15–30 percent, largely by using simple "housekeeping" measures. Beyond such low-cost efforts, the rapid growth of industry in developing nations provides an opportunity for enormous strides in energy efficiency.[83]

As many of the world's energy-intensive basic materials industries shift to the Third World, it is essential that the frontier of technical innovation shift with them. Indeed, enhanced efficiency is critical for success in the tightening international competition that most Third World industries face.

Research for an Efficient Future

The fate of energy efficiency tomo .w rests in part on research and development programs implemer...l today. Increased business and government support can go a long way, but it cannot carry energy efficiency past the frontier drawn by technology. That frontier has been expanding for over a decade, with innovative technologies proliferating. But in the wake of the oil price plunge of 1986, research programs in many countries and industries are being curtailed.

The formula for success in research and development is complex. In each country there is a unique balance between the public and private sectors and a different blend of energy users. Success requires not only the brainpower of talented scientists, but also constant feedback from those who will use the technologies. The relationship between government and private companies must be at least coordinated if not collaborative. The nature of the scientific enterprise generally necessitates steady, long-term support. Perhaps most important, if technologies are ever to be useful, the routes between laboratory, factory, and consumer must be well established, commercialization is an integral part of research and development.

Many private firms carry out extensive research programs. Energy-intensive industries like chemical and metal production, for example, have found many ways to cut energy consumption in recent years. In these industries, energy efficiency can often make the difference between a profitable and an unprofitable enterprise, and so there is relatively little need for government intervention.

For the automobile industry the issue is less the energy efficiency of production than the energy efficiency of its products. Automobile companies have always invested large sums in improving the style and performance of their cars, and since the mid-seventies have poured hundreds of millions of dollars into boosting fuel economy. These efforts have yielded excellent results, but in recent years have slowed measurably.

38 In the early eighties, the three American auto manufacturers started well-publicized, multimillion-dollar programs to produce a second generation of fuel-efficient models. Their professed aim was to catch or surpass their overseas competitors in small-car development and remain ahead in larger cars. But by late 1987, all three programs had essentially been gutted in favor of the relatively mundane application of existing techniques. The major U.S. carmakers appear not only to have given up on the small car market, but are lagging badly in many areas of automotive technology.[84]

Japanese manufacturers, by contrast, remain committed to large research programs in all areas, many of them with potential to improve fuel economy. They are investigating a wider variety of technologies than American firms, and they have brought technologies such as lean-burn engines and continuously variable transmissions to the commercial market much more rapidly. Indeed, the Tokyo auto show is now the premier automotive technology event, attended by auto analysts from around the world.[85]

The public sector has a key role to play in supporting and filling the gaps in private research and development. Governments have the ability to invest in new technologies with no immediate commercial applications, and the results of their successes are more easily disseminated than are the often-proprietary successes of private industry. However, to be effective, government programs in energy efficiency research must be closely linked to the private companies that will use them. Not to do so would be like ignoring the role of doctors in health-related research. Programs must be cost-shared, and commercialization must be made part of the R&D process.

One of the largest R&D gaps is in the construction industry, which, in much of the world is highly decentralized and frequently battered by interest rate shifts and recessions. The Swedish government provides an example of effective research and development in the housing sector. It has made a major commitment to energy efficiency and has cooperated with Swedish builders in developing the techniques that make Swedish homes the most efficient on earth. One key to this success is that most Swedish homes are built in factories by highly

"Since President Reagan took office, efficiency R&D has been cut by about 55 percent."

skilled artisans. However, Sweden has also demonstrated the importance of spreading the results of government-sponsored research. Thousands of companies, after all, construct the world's buildings.[86]

The Soviet Union provides a classic example of failure to effectively capitalize on research and development. Soviet laboratories are second to none in basic and applied research on energy efficiency, the result of steady support over many years. Soviet factories, buildings, and vehicles hardly reflect this sophistication, however. The Soviets invented more-efficient continuous casting for steelmaking, for example, but few Soviet steelmills use it. Some in the Kremlin have acknowledged that a key element of *perestroika* (economic restructuring) must be to move these new technologies more smoothly from the laboratory into the economy.[87]

The U.S. Department of Energy (DOE) research program has had a mixed record in commercializing more-efficient technologies. During the late seventies, these programs grew quickly and somewhat chaotically, and many included commercialization. However, since President Reagan took office in 1981, efficiency R&D has been cut by about 55 percent. The Administration's research policy explicitly excluded technologies with near-term commercial opportunities, holding that the private sector should take care of applied research, while the government should help in basic research.[88]

The result frequently has been failure on both fronts. A 1987 General Accounting Office study found that in most cases where federal support of technologies has been limited to basic research, private industry has not gone forward with commercialization. Several important efficiency projects have died on the vine, and the government's research program is in disarray.[89]

Despite this shift in focus, a number of technologies developed under DOE contracts in the late seventies have moved with relative ease into commercial markets. One study found that $16 million spent for R&D on just seven efficiency technologies will save the United States $63 billion worth of energy by 2010.[90]

In 1976, for example, the Department of Energy and the Lawrence Berkeley Laboratory began a program to develop high-frequency ballasts that can make fluorescent lamps 20–40 percent more efficient. By 1980, prototype lamps installed at a federal office building met both reliability and performance standards. Several small U.S. manufacturers began producing the new models, taking just 1.4 percent of the ballast market.[91]

In 1984, General Electric, GTE, and all of the other major lamp manufacturers entered the market for high-frequency ballasts. The American Council for an Energy-Efficient Economy found that the 2 million ballasts in use by 1987 were already saving $15 million worth of electricity each year. Over the next 30 years, the new ballasts are expected to save $25 billion worth of electricity—not bad, considering that the government seed money amounted to only $2.7 million.[92]

The Department of Energy began another program in 1976 to develop special window coatings that allow light to pass unimpeded but retain heat within a building. Federal contractors developed several early generations of the new coatings, and after a few years some were able to raise venture capital to continue the process privately. The technology did not really catch on until 1983, however, when a large window manufacturer adopted it.

Just $2 million was spent on the initial federal program to spur the development of the new windows, and private industry later spent over $150 million on facilities to manufacture them. The windows are projected to save $120 million worth of heating fuel annually in 1995, with cumulative savings reaching $3 billion in the year 2000.[93]

In 1986, the OECD member countries spent $622 million on improved energy efficiency research and development—a small sum compared to the $4.5 billion spent on nuclear technologies. (See Table 7.) When the relative contribution of efficiency is considered, it is clear that efficiency R&D is drastically underfunded. Only in Demark and Sweden, two countries with major commitments to energy efficiency, is more than one-third of the energy research and development budget spent on efficiency technologies.[94]

Table 7: Government Efficiency Research and Development Budgets in OECD Member Countries, 1986

Country	Efficiency	Total	Efficiency as Share
	(million 1986 dollars)		(percent)
Japan	78	2,311	3
United States	275	2,261	12
Italy	48	761	6
West Germany	21	566	4
United Kingdom	43	378	11
Canada	34	336	10
Sweden	29	79	37
Greece	0	15	0
Denmark	5	14	36
Total OECD[1]	622	7,133	9

[1]Total includes minor additional expenditures. Excludes France.

Source: International Energy Agency, *Energy Policies and Programmes in IEA Countries, 1986 Review* (Paris. Organisation for Economic Co-operation and Development, 1987).

In many countries, efficiency R&D budgets have fluctuated in recent years, and this uncertainty has impeded progress. Japan, however, has been more consistent than most, despite its relatively modest budget of $78 million. Government policy states that "It is necessary to offer the appropriate guidance to the private sector's energy conservation efforts, and to prevent the consciousness toward energy conservation . . . from being affected . . . by short-term trends in the oil markets."[95]

An effective process must be set up to choose among myriad proposals for research and development. In many countries a built-in bias favors the proposals of large, well-established companies. Ideally, though, new projects should be chosen on their merits. Independent engineering panels can be assembled to ensure this, something that has been successful with some of the U.S. programs. Such panels could also oversee the large, but gradual, increases in spending on efficiency research that are required in order to right the current imbalance. In most cases, private partners in these programs should be required to provide at least half of the funding.

International collaboration in energy research and development should also be made a high priority. The recent mushrooming of energy technology developments means that even wealthy nations can no longer afford to have independent research programs in every promising field. So far, the European Economic Community has the largest joint effort, and many European countries channel most of their energy research and development funds through the program. Total funding is now about $60 million per year for non-nuclear energy research and development, split almost evenly between renewables and efficiency. In addition, the International Energy Agency maintains a cooperative program among OECD member countries that has spent about $600 million during the past decade.[96]

It is unfortunate that for the most part such programs have not been broadened to include centrally planned and developing nations. The Third World has been able to fund only small projects and needs to share in the latest developments, particularly those involving decentralized technologies. Although some foreign aid programs have effectively promoted the development of indigenous energy resources, these are neither as strong nor as numerous as they could be. The United Nations Conference on New and Renewable Sources of Energy in 1981 was supposed to lead to collaborative research and development programs, but it bogged down in political infighting and bureaucratic inertia. It is time for world leaders to recognize their common economic and environmental interest in more-efficient technologies.

Prices, Taxes, and Standards

Energy prices are one key to a rational energy system. Prices affect the overall economic efficiency of the energy system and the value that is

"Energy prices in most countries reflect neither the true replacement cost of nonrenewable resources nor the environmental damage that their use can cause."

placed on climate protection and other environmental considerations. Unfortunately, energy prices in most countries reflect neither the true replacement cost of nonrenewable resources nor the environmental damage that their use can cause. In centrally planned economies, low or nonexistent prices have encouraged waste. An effective energy pricing system is a necessary but not a sufficient condition for an energy efficient economy.

The most important energy price is that of oil. Indeed, world oil prices have become one of the most closely watched economic indicators. The impact of major price shifts is felt by everyone from Brazilian charcoal vendors to Tokyo stock traders. When the price of oil fell in 1986, not only did gasoline prices plummet, but U.S. wholesale natural gas prices declined almost 40 percent in 15 months and coal prices fell 8 percent.[97]

One of the chief stumbling blocks to promoting energy efficiency today is the instability of the price of oil. After increasing more than eightfold during a seven-year period in the seventies, real oil prices fell 75 percent between 1981 and 1986, hitting a low of about $12 per barrel before rebounding to $18 in 1987.[98] (See Figure 1.)

Many energy economists are now asking what the true price of oil is. The concept of marginal cost pricing is normally used by economists to indicate the price that reflects the cost of the next unit of a particular good to be produced. Ideally, this should encourage maximum economic efficiency. While a resource such as oil is gradually depleted, rising marginal extraction costs should encourage the development of alternatives.[99]

But in heavily manipulated and complex energy markets, marginal cost pricing becomes almost a black art. While the marginal cost of oil production in the Middle East is reportedly still under $2 per barrel, a significant share of the world's oil is being extracted in places like the Alaskan North Slope and the North Sea at costs as high as $20 per barrel. As a result, there is no true marginal cost price of oil, prices can swing within a broad range, influenced by politics as much as economics.[100]

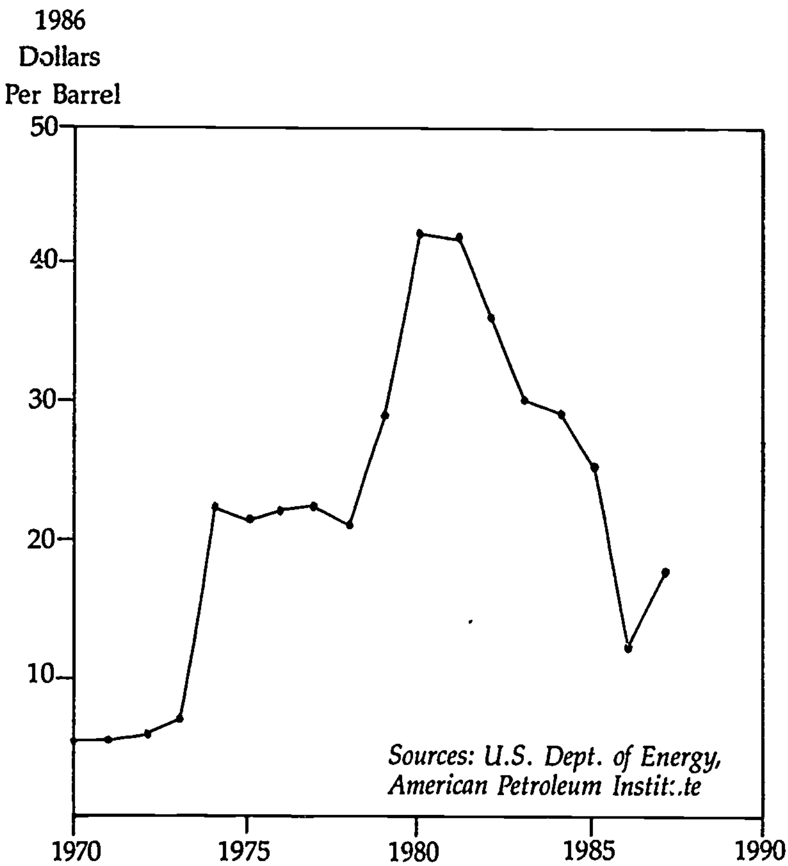

Figure 1. World Price of Oil, 1970-87

Since the early eighties the world oil market has been dominated by excess production capacity, caused in large measure by the efficiency gains of the last decade. This condition is likely to last for some years, given the large excess production capacity in the Middle East, which has 57 percent of the world's proven oil reserves. Although pressures on oil prices during the next few years are likely to be mainly on the downward side, sudden and catastrophic increases are possible, and even likely. Such uncertainty works against efficiency as powerfully as do low prices: Unpredictability discourages decisionmakers from taking the long view.[101]

Relying on imported oil entails a national security cost that is not included in market prices. In recognition of this, industrial countries have wisely spent billions of dollars building up "strategic petroleum reserves." The United States has filled salt caverns in Louisiana with stockpiled oil, while Japan has a fully loaded tanker fleet in Tokyo Bay. More dubiously, the United States alone spent \$47 billion to defend the Middle East region in fiscal year 1985. This comes to \$26 per barrel of oil shipped through the Strait of Hormuz.[102]

One means of ensuring that cheap imported oil does not undermine alternative energy efficiency investments is to tax oil or oil products. The impact of varying tax systems is seen in the differing prices paid for gasoline around the world. (See Table 8.) Gasoline prices in 1987 ranged from 94¢ per gallon in the United States to \$3.34 in Japan and \$3.76 in Italy. Taxes account for most of the difference.[103]

In Europe, fuel taxes are commonly used to raise government revenues and discourage gasoline consumption. In the United States, however, efforts to raise gasoline taxes have been beaten back by the oil industry, consumer groups, and wary politicians. U.S. retail gasoline prices plummeted in 1986, encouraging more driving, in Europe prices declined moderately, and the conservation incentive remains strong.[104]

A few countries deliberately tax fuel to encourage conservation. In 1983, Sweden passed a law requiring the government to use fuel taxes to dampen fluctuations in gasoline prices, a provision that was acti-

Table 8: Gasoline Prices and Taxes in Selected Countries, 1987

Country	Price[1] (including tax)	Tax
	(dollars per gallon)	
United States	.94	.29
Australia	1.47	.65
West Germany	2.31	1.34
United Kingdom	2.39	1.53
France	3.06	2.32
Japan	3.34	1.47
Denmark	3.76	2.93
Italy	3.76	2.78

[1]Average price for April-June 1987.

Source: International Energy Agency, *Energy Prices and Taxes, Second Quarter 1987* (Paris. Organisation for Economic Co-operation and Development, 1987).

vated by the 1986 price collapse. Also in 1986, Denmark and Portugal took steps to raise taxes, keep retail gasoline prices high, and promote conservation. Although such policies are generally not popular, they encourage needed efficiency investments and will benefit consumers in the long run.[105]

In many Third World countries, kerosene and diesel fuel are subsidized, a practice that places a heavy burden on government treasuries but is highly popular among consumers. When the government of the Philippines attempted to raise fuel prices in August 1987, demonstrations erupted in the streets of Manila. Such reactions are common and create a dilemma in countries where most of the population cannot afford fuel at the world price. In order to ensure that fuel taxes do not exacerbate equity problems, they should be offset by eliminating income taxes for low-income people or even providing government loans for the purchase of vehicles and appliances that are more fuel-efficient.[106]

Energy prices should also reflect the environmental effects of using particular energy sources. Burning coal in a power plant creates air and water pollution, and often entails land-damaging strip mining. Yet without government intervention, consumers might use large quantities of cheap electricity without regard to the wider costs. A tax can put a price tag on environmental damage and so discourage pollution. No country has yet enacted such a tax, but the time may be ripe.

Most governments have chosen to deal with conventional pollutants by enacting regulatory standards or requiring the use of emission control devices, but the global warming caused by carbon dioxide is not amenable to technical fixes. So far, improving energy efficiency seems to be the only practical means of limiting carbon output.

A carbon tax on all fossil fuel use—in effect, a climate protection tax—would ensure that the cost of burning a fuel reflects the risk of damage to the world climate. If it were tied to the fuel's carbon content, coal would be taxed most heavily, oil somewhat less, and natural gas the least. A tax of $1 per million Btu on coal and 80¢ per million on crude oil would boost average electricity prices by 10 percent and increase gasoline prices by 11¢ per gallon, while raising $53 billion in revenues in the United States alone.[107]

Market incentives are generally more efficient than legislated standards for encouraging policy changes. Even the most omniscient legislators cannot foresee all the perverse effects that new laws can have, nor the evasive tactics they can inspire. It is also difficult to anticipate future changes in technology, legislated standards can lock society into a less-than-ideal solution to a particular problem. One example is acid rain legislation that would mandate expensive flue gas desulfurization but not allow utilities to achieve the same sulfur dioxide reductions by investing in improved energy efficiency.

Despite such objections, mandatory efficiency standards do have a role to play. Often the impact of standards is easier to predict than is the impact of financial incentives. They can ensure that the least efficient or most wasteful practices are eliminated, so that even those without investment capital get the benefit of needed improvements. Dozens of countries have enacted minimum energy efficiency standards since the early seventies. Overall, the United States has shown the most fondness for such legislation, perhaps as a way of counteracting the country's low energy prices. But support for this approach has fluctuated over the years.[108]

Most industrial market economies have automobile efficiency standards, but only in the United States are they mandatory. Under legislation passed in the mid-seventies, U.S. auto manufacturers were required to increase the average fuel efficiency of new cars from 13 MPG in 1973 to 27.5 MPG in 1985. These standards were crucial in encouraging the carmakers to invest in a new generation of lighter, front-wheel-drive cars in the years between the two oil price increases. The mandated levels were easily met until 1985. Then in the face of falling oil prices and auto company pressure, the Reagan administration relaxed them, encouraging U.S. manufacturers to indefinitely delay programs to further improve energy efficiency. A new set of tough but achievable standards is needed to take average new-car fuel efficiency up to at least 40 MPG by the year 2000.

Energy codes for new residential buildings are more common, now found throughout the industrial world as well as in some developing countries. Some are mandatory while others merely provide general guidelines to builders. The toughest building efficiency standards are found in South Korea and Sweden. Studies in Europe indicate that in most countries further tightening of standards could be economically justified.[109]

The problem with energy codes for buildings is that they can easily become complex and cumbersome, causing problems for the construction industry. It is important that such codes be as simple as possible, based more on measured performance than on bureaucratic prescriptions. An alternative to new building standards now under consideration in Texas is a graduated, progressive hook-up fee system: Energy-wise new buildings receive cash bonuses from the utility, while energy gluttons pay for their inefficiency.[110]

Energy efficiency standards for household appliances have been hotly debated in recent years. In November 1978, the U.S. Congress directed the Department of Energy to issue minimum standards. Because of fierce opposition from appliance manufacturers and its own distaste for government regulation, the incoming Reagan administration delayed implementation. Finally, it claimed in 1982 that the best way to regulate appliance efficiency is not to regulate it at all, and then went to court to fight the ensuing lawsuits.[111]

Meanwhile, California instituted its own tough appliance efficiency standards in December 1984, and New York followed suit, after calculating that consumers would save billions of dollars worth of electricity. As such legislation proliferated, manufacturers' worst nightmares were realized: Even a relatively tough national appliance efficiency law would be less onerous than a plethora of varying state laws. Manufacturers, utilities, consumer advocates, and environmentalists began negotiating in 1986 to develop a new appliance efficiency bill. After several months of tough bargaining, an historic agreement was reached; the resulting bill sailed through Congress and was finally signed by a reluctant president.[112]

The successful saga of appliance efficiency standards can be viewed as a strategic model. Efficiency standards can complement improved market signals. Manufacturers themselves benefit when future requirements are clear and all competitors face the same standards. The potential savings are enormous. It is estimated that between now and the turn of the century the new U.S. appliance efficiency standards will save $28 billion worth of electricity and gas and will keep 342 million tons of carbon out of the atmosphere.[113]

No single mix of policy measures is appropriate for all circumstances. Improved price signals are a precondition of an effective energy policy, but they must be creatively blended with special incentives and standards. Policymakers have the difficult job of designing a package of measures that will encourage efficiency without burdening society with excessively onerous taxes or standards. Indeed, policymakers must never lose sight of their goal. to unleash the creative energies of consumers and businesses, who ultimately determine how energy efficient societies become.

Institutionalizing Efficiency

If energy efficiency is to realize its full potential to revitalize economies and protect the environment, major institutional reforms will be needed. Government standards and price incentives can only carry the process so far. Also needed are creative ways of mobilizing consumers, businesses, and nonprofit institutions to initiate energy efficiency improvements themselves.

The most serious obstacle is what energy conservation professionals call the "payback gap." Energy consumers—from homeowners to factory managers—rarely invest in efficiency measures with payback periods longer than two years, while energy producers look to new supply options with payback periods of 20 years or more. If institutional changes bridge this critical gap, energy efficiency might largely take care of itself.

The key is developing markets for saved energy. Consumers do not want energy, they want the services energy provides. Firms that find the cheapest ways to conserve energy, while still meeting standards of quality and reliability, should be rewarded. Already, a sizable energy efficiency industry has grown to serve commercial buildings and factories in the United States. In Canada and some European countries, the industry is only a few years behind. Efficiency will only come into its own, however, when more electric and gas utilities are encouraged to buy saved energy.

Energy efficiency companies can provide one-stop shopping. They inspect the building or factory, select, buy, and install retrofit measures and new equipment, and often operate and maintain the equipment. Currently they recoup their investment either by taking a share of the owner's savings for a set period or by receiving prearranged monthly payments. Over 100 firms now hold contracts on some 2,000 U.S. buildings. Because of economies of scale, most contracts to date

"Efficiency will only come into its own when more electric and gas utilities are encourged to buy saved energy."

have been for buildings or factories with potential savings over $50,000. At least one sm-'l company in Minnesota, however, offers home retrofits on a shared-savings basis.[114]

In energy supply, technology is the central concern, but in energy efficiency, contract negotiations and financing are critical to success. Saved energy cannot be metered. Its quantity can only be estimated based on past experience and current conditions. Complex, computer-based methodologies must be developed to measure saved energy, and legal and financial practices must be standardized to streamline the process.

One effective means of promoting energy efficiency is through utility sponsorship, an approach that has been tried in several areas of the United States. One successful, if small, program is run by the city-owned utility of Osage, Iowa. Since 1974, Osage has invested heavily in energy efficiency by funding extensive energy audits of almost half the town's residences. These audits, combined with peer pressure to encourage participation, have led to weatherization of hundreds of homes. As a result, Osage managed to cut electric demand growth to zero through 1985, defer planned construction programs, and cut electric rates five times in four years. The lower electricity bills have helped Osage to attract new industry.[115]

Large electric utilities have also begun to play a central role in institutionalizing energy efficiency. Since the late seventies, regulators and legislators have pushed many to adopt conservation programs, often based on the concept of least-cost planning. Using this approach, utilities invest in improving customers' efficiency as long as greater efficiency costs less than new supply. This essentially mimics the effects of a market. The cheapest options sell first in a market, and they are chosen first in least-cost planning. A 1987 survey indicated that 23 state regulatory commissions are studying or have adopted the concept of least-cost planning.[116]

According to a survey of U.S. electric utilities by the Investor Responsibility Research Center of Washington, D.C., 75 utilities spent $582 million on efficiency programs in 1985. Aggressive programs at six of the largest utilities have eliminated the need for 7,240 megawatts of generating capacity—at less than a fifth the cost of new plant construction. The more comprehensive programs include building inspections, free energy-saving showerheads and water tank insulation, rebates for efficient appliances, and loans for home weatherization. Unfortunately, many programs are little more than public relations campaigns, and others are being scaled back in the face of power gluts.[117]

Among leading utilities are Pacific Gas & Electric Company which has already saved 1,100 megawatts of power-generating capacity, and the publicly owned Austin Electric Company, which has been building a "conservation power plant" since 1984. One of the most ambitious utility plans is the regional Northwest Conservation and Electric Power Plan, created by federal legislation in the early eighties. It requires that in the future energy efficiency be considered along with new power plants. Plans are now in place to begin investing in efficiency before any additional power plants are needed.[118]

Several utilities have gone beyond promoting efficiency to buying saved energy. General Public Utilities Company of Pennsylvania (owner of the infamous Three Mile Island plant) pays for conservation by offering companies a fixed return on every kilowatt-hour saved. Conservation companies take out contracts for blocks of houses, inspect them, choose the most cost-effective investments, and make the improvements. The companies are chosen by competitive bidding, and they pay for any cost overruns or faulty installations. The utility helps with low-cost financing, and monitors the resulting improvements to measure the saved energy.[119]

In most cases these energy efficiency programs are required by state regulators as part of a "least cost planning" mandate. The utilities are fined unless they invest in improved efficiency whenever it is less expensive than a new generating facility. However, these utility-sponsored efficiency projects can only be as successful as utilities want them to be. The ultimate guarantee that efficiency gets a fair shake must be to create markets in saved energy, introducing competition between energy supply and energy efficiency.

"Competitive bidding could help boost efficiency to its maximum cost-effective level."

When Congress passed the Public Utility Regulatory Policies Act in 1978, it began to open up the monopolistic U.S. power industry. This legislation enables newcomers to the energy market to compete by building small plants based on renewable energy or cogeneration and selling the electricity to utilities. By late 1987, FERC had granted licenses to projects that would generate more than 63,000 megawatts, equivalent to 63 nuclear plants or over two-thirds of the current nuclear industry. Some 20,000 megawatts may have already been installed. Meanwhile, since 1980, orders for utility coal plants have slowed to one or two per year, and nuclear orders have stopped entirely. A transition, it seems, has occurred.[120]

Logically, this competitive market should be extended to efficiency, so that a company that can provide "saved energy" in an office building or a factory for less than the cost of building a new power plant or running an old one would win the bid. The privately owned Central Maine Power Company has already taken that step. It is currently evaluating energy efficiency proposals submitted in the most recent round of power contract bidding. Energy efficiency firms representing blocks of consumers or individual large consumers have made proposals to provide the utility with "negawatts" of power. The proposals are being weighed against cogeneration and renewable power on the basis of price, reliability, and other factors.[121]

This competitive bidding formula could help boost efficiency to its maximum cost-effective level and put the energy conservation industry on a solid footing. Competitive bidding that includes efficiency would be particularly effective in rental housing, where waste is perpetuated by the diverging interests of tenants and owners. Efficiency companies would identify potential improvements and provide the capital, removing the need for either the landlord or tenant to raise large sums of money. In addition, competitive bidding would weed out superficial or unreliable efficiency measures and ensure that the efficiency industry has the necessary skills, equipment, and professional standards to perform effective, high-quality retrofits.

The U.S. utility industry is in an unprecedented state of flux. Both state and federal regulators appear bent on creating a more competitive electricity market, and many utilities are responding by creating unregulated subsidiaries to compete in the bulk power market.

The very structure of the industry a decade from now is uncertain, let alone the role that energy efficiency programs will end up playing.

One attractive approach to competition is to make a clear separation between power generation on one side and transmission and distribution on the other. The former would be competitive and market-driven, and the latter would be planned and regulated, somewhat similar to the way the U.S. telephone industry is now structured. This would give the regulated utilities a much clearer and less conflict-ridden mission. Regulators would allow them to earn the revenues necessary to provide customers with consistent service. Utilities would become honest brokers between energy producers, consumers, and savers.[122]

Utilities—because of their links to energy users through centralized billing and metering services—will likely retain a central role in energy efficiency. In addition, utilities, regulators, and government bodies will have to vigorously police the market. Precautions should be taken against counterproductive "cream skimming" (making improvements with high return rates that preclude other worthwhile but less profitable improvements). Of course, energy efficiency firms will have to be licensed, projects inspected, and savings verified. If efficiency programs are to be treated like new power plants, they must be planned, designed, and implemented with the highest of standards.

Although much of the experimentation in providing energy efficiency services has involved electric utilities, ways must be found to make similar gains in other sectors of the energy economy where saved energy is displacing oil or natural gas rather than electricity. Some local gas companies have begun providing energy services, but gas companies do not have expensive new power plants that can be displaced. Still, if regulators reward them for the effort, there is no reason that gas distribution companies could not provide these services. Amory Lovins has proposed that gas companies be encouraged to compete with electric utilities in displacing electric power supplies.

Energy efficiency by its nature requires a variety of decentralized responses rather than a monolithic solution. Finding ways to bridge the gap between the public and private sectors—something between sweeping government mandates and unfettered markets—is essential to realizing efficiency's potential.

The North Carolina Alternative Energy Corporation (AEC), established in 1980 by joint agreement between utilities and the state government, bridges this gap. Funded by a special utility tax, and run by a board that includes utility officials, business leaders, and consumers, the AEC has sponsored projects ranging from community energy planning to minifluorescent lighting retrofits in the state's chicken farms. With a limited budget of $2.3 million a year, the AEC relies on a "multiplier effect" to spread effective solutions throughout the state.[123]

As a nonprofit, utility-funded organization, the AEC can try things on which the private sector would not risk economic capital and on which the government would not risk political capital. Several other states are now studying the North Carolina model, and it is quite possible that such hybrid approaches will one day be widespread.

The Limits to Energy Growth

In 1972, the Club of Rome warned that the world would run out of fuels and raw materials. To the contrary, the world today faces a glut rather than a shortage of fossil fuels, but that glut is itself a product of temporary shortages and soaring prices. Efficiency made it possible for the world to climb out of the severe 1981-82 recession, and led to a 75-percent decline in the real price of oil between 1981 and 1986. But the global environmental limits now emerging may turn out to be far more stringent and dangerous, sorely testing the resolve of policymakers and citizens alike.[124]

Investment in energy efficiency is the most effective response to those limits, for it is simultaneously an investment in lowered oil dependence, reduced air pollution, and climate protection. Doubling the fuel efficiency of a typical car to 50 MPG lowers its annual fuel bill by almost $400; significantly cuts emissions of nitrogen oxides, hydrocarbons, and carbon monoxide, and reduces carbon emissions by half, or 450 kilograms annually. A similar improvement for the world as a whole would cut carbon emissions by 6 percent or almost 200 million tons annually, a substantial contribution to climate protection.[125]

In 1986, oil imports in many countries rose for the first time in almost a decade—by more than 1 million barrels per day in the United States alone. If current trends continue, the United States will be importing more oil than ever by the mid-nineties. Meanwhile, the concentration of remaining petroleum reserves in the Persian Gulf grows ever more pronounced. By the late nineties, the United States and the United Kingdom are likely to be minor oil producers, a half-dozen Persian Gulf countries with at least 80 years' worth of remaining reserves will be back in control.[126]

These growing imbalances in the world oil market jeopardize the energy security of importing nations and the collective security of the world community. If Middle Eastern oil production reaches 80 percent of capacity—as it did in 1973 and 1979—it will take only a minor political or military conflict to send prices soaring. The increases that follow could well exceed those of the seventies. With world consumption now rising about 1 percent annually and production plummeting in the United States, the danger zone is likely to be reached in the mid-nineties.[127]

The only realistic means of avoiding another oil crunch in the nineties is to invest heavily in energy efficiency—largely in transportation. One change alone—the increase in the average fuel efficiency of American automobiles from 13.1 MPG in 1973 to 17.9 MPG in 1985—cut U.S. gasoline consumption by 20 billion gallons per year, lowering oil imports by 1.3 million barrels per day, two-thirds of the peak production from the rich oil fields of Alaska.[128]

Petroleum geologists agree that the United States is unlikely to find another oil field as large as Prudhoe Bay's, but the country could save

> "Improving worldwide efficiency by 2 percent annually would keep the world's temperature within 1 degree Celsius of current levels."

another 1.9 million barrels per day by the year 2000 by raising new-automobile fuel efficiency to 45 MPG in 1995, according to a study by Deborah Bleviss of the International Institute for Energy Conservation. In general, most countries should strive for a minimum 1 MPG annual improvement in the fuel economy of new cars.[129]

After a decade of control efforts, air pollution remains a growing problem in most cities. Improved efficiency has the potential to reduce emissions of most dangerous pollutants, though this depends to some degree on the technologies employed. A 1987 study by the American Council for an Energy-Efficient Economy concludes that increased energy efficiency could cut electricity consumption in the Midwest by 15-25 percent, making it possible to reduce use of the region's dirtiest coal-fired power plants and so limit acid rain. Because the efficiency savings are economical in their own right, the funds saved could be used to invest in additional pollution controls.[130]

Climate change looms as the ultimate environmental threat. Its impact would be global and, for all practical purposes, irreversible. Improving worldwide efficiency by 2 percent annually would keep the world's temperature within 1 degree Celsius of current levels, avoiding the most catastrophic climatic effects.[131]

Improving energy efficiency by 2 percent per year for several decades is challenging but feasible. Over 50 years it would reduce global energy intensity by almost two-thirds. Some industrial market countries have been achieving this rate during the past 15 years. Sustaining this pace through decades of fluctuating fuel prices will be a difficult task however, requiring major institutional changes. Fortunately, many of the needed technologies are already in place, and some countries are showing the way. Buildings worldwide must become as efficient as Sweden's and industry must become as efficient as Japan's. Automobiles must become as efficient as the best prototype models now found in the engineering facilities of Europe and Japan.

Priorities in energy efficiency vary among countries. Industry is the top priority in the Third World and centrally planned nations since it is the largest energy user and is a key determinant of both environmental quality and economic competitiveness. In industrial countries, this sector probably needs less government attention than others. Transportation efficiency is crucial for most countries. Improved automobile fuel economy could be accomplished with a package of consumer incentives for the purchase of more-efficient cars, fuel efficiency standards, industry R&D programs, and fuel taxes. Automobile fuel efficiencies will eventually reach some practical limits, at which point it will be important to have developed economical alternative fuels and be well on the way to more-efficiently designed communities that rely mainly on walking, bicycling, and mass transit.

In industrial market countries, buildings are the most wasteful energy users and deserve the greatest attention from government programs. Improvements already made in buildings there spare the atmosphere 225 million tons of carbon emissions annually, but heating, cooling, and lighting those buildings still pumps out over 900 million tons each year—17 percent of world carbon emissions from fossil fuels. Whereas the energy requirements of automobiles and industry could be halved with available technologies, building energy requirements can be reduced by 70 percent or more when new buildings are constructed. To sustain a 2-percent annual rate of improvement over the long run, building efficiency will have to compensate for diminishing returns in industry and transportation.[132]

The investments required to sustain a 2-percent rate of improvement in energy efficiency in the next decade or two can be justified on purely economic grounds. The world has achieved over $300 billion worth of annual energy savings since 1973, mostly as a result of private investment decisions. Each additional 2 percent of savings will reduce bills by about $20 billion annually. It is impossible to estimate how much has been invested in energy efficiency during this period, but even assuming a large payback, the annual investments in the early eighties must have reached at least $20–30 billion.[133]

In market economies, improved efficiency falls primarily to the private sector, which pays for the big ticket items such as home weatherization and the modernization of industrial equipment. However, governments must ensure that institutions and incentives are in place to encourage the needed investments.

The United States and the Soviet Union have pivotal roles to play in energy efficiency. The United States is the world's largest energy consumer, and led other nations into the profligate energy practices of the postwar period. The Soviet Union is the least energy-efficient major industrial country, and its claim on global energy resources is among the fastest growing. Together the two countries, with 10 percent of the world's population, account for 42 percent of the carbon now entering the atmosphere from fossil fuels. A joint commitment to improved energy efficiency by the superpowers would make a major contribution to climate protection, and might help mobilize action around the world.[134]

There are indications that the Soviet Union may soon make improved energy efficiency a national priority. Senior officials have gone on record as saying that efficiency gains will be essential if the country's economic restructuring is to be successful. Already, meetings have taken place with energy efficiency experts in the West, including representatives of the Rocky Mountain Institute and the U.S. National Academy of Sciences. Yevgeny Velikhov, vice president of the Soviet Academy of Sciences and an advisor to General Secretary Gorbachev, appears to have put his personal authority behind these new efforts.[135]

The Third World is also critical to any long-term energy scenario. Indeed, one of the most troubling features of recent forecasts is the assumption that industrial countries will continue to use a disproportionate share of the world's energy, despite the fact that developing countries will soon have three-quarters of the world's population. A 1981 study by the International Institute for Applied Systems Analysis was ostensibly attuned to global equity issues, yet it still assumed the Third World would use just 36 percent of the global energy supply in the year 2020.[136]

Such scenarios imply that while Third World energy use grows, per capita energy use will stagnate, presumably making it impossible for most developing countries to follow the modernization path taken by the newly industrializing nations in recent years. Although many developing nations are burdened with unmanageable foreign debt and have been priced out of the oil market, this is a morally intolerable vision, inconsistent with the articulated goals of the international community. Poverty-induced conservation is not conservation at all. It is just plain poverty.

One of the greatest challenges will be to meet the energy needs of the poor without repeating the mistakes of the rich. Only rapid advances in energy efficiency and a decentralized, agriculturally based development path can allow the Third World to fuel improved living standards with limited energy supplies. In the poorer countries of Africa and Latin America, the rapid onset of an energy efficiency revolution is critical. Some Asian countries, including China, with the world's largest coal reserves, have sufficient fossil fuels to last for many decades but face a critical environmental choice. Using energy efficiency to displace coal may be essential to protecting human health as well as the climate.

A global energy study developed by an international team and published by the World Resources Institute in Washington, D.C., points up both the challenge and the promise of increased energy efficiency in the Third World. (See Table 9.) It concludes that the world energy supply in the year 2020 can hover just above the current level if energy efficiency is employed both to halve per capita energy consumption in industrial countries and to keep Third World per capita energy use steady while boosting living standards to current European levels. Some of the most dramatic improvements in Third World efficiency are projected for rural areas, as fuelwood cooking systems are replaced by more-efficient devices run on renewable fuels.[137]

This scenario is consistent with the goal of improving energy efficiency by 2 percent annually. It would help foster greater equality in material living standards between industrial and developing countries. And it would make it possible to avoid the worst consequences of a global warming. But such scenarios are far easier to model on computers than to achieve in practice. Third World and industrial

Table 9: World Energy Consumption, by Region, 1980, with Scenarios for 2020

Region	1980	2020[1] WRI	2020[1] IIASA
		(terawatts)	
Developing Countries	3.3	7.4	9.2
Industrial Countries	7.0	3.8	14.6
World	10.3	11.2	23.8

[1]Scenarios developed by the World Resources Institute and the International Institute for Applied Systems Analysis, mid-range figures are given for the latter.

Source: José Goldemberg et al., *Energy for a Sustainable World* (Washington, D.C.. World Resources Institute, 1987).

countries alike will have to overcome political obstacles and begin ambitious efforts to improve energy efficiency.

To achieve its full potential, energy efficiency must emerge from the obscure corners of Energy Ministries and rise to the top of planning agendas throughout government and industry. The very term energy efficiency must be transformed from a watchword of specialists to a centerpiece of national—and international—economic philosophy. As an essential ingredient of economic and ecological progress, its status should be charted as closely as productivity or inflation. The Commission of the European Communities has suggested the need for such a commitment. At a 1986 meeting, national energy ministers agreed to a target of a 20-percent improvement in energy efficiency by 1995.[138]

Energy efficiency improvements are by nature fragmented and often unglamorous. Thicker insulation and ceramic auto parts are not perhaps as intrinsically captivating as nuclear fusion or orbiting solar collectors. But infatuation with grandiose energy supply options helped get us into our current predicament, focusing on the mundane may be the only way to get out. Indeed, perhaps no other endeavor is as vital to the goal of fostering sustainable societies. Without improved efficiency, it is only a question of which will collapse first. the global economy or its ecological support systems. With greater energy efficiency, we stand at least a fighting chance.

Notes

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