DOCUMENT RESUME

ED 327 374 SE 051 818

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TITLE Beyond the Petroleum Age: Designing a Solar Economy. Worldwatch Paper 100.
INSTITUTION Worldwatch Inst., Washington, D.C.
REPORT NO ISBN-1-878071-01-7
PUB DATE Dec 90
NOTE 67p.
AVAILABLE FROM Worldwatch Institute, 1776 Massachusetts Avenue, N.W., Washington, DC 20036 ($4.00).
PUB TYPE Viewpoints (120)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Alternative Energy Sources; *Conservation (Environment); *Depleted Resources; Energy Conservation; Environment; *Environmental Education; Fuels; Natural Resources; Pollution; Science Education; *Solar Energy; Wind (Meteorology)

ABSTRACT

Alternatives to fossil fuels as energy resources are discussed. Energy from the sun and other renewable resources are cited as the alternatives. Constructed is a practical energy scenario for the year 2030 that involves a 55-percent cut in carbon dioxide emissions, greatly improved energy efficie and an energy production system that relies heavily on solar energy, geothermal energy, wind power. and the energy of living plants. World petroleum resources in the Middle East and worldwide are described. Chapters include: (1) "The Next Energy Transition"; (2) "Power from the Sun"; (3) "A Policy Agenda"; (4) "Energy and Jobs"; and (5) "Toward a Solar Economy". (KR)

Beyond the Petroleum Age: Designing a Solar Economy

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Worldwatch Paper 100
December 1990

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Introduction

The end of the fossil fuel age is now in sight. As the world lurches from one energy crisis to another, fossil fuel dependence threatens at every turn to derail the global economy or disrupt its environmental support systems. If we are to ensure a healthy and prosperous world for future generations, only a few decades remain to redirect the energy economy.

Though it has fueled the economic boom of the past 40 years, petroleum is no longer a reliable source of energy. Three severe oil shocks in 17 years are a clear warning that the world cannot continue indefinitely along a path of petroleum dependence. The ultimate constraint is physical—oil supplies are finite—but the immediate limits are geographical and political: nearly two-thirds of the world's proven oil reserves are in the volatile Persian Gulf region.[1]

An even more fundamental limit on fossil fuel use is the atmosphere's capacity to cope with the burden of nearly 6 billion tons of carbon emissions each year. Scientists predict that these emissions will warm the atmosphere at an unprecedented rate, and may eventually undermine the economy itself. Combustion of all the world's remaining fossil fuels would raise the concentration of carbon dioxide as much as tenfold, compared with the mere doubling that now concerns scientists. Slowing global warming inevitably means placing limits on fossil fuel combustion.[2]

Since the mid-seventies, many countries have sought to redirect their energy policies. Most of these efforts were aimed at reducing depen-

The authors would like to thank Marnie Stetson for her invaluable assistance and W.U. Chandler, W.W Charters, M. Dayal, D Goldstein, M. Grubb, H.M Hubbard, S. Laitner, R.K. Pachauri, C. Weinberg, and C.-J. Winter for their reviews of drafts of this paper.

dence on oil, and initially were quite effective. World oil consumption fell during the early eighties, but then climbed in the late eighties as oil prices dropped and energy policies were abandoned. By 1990, oil demand was nearing the levels of the late seventies. Without renewed efforts, the use of oil will continue to grow in the future, making the world vulnerable to even minor political disruptions in the Middle East.

Since 1988, the world community has begun to consider more profound energy policy changes, focusing on limits to carbon dioxide emissions Some 15 countries have established goals, ranging from freezing emissions at current levels to cutting them by 50 percent. At the Second World Climate Conference, held in Geneva in November 1990, 137 nations agreed to draft a treaty by 1992 to slow global warming. While the details of the treaty remain to be determined, the world is now apparently headed toward a commitment to develop energy systems less dependent on fossil fuels.[3]

Initial efforts to stabilize the climate will focus largely on strategies to improve energy efficiency. Studies conducted in several countries have found that reducing energy use in buildings, factories, and transportation systems saves more money than it costs. Indeed, many rich nations could reduce their carbon dioxide emissions by as much as 20 percent over 15 years, while actually strengthening their economies.[4]

The more difficult question is, what comes next? Scientists have concluded that stabilizing the climate will ultimately require reducing global carbon dioxide emissions by 60 to 80 percent. The wealthy nations, which currently produce most of the carbon dioxide, would have to make even more dramatic cuts to allow for population and economic growth in the Third World. These changes imply the development of a far different energy system. But few political leaders have any notion of an economy not based on fossil fuels Indeed, the inability of societies to redirect their energy course is as much a failure of vision as a failure of policy.

Efforts by the energy establishment to map out such a course have been based on the mistaken assumption that future energy systems must follow a centralized, fossil-fuel-dependent path. The most recent meeting

"Stabilizing the climate will ultimately require reducing global carbon dioxide emissions by 60 to 80 percent."

of the World Energy Conference, a gathering of government officials and experts, concluded that energy needs three decades from now will be 75 percent higher than current levels, and will be met mainly by coal, oil, and nuclear power. While traditional energy planners may view such a future as logical, close examination raises doubts about its desirability or even feasibility.[5]

The World Energy Conference scenario would entail relying on Persian Gulf nations for more than two-thirds of the world's oil, compared with one-quarter today. It would lead to soaring carbon dioxide emissions and accelerated global warming. It would also require building three times as many nuclear plants as the world has so far, which would likely lead to more frequent nuclear accidents and growing stockpiles of nuclear waste and plutonium. And the growing scale of energy systems might well require tight police supervision and restrictions on public participation.[6]

Such a future is not only unattractive, it is now being decisively rejected by societies around the world. The people of Germany, for example, effectively stopped nuclear construction during the eighties, and those in the Soviet Union are doing the same. Coal-fired power plants have been ruled out in California, and the Indian government's efforts to build large new hydroelectric dams recently have met with massive public protest. Political leaders are realizing that people's concerns cannot be swept aside.[7]

In rejecting this course, we can begin to see some of the elements of an energy system that would be truly sustainable—not only in a global ecological sense, but in social and political terms as well. The most difficult challenge is to provide for this generation's needs safely and economically, without sacrificing the living standards of generations to come.

To stabilize the climate, the world soon will have to reduce its consumption of fossil fuels; this entails not only improving energy efficiency but also developing major new energy sources. Problem-plagued nuclear technologies clearly are not ready to play this role. Indeed, nuclear expansion has now come to a halt in many nations.

The alternative is as obvious as the sunrise: energy from the sun and other renewable resources. The technologies are at hand to greatly expand the use of renewable energy in the next few decades. We have
 constructed a practical energy scenario for the year 2030 that involves a 55-percent cut in carbon dioxide emissions, greatly improved energy efficiency, and an energy production system that relies heavily on solar energy, geothermal energy, wind power, and the energy of living plants. The year 2030 can be viewed as a mid-point in a long-term energy transition—enough time to develop major new energy systems, but not to eliminate fossil fuels entirely

The gradual transition to a solar-based economy would inevitably lead to the creation of entirely new industries and jobs Just as petroleum has helped shape today's society, so would a sustainable energy economy shape society in the future. Ultimately, new transportation systems will likely evolve, and cities become more compact and conveniently laid out. Agriculture would undoubtedly become less energy intensive, and many farms be transformed into producers of both food and energy The economy as a whole is likely to become gradually more decentralized.

The future, of course, is not something to be passively predicted but actively struggled for. The challenge ahead is partly technological: continuing to develop new methods of using energy efficiently and harnessing renewable resources economically. But the challenge is also political: overcoming narrow economic interests, and revamping policies to create sustainable energy systems We must start, however, with a conviction that such a future is possible The alternative is to risk a future of economic and ecological decline

The Next Energy Transition

As the 20th century comes to a close, powerful economic, social, and environmental forces are pushing the world toward a new energy system. Such major energy transitions have occurred before. Human societies first turned to water, wind, and wood to meet their energy needs, a pattern that prevailed until the 18th century. The Industrial Revolution, inaugurated by the invention of the steam engine, was fueled by coal.

"Not only is the world addicted to cheap oil, but the largest liquor store is in a very dangerous neighborhood."

Petroleum next became the main fuel of the world economy, starting early in the 20th century. The age of oil took several decades to mature, however. Even by 1950, world oil consumption was one-sixth the current level, with half of it being used in North America alone. Indeed, at that time, the petroleum economy had touched the lives of only a tiny fraction of humanity. Today, oil shapes economies the world over and is deeply enmeshed in many aspects of daily life, from travel to clothing.[8]

While oil dependence may seem inevitable and permanent, it could turn out to be shorter than the 200-year age of coal. Basic resource and environmental limits suggest that a transition away from oil will have to occur largely in the next few decades. Like the great energy transitions of the past, this one will be shaped by many different forces. In the immediate future, a chaotic oil market may do the most to alter global energy trends. When Iraq's tanks rumbled into Kuwait in August 1990, the world suffered its third oil shock in just 17 years. (See Figure 1.) The invasion, which immediately raised Iraq's share of world oil reserves from 10 to nearly 20 percent, caused a 170-percent increase in oil prices in three months and led to near panic in world financial markets.[9]

The forerunners of the most recent crisis were the failed energy policies that allowed both industrial and developing nations to increase their dependence on Middle Eastern oil in the late eighties. Since 1986, when oil prices fell back below $20 per barrel, the move toward more efficient homes, cars, and factories that began in the mid-seventies slowed to a crawl. As a result, world oil demand shot up by almost 5 million barrels per day, or nearly 10 percent.[10]

Virtually all the extra oil being consumed is supplied by a handful of countries in the Middle East, a region that faces the stresses of rapidly growing populations, autocratic political systems, rampant poverty, and a deadly arms race. Not only is the world addicted to cheap oil, but the largest liquor store is in a very dangerous neighborhood.

The uneven distribution of world petroleum resources is growing more lopsided all the time. While the Persian Gulf countries had 55 percent of proven global reserves in 1980, by 1989 that figure had climbed to 65 percent—almost all the major oil discoveries during the past decade

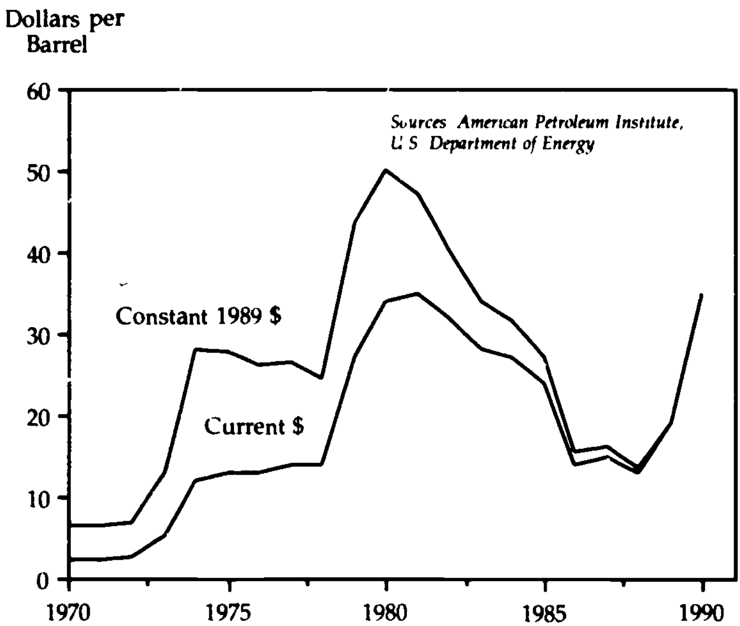

Figure 1: World Price of Oil, 1970–1990

occurred in that region. (See Table 1.) Most of the nations in the Persian Gulf have at least 100 years of proven reserves left at current extraction rates, compared with less than 20 years' worth in Europe, North America, and the Soviet Union.[11]

Outside the Middle East, much of the cheap oil has already been consumed. Production by the Soviet Union and the United States is now declining. The U.S. fall is hardly surprising; the country's heavily exploited oil fields have only 4 percent of global reserves while still accounting for 12 percent of world production. Whereas the average oil well in Saudi Arabia produces 9,000 barrels per day, the average well in the United States yields 15. The Soviet Union also appears poised for a

Table 1: World Oil Reserves by Region, 1980 and 1989

Region	Oil Reserves 1980	Oil Reserves 1989	Share of 1989 Reserves	Reserves Remaining at 1989 Production Rates
	(billion barrels)		(percent)	(years)
Middle East	362	660	65	110
Latin America	70	125	12	51
Soviet Union & East. Europe	66	60	6	13
Africa	55	59	6	28
Australasia	40	47	5	20
North America	39	42	4	10
Western Europe	23	18	2	13
TOTAL	655	1,011	100	44

Source: British Petroleum *BP Statistical Review of World Energy* (London various years)

steep production decline as it seeks to cut its excessive spending in the petroleum sector. Infusions of Western money and technology could slow the fall but are unlikely to stop it entirely.[12]

If the past is any guide, the nations of the Persian Gulf are in no position to provide a steady long-term supply of oil. To rely increasingly on them would set the stage for an unending series of economic crises and oil wars. Developing countries with large debt burdens are particularly vulnerable to a continuation of the oil-price roller coaster. India, for example, was forced to cut its oil consumption by a remarkable 25 percent as prices skyrocketed in late 1990.[13]

Oil-consuming nations therefore face the imperative of reducing their petroleum dependence. The question is, how much? Current oil use per person averages 4.5 barrels a year worldwide, ranging from 24 barrels in the United States to 12 in Western Europe and less than 1 in sub-Saharan Africa. As supplies run short and prices rise, world oil consumption will likely fall over the coming decades. Given these constraints, it seems doubtful that world oil output will exceed 30 million barrels per day—one-half the current level--by the year 2030. With projected population increases, this would allow for an average of just 1.2 barrels per person a year, implying extensive changes in the world energy economy.[14]

The capacity of the global biosphere to absorb the emissions of a fossil-fuel-based economy will in the end prove even more constraining than the limits posed by oil. Nearly 6 billion tons of carbon are spewed into the air each year in the form of carbon dioxide, a greenhouse gas building steadily in the atmosphere and gradually heating the planet. Despite public attention to the problem of global warming in recent years, the amount of carbon released annually has risen by 400 million tons since 1986—exactly the opposite of what many scientists believe is necessary. While carbon emissions growth has moderated somewhat in the rich countries, it has surged in the Third World. (See Figure 2.)[15]

A scientific study released in 1990 by the United Nations-commissioned International Panel on Climate Change confirmed that a rapid and highly disruptive increase in global temperatures would likely occur unless emissions are cut. Upon releasing the report, Dr. John Houghton, head of the British Meteorological Service, noted that it represented "remarkable consensus," with fewer than 10 of 200 scientists dissenting. Although greenhouse gas concentrations rise slowly, future climate disruptions are likely to be abrupt and catastrophic.[16]

Although major cuts in carbon dioxide emissions will take decades, the long-term goals will be far more difficult to achieve if the first steps are not taken soon. Some 15 nations and the European Community as a whole have taken this message to heart. They have begun to limit their emissions of carbon dioxide—and, by implication, their use of fossil fuels. (See Table 2.) The leader is Germany, which aims to cut emissions within the former West Germany by 25 percent over the next 15 years.[17]

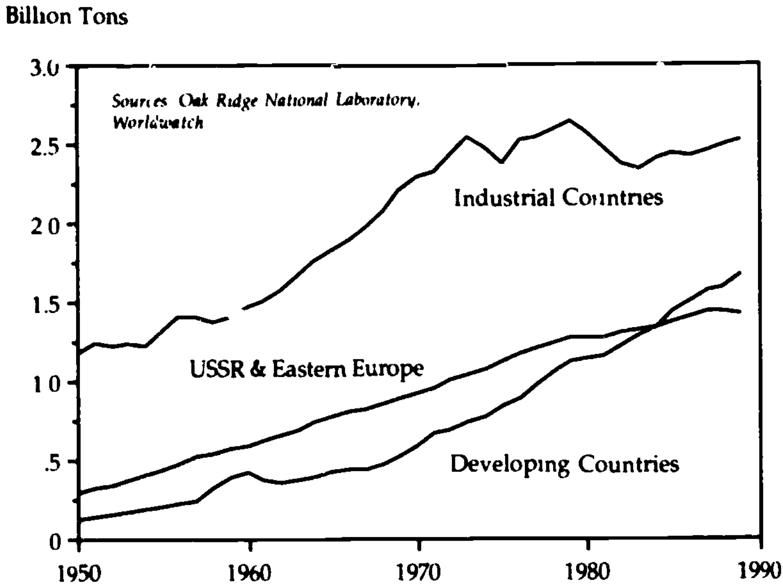

Figure 2: Carbon Emissions from Fossil Fuels, 1950–1989

Yet in order to stabilize the atmospheric concentration of carbon dioxide, scientists believe global emissions eventually must be cut by 60 to 80 percent. This must be the long-term goal of any society that wishes to ensure its survival. It may be difficult to fully achieve such an objective during the next 40 years, but climate stability demands movement in that direction. Our proposed carbon budget for the year 2030 is 2.5 billion tons—roughly a 55-percent cut from current levels.[18]

A world that produces 2.5 billion tons of carbon a year will be far different from one that produces nearly 6 billion. (See Table 3.) Per capita carbon emissions 40 years from now would need to be one-fourth the

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Table 2: National Climate Policies, Proposed or Enacted, October 1990

Nation	Goal	Status
Australia	Reduce greenhouse gas emissions 20 percent from 1988 level by 2005	Commission is studying cost-effective measures
Austria	Reduce CO_2 emissions 20 percent by 2005	Commission to study policy options, including improved efficiency
Canada	Freeze CO_2 emissions at 1990 level by 2000	Task force to report recommended policies in November 1990
Denmark	Reduce CO_2 emissions 20 percent by 2005, 50 percent by 2020-2040	Energy plan approved with focus on efficiency, renewables, natural gas, energy taxes and transportation
France	Freeze CO_2 emissions near 1990 per capita level	No specific policies announced
Germany[1]	Reduce CO_2 emissions 25 percent from 1987 level by 2005	Action plan presented in November 1990, to include energy policy reforms and possible carbon tax
Japan	Freeze CO_2 emissions at 1990 level by 2000	Program announced that includes efficiency, transport, nuclear energy, and renewables
Netherlands	Freeze CO_2 emissions at 1990 level by 1995, followed by reduction	Plan adopted that includes efficiency, renewables, natural gas, carbon tax and transportation reforms
New Zealand	Reduce CO_2 emissions 20 percent by 2005	Government agencies are developing policies
Norway	Freeze CO_2 emissions at 1989 level by 2000	Commission to recommend new policies in January 1991
Sweden	Freeze CO_2 emissions at 1988 level by 2000	Carbon tax will start in January 1991, parliament debating further policies
Switzerland	Reduce CO_2 emissions 10 percent by 2000	Program announced for carbon tax, efficiency, and transport reform
United Kingdom	Freeze CO_2 emissions at 1990 level by 2005	Government paper calls for efficiency, renewables, and transport reforms

[1]German goal is for the former West Germany. Reduction goals for the former East Germany are being assessed

Source: Worldwatch Institute, based on various sources

Table 3: World Energy Use and Carbon Emissions, 1989, with Goals for 2030

Energy Source	1989 Energy (mtoe[1])	1989 Carbon (million tons)	2030 Energy (mtoe[1])	2030 Carbon (million tons)
Oil	3,098	2,393	1,500	1.160
Coal	2,231	2,396	240	430
Natural Gas	1,707	975	1,750	1,000
Renewables[2]	1,813	*	7,000	*
Nuclear[2]	451	*	0	0
TOTAL	9,300	5,764	10,490	2,590

[1]Million tons of oil equivalent.
[2]Under certain circumstances, both renewable energy and nuclear energy can result in net positive carbon emissions

Source: Worldwatch Institute, based on British Petroleum, *Statistical Review of World Energy* (London. 1990), J M O Scurlock and D O Hall, "The Contribution of Biomass to Global Energy Use," *Biomass*, No. 21, 1990, Gregg Marland et al., *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nations Energy Statistics and the U S Bureau of Mines Cement Manufacturing Data* (Oak Ridge, Tenn . Oak Ridge National Laboratory, 1989)

level in Western Europe today, given inevitable growth in world population over the next few decades. These are stringent targets, since fossil fuels now account for 75 percent of world energy supplies. An annual carbon budget of 2.5 billion tons can be met only if the use of coal, the most carbon-intensive fossil fuel, is cut by about 90 percent. Small amounts of coal would still be burned in countries such as China and

India, which have large populations and limited reserves of other fossil fuels. Oil shale and synthetic fuels derived from coal can be ruled out entirely due to their high carbon content.[19]

For most nations, natural gas will likely be the predominant fossil fuel, as it produces roughly twice as much energy per kilogram of carbon released as coal does. Natural gas resources are also believed to be much larger and better distributed than those of oil. While current proven reserves are mostly in the Soviet Union and the Middle East, many parts of the world have not been thoroughly searched for natural gas. Gas resources are sufficiently large that, 40 years from now, this fuel could still be producing as much energy as it does today.[20]

In a world with an energy system that is truly sustainable—economically and socially—nuclear power may not be a major source of energy. During the past 10 years, the pace of nuclear expansion has slowed almost to a halt in many countries. All existing reactors are scheduled to be retired within the next 40 years, and unless fundamental problems are resolved, it seems likely that most will not be replaced. The reasons for nuclear power's decline are high costs, inadequate safety margins, absence of permanent nuclear waste storage facilities, and proliferation of materials that can be used to manufacture nuclear weapons.[21]

Resolving all of these problems may or may not be possible, but it would take at least several decades to restore public confidence in this energy source. That makes nuclear power far too problematic to be considered seriously in a 40-year energy scenario. Another proposed new energy technology—nuclear fusion—will take a minimum of 50 years to reach widespread commercial use, according to its proponents.[22]

Although many of the details of a sustainable energy system are debatable, one point is clear: such a system is possible only if energy efficiency is vastly improved. This is because no future energy source is likely to be as cheap as oil has been. Overall, the world will have to produce goods and services with one-third to one-half as much energy as now. The 21 industrial market nations that belong to the International Energy Agency have lowered their energy use per unit of gross national product 24 percent since 1973, and opportunities for further improvement

"Over the next 30 years, industrial countries could reduce their energy use per capita by at least half without harming their economies."

abound. The Soviet Union, Eastern Europe, and developing countries have an even larger untapped potential for efficiency gains.[23]

Technologies are already available that could quadruple the efficiency of most lighting systems and double the fuel economy of new cars. Efficiency improvements in areas such as lighting, electric motors, and appliances could reduce the need for power by 40 to 75 percent—at less than half the cost of power from new generating plants. Heating and cooling needs of buildings could be cut even further through improved furnaces and air conditioners, as well as better insulation and windows. Over the next 30 years, industrial countries could reduce their energy use per capita by at least half without harming their economies. In developing countries, improved efficiency could allow energy consumption per capita to remain constant or increase modestly while their economies grow.[24]

Even with improved efficiency, total energy needs in 2030 are likely to remain similar to those today because of growing populations and economies. To meet these needs and achieve a two-thirds cut in carbon emissions, the world will need to quadruple its renewable energy output. This would entail expanding the use of energy from biomass (biological sources such as wood or agricultural wastes) and hydropower, but more importantly would require large contributions from solar, wind, and geothermal sources. The technologies to harness these resources are now ready for widespread use—if they receive effective support in the years ahead.[25]

Power from the Sun

Renewable energy resources are actually far more abundant than fossil fuels. The U.S. Department of Energy estimates that the annual influx of accessible renewable resources in the United States, for example, is more than 200 times its use of energy, and more than 10 times its recoverable reserves of fossil and nuclear fuels. Harnessing these resources will inevitably take time, but according to a new study by U.S. government scientific laboratories, renewables could supply the equivalent of 50 to 70 percent of current U.S. energy use by the year 2030.[26]

Contrary to popular belief, renewables—primarily biomass and hydropower—already supply about 20 percent of the world's energy. Biomass alone meets 35 percent of developing countries' total energy needs, though often not in a manner that is renewable or sustainable in the long term. And in certain industrial countries, renewables play a central role: Norway, for example, relies on hydropower and wood for more than 50 percent of its energy.[27]

Steady advances have been made since the mid-seventies in a broad array of new energy technologies that will be needed if the world is to greatly increase its reliance on renewable resources. Indeed, many of the machines and processes that could provide energy in a solar economy are now almost economically competitive with fossil fuels. Further cost reductions are expected in the next decade as these technologies continue to improve. (See Table 4.) As leading solar scientists, Carl Weinberg and Robert Williams, wrote in *Scientific American*: "Electricity from wind, solar-thermal and biomass technologies is likely to be cost-competitive in the 1990s; electricity from photovoltaics and liquid fuels from biomass should be so by the turn of the century." The pace of deployment, however, will be determined by energy prices and government policies. After a period of neglect in the eighties, many governments are now supporting new energy technologies more effectively, which may signal the beginning of a renewable energy boom in the years ahead.[28]

Direct conversion of solar energy will likely be the cornerstone of a sustainable world energy system. Not only is sunshine available in great quantity, it is more widely distributed than any other energy source. Solar energy is especially well suited to supplying heat at or below the boiling point of water (used largely for cooking and heating), which accounts for 30 to 50 percent of energy use in industrial countries and even more in the developing world. A few decades from now, societies may use the sun to heat most of their water, and new buildings may take advantage of natural heating and cooling to cut energy use by more than 80 percent.[29]

Solar rays are free and can be harnessed with minor modifications in building construction, design, or orientation. In Cyprus, Israel, and

Table 4: Costs of Renewable Electricity, 1980–2030[1]

Technology	1980	1988	2000	2030
		(1988 cents per kilowatt-hour)		
Wind	32[2]	8	5	3
Geothermal	4	4	4	3
Photovoltaic	339	30	10	4
Solar Thermal				
trough with gas assistance	24[3]	8[4]	6[5]	—[6]
parabolic/central receiver	85[7]	16	8	5
Biomass[8]	5	5	—	—

[1]All costs are levelized over the expected life of the technology and are rounded, projected costs assume return to high government R&D levels [2]1981 [3]1984 [4]1989. [5]1994 [6]Estimates for 2030 have not been determined, primarily due to uncertainty in natural gas prices [7]1982 [8]Future changes in biomass costs are dependent on feedstock cost

Source: Worldwatch Institute, based on Idaho National Engineering Laboratory et al , *The Potential of Renewable Energy An Interlaboratory White Paper*, prepared for the Office of Policy, Planning and Analysis, U S Department of Energy, in support of the National Energy Strategy (Golden, Colo Solar Energy Research Institute, 1990), and other sources

Jordan, solar panels already heat between 25 and 65 percent of the water in homes. More than 1 million active solar heating systems, and 250,000 passive solar homes, which rely on natural flows of warm and cool air, have been built in the United States. Advanced solar collectors can produce water so hot—200 degrees Celsius—that it can meet the steam needs of many industries. Indeed, using electricity or directly burning fossil fuels to heat water and buildings may become rare during the next few decades.[30]

Solar collectors, along with other renewable technologies, can also turn the sun's rays into electricity. In one design, large mirrored troughs are used to reflect the sun's rays onto an oil-filled tube that produces steam for an electricity-generating turbine A southern Californian company, Luz International, generates 354 megawatts of power with these collectors and has contracts to install an additional 320 megawatts. The newest version of this "solar thermal" system turns 22 percent of the incoming sunlight into electricity. Spread over 750 hectares, the collectors produce enough power for about 170,000 homes for as little as 8¢ per kilowatt-hour, already competitive with generating costs in some regions.[31]

Future solar thermal technologies are expected to produce electricity even more cheaply. Parabolic dishes follow the sun and focus sunlight onto a single point where a small engine that converts heat to electricity can be mounted, or the energy transferred to a central turbine. Since parabolic dishes are built in moderately-sized, standardized units, they allow for generating capacity to be added incrementally as needed. By the middle of the next century, vast areas of arid and semiarid countryside could be used to produce electricity for export to power-short regions.[32]

Photovoltaic or solar cells, which convert sunlight into electricity directly, almost certainly will be ubiquitous by 2030. These small, modular units are already used to power pocket calculators and to provide electricity in remote areas. Within a generation, solar cells could be installed widely on building rooftops, along transportation rights-of-way, and at central generating facilities. A Japanese company, Sanyo Electric, has incorporated them into roofing shingles.[33]

Over the past two decades, the cost of photovoltaic electricity has fallen from $30 a kilowatt-hour to just 30¢. The forces behind the decline are steady improvement in cell efficiency and manufacturing, as well as a demand that has more than doubled every five years. These cost reductions mean that in rural areas, pumping water with photovoltaics is already often cheaper than using diesel generators. Solar cells are also the least expensive source of electricity for much of the rural Third World; more than 6,000 villages in India now rely on them, and Indonesia and Sri Lanka also have initiated ambitious programs.[34]

> **"In rural areas, pumping water with photovoltaics is already often cheaper than using diesel generators."**

Photovoltaics, because of their lower projected cost, might eventually take over the central generating role of solar thermal power. By the end of this decade, when solar cell electricity is expected to cost 10¢ a kilowatt-hour, some countries may be turning to photovoltaics to provide power for well-established grids. By 2030, photovoltaics could provide a large share of the world's electricity—for as little as 4¢ a kilowatt-hour.[15]

Another form of solar energy, wind power, captures the energy that results from the sun's unequal heating of the earth's atmosphere. Electricity is generated by propeller-driven mechanical turbines perched on towers located in windy regions. The cost of this source of electricity has fallen from more than 30¢ a kilowatt-hour in the early eighties to a current average of just 8¢. By the end of the nineties, the cost is expected to be around 5¢. Most of the price reductions have come from experience gained in California, which accounts for nearly 80 percent of the world's wind-produced electricity. Denmark, the world's second-largest wind energy producer, received about 2 percent of its power from wind turbines in 1990.[16]

Wind power has a huge potential. It could provide many countries with one-fifth or more of their electricity. Some of the most promising areas are in northern Europe, northern Africa, southern South America, the U.S. western plains, and the trade wind belt around the tropics. A single windy ridge in Minnesota, 160 kilometers long and 1.6 kilometers wide, could be used to generate three times as much wind power as California gets today. Even more productive sites have been mapped out in Montana and Idaho.[17]

Living green plants provide another means of capturing solar energy. Through photosynthesis, they convert sunlight into biomass that, burned in the form of wood, charcoal, agricultural wastes, or animal dung, is the primary source of energy for nearly half the world—about 2.5 billion people in developing countries. Sub-Saharan Africa derives some 75 percent of its energy from biomass, most of it using primitive technologies and at considerable cost to the environment.[18]

Many uses of bioenergy will undoubtedly increase in the decades ahead, though not as much as some enthusiasts assume. Developing nations will need to find more sophisticated and efficient means of using biomass to meet their rapidly increasing fuel needs. With many forests and croplands already overstressed, and with food needs competing for agricultural resources, it is unrealistic to think that ethanol distilled from corn can supply more than a tiny fraction of the world's liquid fuels. And shortages of irrigating water may complicate matters, especially in a rapidly warming world.[39]

In the future, ethanol probably will be produced from agricultural and wood wastes rather than precious grain. By employing an enzymatic process, rather than inefficient fermentation, scientists have reduced the cost of wood ethanol from $4 a gallon to $1.35 over the past 10 years, and expect it to reach about 60¢ a gallon by the end of the nineties. Within a few decades, however, liquid fuel from biomass will be at a premium as oil production declines.[40]

More efficient conversion of agricultural and forestry wastes to energy could boost biomass energy's role in the future, particularly in developing countries already reliant on this source. Wood stoves that double or treble today's efficiency levels already exist, and better designs are under development. For modular electricity generation, highly efficient gas turbines fueled by biomass can be built even at a very small scale. Some 50,000 megawatts of generating capacity, 75 percent of Africa's current total, could come from burning sugarcane residues alone. In the future, integrated farming systems, known as agroforestry, could produce fuel, food, and building materials.[41]

Hydropower now supplies nearly a fifth of the world's electricity. Although there is still ample growth potential, particularly in developing countries, environmental constraints will greatly limit such development. Small-scale projects are generally more promising than the massive ones favored by governments and international lending agencies. Smaller dams and reservoirs cause less social and ecological disruption. In deciding which hydropower resources to develop, issues such as land flooding, siltation, and human displacement will play an important role. These considerations will likely keep most nations from exploiting all of their potential.[42]

Another important element of a renewable-based energy system is geothermal energy—the heat of the earth's core. This is not strictly a renewable resource, however, and it needs to be carefully tapped so as not to deplete the local heat source. Since geothermal plants can produce power more than 90 percent of the time, they can provide electricity when there is no sun or wind.

Geothermal resources are localized, though found in many regions. Worldwide, more than 5,600 megawatts' worth of geothermal power plants have been built. El Salvador gets 40 percent of its electricity from the earth's natural heat, Nicaragua 28 percent, and Kenya 11 percent. Most Pacific Rim countries, as well as those along East Africa's Great Rift Valley and around the Mediterranean, could tap geothermal energy. Virtually the entire country of Japan, for example, lies over an enormous heat source that one day could meet much of the country's energy needs.[43]

While fossil fuels have been in storage for millions of years, renewable energy is in constant flux—replenished as the sun shines. While not a constraint in the near future, the intermittent nature of sunshine and wind means that the large-scale use of renewables will need to be backed by some form of energy storage. Indeed, biomass energy and hydropower are the only forms that can be stored easily. Developing new and improved storage systems is therefore one of the key challenges in building a sustainable energy economy.

Heat below the boiling point of water can be stored in simple devices that rely on water, bedrock, oil, or salt. Thermal storage systems pump heat captured on sunny summer days through these substances, and then extract the heat when it is needed, such as on a cold winter night. Such systems can recover as much as 85 percent of the heat originally captured. Already, some 30 large solar-storage installations have been built in Europe, including 10 district heating systems in Sweden. District heating traditionally employs a central fossil-fuel-burning plant that delivers steam or hot water to neighboring buildings; the Swedish plants, however, use stored sunlight to supply heat to nearby schools, office buildings, and apartments.[44]

Storing electricity is a greater challenge. Pumped hydroelectric storage systems—which elevate water to a reservoir, then drop it through a turbine to produce electricity—are now used in some regions. Though their use is growing, pumped storage systems will likely be limited by the availability of sites and by environmental objections to dam building. Another less disruptive alternative is a storage system that uses electricity to compress air into an underground reservoir. When power is needed, the air is released, heated up, and forced through a turbine. As with pumped-hydro, compressed-air storage systems can achieve about 70-percent efficiency. A 290-megawatt system is already operating in Germany. Another technology, superconducting magnets, could offer highly efficient and inexpensive electricity storage, according to scientists, but it will not be ready for at least several decades.[45]

Battery storage is a more flexible alternative. Home photovoltaic panels can be hooked up to batteries, as can utility-scale wind or solar plants. Batteries could also play a role in transportation, without greatly increasing electricity demand. If electric cars were used for one-quarter of U.S. auto travel, total electricity use would rise only 7 percent. At today's electricity prices, electric cars are already competitive with gasoline-driven ones in terms of fuel price. The challenge is to reduce the cost and extend the range of batteries beyond the current limit of 125 kilometers. During the early nineties, several major auto companies are scheduled to introduce electric vehicles.[46]

Several new batteries are being developed. One cell that has been tested, the sodium sulfur battery, is more efficient, more compact, longer lasting, and lighter than current lead-acid models. But it requires further improvements before commercial use, including cheaper ways to keep the battery hot enough to function properly.[47]

Hydrogen is the strongest candidate for large-scale storage. It is the cleanest burning fuel, producing only water vapor and small amounts of nitrogen oxides. These emissions can be reduced with lower combustion temperatures and nearly eliminated with specially designed catalytic converters. Hydrogen also can be burned in place of petroleum, coal, or natural gas.[48]

The chemical industry currently produces hydrogen from fossil fuels,

"If electric cars were used for one-quarter of U.S. auto travel, total electricity use would rise only 7 percent."

t it can also be made by electrolysis splitting water molecules into hydrogen and oxygen with an electric current. German and Saudi engineers are developing electrolysis systems powered by electricity from photovoltaic cells Proponents of solar hydrogen envision huge desert photovoltaic farms connected by pipelines to cities. Hydrogen can be stored in metal hydrides—metal powders that naturally absorb gaseous hydrogen, and release it when heated—or in pressurized tanks or underground reservoirs, thus providing a readily accessible form of energy.[49]

Hydrogen can also be used to generate electricity without producing nitrogen oxides by chemically combining it with oxygen in a fuel cell Hydrogen fuel cells are 70-percent efficient and could be used in hydrogen-powered electric cars. Internal combustion engines, by comparison, rarely convert even 25 percent of gasoline to usable energy, while standard power plants operate at about 35-percent efficiency[50]

The shape of a renewable energy system is beginning to emerge. What stands out is the enormous abundance and versatility of the available resources. It seems certain that the mix of technologies used in a solar economy would be diverse; the energy sources harnessed would vary with the climate and natural resources of each region. Northern Europe, for example, would probably rely on a mixture of wind, biomass, solar, and hydropower, while northern Africa and the Middle East would depend more on direct sunlight. Wood, agricultural wastes, sunshine, and geothermal energy would likely provide energy throughout Southeast Asia.

No completely new technologies are needed to bring this transformation about, only modest, achievable advances in those already in use or under development. Unlike nuclear power plants, each of which takes 6 to 10 years to build, renewable energy technologies are generally small and modular, and can evolve rapidly in a single decade. Renewable energy is already well ahead of fusion energy technologies, for example, which have received several billion dollars of government funds without producing even a detailed design for a workable power plant.[51]

Vastly improved energy efficiency—along with being intrinsically important in any effort to move away from fossil fuels—is the key to

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making a sustainable energy system work. If a home's electricity needs are cut by two-thirds, for example, the investment cost for a rooftop photovoltaic power plant could be halved. Similarly, a highly efficient electric car would go further and would need smaller batteries than a less efficient one, reducing its cost and weight. Thus, the development of more energy-efficient technologies is as crucial to the viability of an economy based on renewable energy as the solar technologies themselves.

One significant aspect of a renewable energy system is that it must be built virtually from scratch in every country. Although the rich nations will have an obvious advantage in terms of technical knowledge and investment capital, developing countries in many cases have extensive renewable energy resources, and will have lower conversion costs. Renewable energy will also help protect developing countries from the devastating fluctuations in the world oil market that have so complicated their development plans in recent years.

A Policy Agenda

The technologies are at hand to initiate an historic energy transition, but formidable barriers remain. The largest obstacles are political and institutional. Carl Weinberg, the director of research and development at the Pacific Gas and Electric Company, the largest U.S. electric utility, notes: "The rules of the present energy economy were established to favor systems now in place. Not surprisingly, the rules tend to be biased against solar energy." Most of these rules were created decades ago, when the central issue was how to expand fossil fuel use rapidly. Hastening the transition to a sustainable energy economy requires a major shift in priorities—a shift that existing institutions and industries may find threatening.[52]

The process of dismantling outdated energy policies began in the seventies in response to two major oil crises. The reforms proceeded haltingly during the eighties, encouraged by growing awareness of environmental problems but slowed by declining oil prices. Nonetheless, many needed changes are beginning to appear—occasionally with startling success. The first step has already been taken by 15

"Governments routinely provide inappropriate subsidies to traditional energy sources."

industrial countries: the adoption of national goals to limit the production of carbon dioxide, the major greenhouse gas, while meeting energy needs economically and with minimal environmental damage.

Such goals can provide the basis for a wholesale reordering of energy priorities, so as to redirect government policies to improve energy efficiency and expand the use of renewable energy. While needed policy changes number in the hundreds, this paper focuses on four priorities: reducing subsidies for fossil fuels and raising their taxes to reflect security and environmental costs; increasing research and development of efficiency and renewable energy technologies; reforming the electric utility industry; and strengthening state and local energy policies. The expansion of natural gas use is another priority, but will occur even without major policy changes.

Energy price reform is a prerequisite to the development of a sustainable energy system. Today, governments routinely provide inappropriate subsidies to traditional energy sources, keeping prices artificially low and encouraging energy waste. Among the worst examples are China, where coal costs about one-quarter the world market price, and the Soviet Union, where oil is still traded among state companies for less than $1 a barrel. Market reforms in the centrally planned countries may provoke changes in these policies. The price of Soviet oil, for example, is scheduled to triple in 1991.[53]

In the industrial market countries, smaller but still pernicious subsidies exist. Energy industries in the United States received federal subsidies worth more than $44 billion in 1984 (the most recent data available). President Bush's successful 1990 effort to gain $2.5 billion in additional tax breaks for the U.S. oil and gas industry is a recent example of the special treatment still received by entrenched industries.[54]

As subsidies are removed, governments can also take steps to ensure that fossil fuel prices reflect their full security and environmental price tag. The cost of deploying armed forces in the Persian Gulf, for example, is not now being paid by consumers of Middle Eastern oil. Counting the cost of U.S. preparations for war in the region, even before the 1990 troop deployment, for example, would add more than $60 to each barrel of oil imported into the country, according to Alan Tonelson and Andrew Hurd of the Economics Strategy Institute, in Washington, D.C. The U.S. military response to Iraq's invasion has a projected additional price tag of $10 to $20 billion for the first six months alone.[55]

Fossil fuel burning is exacting an even larger cost on the health of people and ecosystems around the globe. In the United States, air pollution from automobiles, for example, is estimated to add more than $40 billion to annual medical bills, according to the American Lung Association. Including such costs in the price of energy would allow markets to more accurately determine the least expensive means of meeting energy needs. Governments could accomplish this by taxing energy to incorporate environmental costs into the price paid by consumers.[56]

A 1990 study by researchers at Pace University, in White Plains, New York, reviewed various estimates of the environmental costs of electricity technologies. The study found that electricity from coal would need to be priced at least 100 percent higher to cover its environmental costs, chiefly those resulting from air pollution-related damage. Oil-generated electricity would need to rise at least 50 percent, and natural gas much less.[57]

Seventeen U.S. states are already incorporating environmental costs in their regulation and planning of electric utilities, though at levels far below those that might be justified. European countries are also beginning to account for the costs of pollution, primarily through increased taxes. Sweden, for example, proposed taxing sulfur and nitrogen oxide emissions in April 1990; the following month, France instituted a tax on sulfur dioxide emissions. Italy started taxing low-sulfur fuels at half the rate of high-sulfur fuels in July 1990.[58]

Energy taxes are another effective policy tool. Most countries already tax energy, though the levels vary widely. The most popular energy tax is on gasoline. In Europe and Japan, gasoline taxes now range from $1.44 to $3.56 per gallon, resulting in total retail prices of $4 to $5 per gallon in some countries. (See Table 5.) In the United States, however, the combined federal and state tax averages just 30¢ per gallon, and is scheduled to rise modestly to 35¢ per gallon in December 1990. The inability of the United States to levy a higher gasoline tax is both a stim-

Table 5: Gasoline Prices and Taxes, Selected Countries, October 1990

Nation	Price (including tax)	Tax	Equivalent Carbon Tax[1]
	(dollars/gallon)		(dollars/ton of carbon)
United States	1.32	.30	121
Japan	3.44	1.44	575
Germany	3.52	1.97	787
United Kingdom	3.71	2.08	833
France	4.32	2.95	1,181
Italy	5.19	3.56	1,423

[1]Current gasoline taxes translated into a levy on the carbon content of fuel.

Sources: Karen Treanton, Statistics Department, International Energy Agency, Paris, private communication and printout, November 2, 1990; Carbon content of gasoline from Gregg Marland, "Carbon Dioxide Emission Rates for Conventional and Synthetic Fuels," *Energy*, Vol 8, No 12, 1983.

ulus for the country's energy waste and a contributor to its huge federal budget deficit.[59]

Another way of reflecting environmental costs is a broader energy tax linked to emissions of carbon dioxide. Such a tax would directly incorporate the anticipated costs of global warming in the prices paid for energy. Under such a levy, coal would be taxed the heaviest, since it releases the most carbon dioxide when burned, followed by oil, and finally natural gas. Nuclear power and renewable energy sources, which do not release carbon dioxide directly, would go untaxed. A reasonably high carbon tax could greatly accelerate the deployment of energy-efficient and renewable energy technologies.

Carbon taxes are fast becoming a reality in Europe. Finland introduced such a tax in January 1990, the Dutch government followed in February, and Sweden will levy one in January 1991. Germany, Norway, and Switzerland are also weighing carbon taxes. While most of the taxes proposed so far are relatively small, a larger tax of at least $100 per ton of carbon would be needed to significantly affect energy trends. A $100-per-ton tax, if adopted worldwide, would raise more than $500 billion per year, the bulk of it from industrial countries. While this may seem like a huge sum, most countries already tax gasoline at an effective rate of more than $100 per ton. Indeed, Italy's current gasoline tax is equivalent to a carbon tax of more than $1,400 per ton.[60]

Some analysts argue that energy taxes will lead to economic chaos, noting that higher energy prices in 1973 and 1979 had a devastating effect. But as Harvard economist Dale Jorgenson has shown, two-thirds of the economic slowdown after the oil shocks of the seventies was caused by the speed of the energy price increases. If price rises are gradual, as planned in most carbon tax proposals, the threat of an energy-price-induced recession can be removed. Indeed, European countries and Japan already have energy taxes far greater than those in the United States, yet their economies are, if anything, stronger.[61]

One energy model examined by the U.S. Congressional Budget Office found that a slowly phased-in $110-per-ton carbon tax would reduce carbon emissions 27 percent from 1988 levels by the year 2000, and reduce the country's economic output that year by less than 1 percent. Another analysis, by William Chandler of Pacific Northwest Laboratories in Washington, D.C., concluded that a $94-per-ton carbon tax would hold carbon emissions at today's level by the year 2000. Such a tax could actually boost economic output if it were used to offset other taxes, and if cost-effective investments in energy efficiency were the main response to the higher prices.[62]

Changing energy prices will not remove all the barriers to a sustainable energy economy, however. Basic reforms of energy institutions and industries are a second priority—particularly the publicly owned or regulated electric utilities. These companies were set up to create large electric power systems rapidly from scratch, and they mainly succeeded: electricity now represents roughly one-third of the world's primary energy supply. Whether privately owned, as in the United States, or state-owned, as in France and India, these utility monopolies are now anachronistic. At a time when the world needs to use electricity more

"Italy's current gasoline tax is equivalent to a carbon tax of more than $1,400 per ton."

efficiently and develop new and cleaner ways to generate power, major reforms are in order.[63]

Since the early eighties, a growing number of countries have begun to rebuild their electric utility systems in a more flexible, decentralized, and competitive mold. These reforms have varied from the encouragement of an independent power industry in Costa Rica to the sale of the national electric power system to private investors in the United Kingdom. Pakistan and Portugal are allowing private companies to build their own plants and sell power to the utilities, while Norway is stripping its powerful national utility company of its monopoly status. (See Table 6.) No country has completed the process of utility reform, and most have a long way to go.[64]

The broadest efforts at utility reform are found in the United States, where diverse state-by-state efforts have been underway since the passage of the federal Public Utility Reform and Policies Act of 1978. In California, for example, state regulators have required the privately owned companies that provide most of California's electricity to invest in energy efficiency, not just power plants. As a result of their efforts, as well as additional policy measures, per capita use of electricity in the state actually fell slightly between 1978 and 1988, compared with an 11-percent rise in the rest of the United States. Even more striking, California eliminated the need for $10 billion worth of new power plants and reduced electricity consumption per dollar of gross state product by 17 percent.[65]

California officials expect future gains to exceed those of the past. In August 1990, the state's four largest utilities agreed to spend $500 million over two years on improved energy efficiency; state regulators will ensure that the utilities profit from these investments, more than compensating them for the lost revenues from reduced electricity sales. Consumers will benefit as well, since their electric bills will be lower than if the utilities built expensive new power plants. New York, Oregon, and five New England states now have similar programs. Utilities are gradually being converted from energy producers to energy service companies, and the California Energy Commission believes this change may soon stop the growth of electricity demand.[66]

Table 6: Electric Utility Reform, Selected Countries, October 1990

Nation	Description of Action
Brazil	Independent power producers permitted to connect to electricity grid
Costa Rica	Utilities required to pay competitive prices to independent power producers
Denmark	Utilities required to purchase power from independent renewable power producers and district heating plants
Dominican Republic	Utilities required to pay competitive prices to independent power producers
Germany	Independent power generation being encouraged; competitive prices to be paid to renewable energy producers
Norway	Utility reform approved, aimed at increasing competition in electricity generation
Pakistan	Incentives offered for independent power producers
Portugal	Power plant construction and ownership being shifted to private companies; independent power producers, including renewables, emerging
Thailand	Limited sale of state-owned utility planned, incentives for cogeneration and biomass producers
United Kingdom	State-owned utility being broken up and sold to private investors, independent producers emerging
United States	Reforms by individual states including competitive bidding, integrated resource management, and incentives for efficiency investments

Source: Worldwatch Institute, based on various sources

Since the early eighties, California has also required utilities to purchase power from qualifying private companies. In just a decade, the state has developed a thriving independent and renewable electricity system. In 1990, 12 percent of the state's electricity is expected to come from alternatives such as geothermal, solar, wind, and biomass. Renewables, including hydroelectric power, now produce more than 40 percent of the state's electricity. By encouraging energy sources that are inflation- and embargo-proof, California demonstrated that with the right policies, energy transitions need not be long, painful affairs. Indeed, California has cut emissions of carbon dioxide in electric power generation by 17 percent during the past decade, despite rapid growth of the state's economy and population.[57]

Today, California and several other states are working on new policies to encourage more independent power development at the lowest possible cost. The key is to create a bidding system that allows companies to compete against each other for the right to produce power—the kind of competition that exists in any market. While devising bidding rules is extraordinarily complex, these rules are crucial to the pace of development of new energy systems.

So far, most governments have been slow to open their power industries to competition. Some companies have been sold to private investors but retain their monopoly status, while in nations such as Germany, only small renewable producers are permitted to join the competitive power market. This slow progress reflects the enormous political strength of utilities, and skepticism about the reliability of a redesigned power industry. But strong evidence now shows that, while power-transmission and distribution need to be a regulated monopoly, the generation business works better as a competitive, market-regulated enterprise. A main role of utility companies in the decades ahead may be on the demand side—providing the capital and expertise needed to drastically improve energy efficiency.[58]

Local governments also play a large role in shaping energy trends. They are best equipped to encourage energy savings in housing, transportation, land use planning, and solid waste policies. Transportation and buildings together account for nearly two-thirds of all the energy consumed in industrial countries Building codes in many areas have been modified recently to include tougher energy standards for new construction. Since 1986, for example, Washington State has required that its new buildings be far more efficient than the U.S. norm, with estimated savings over seven years averaging $328 for each household. In most regions, standards need to be tightened and energy consumption in existing buildings cut through weatherization programs.[69]

A sustainable transportation system can only be created with policies that reduce reliance on automobiles and encourage a switch to public transport, biking, and walking. Restricting cars in urban centers, partly through parking bans, and providing bicyclists and pedestrians with safe routes will help to reduce energy consumption. Copenhagen, for example, has banned all on-street parking in the city center, while providing ample bicycle parking downtown and at rail stations. In California, cities such as San Diego and San Jose are moving back to commuter rail transportation, to relieve congestion and pollution.[70]

Other policies are needed to control urban sprawl. The density of human settlements is not an accident, but results from decisions made by local and regional officials. Careful land-use planning can reduce transportation needs, primarily by increasing development density and consolidating jobs, homes, and services near public transport. Cities can use tax incentives and zoning regulations to achieve these goals.[71]

Some governments have model policies that cut energy bills and enhance self-reliance. Saarbrucken, Germany, for example, cut energy consumption nearly 20 percent between 1980 and 1989 with a comprehensive conservation program run by the city's public utility company. Portland, Oregon, approved an energy plan in 1979 to encourage energy conservation in buildings to counter growing energy bills. The city adopted a new program in 1990 that strengthens existing conservation measures and also encourages a shift from automobiles to buses, light rail, bicycles, and walking.[72]

City policies can also promote the use of renewable energy resources. Portland has an ordinance that protects the right of building owners to capture the sun's rays for heating. Saarbrucken and Berlin are planning to install photovoltaic cells on the roofs of city buildings. And Tucson, Arizona, is planning a 300-hectare solar village that will minimize energy needs and maximize the use of renewable resources.[73]

Energy research-and-development programs are even more in need of reform. In 1989, the 21 member governments of the International Energy Agency (IEA) spent three-quarters of their $7.3-billion energy research budgets on nuclear energy and fossil fuels. (See Table 7.) West Germany spent $179 million on nuclear research in 1989, more than 36 percent of its total energy research budget, while Spain spent 51 percent and the United Kingdom 54 percent. Only one of these countries has even a single commercial nuclear plant under construction. While the problems of radioactive waste disposal and plant decommissioning still need research, costly efforts to develop new plant designs—particularly breeder reactors that produce bomb-grade materials—are badly out of date.[74]

Another example of skewed priorities is the $883 million spent on nuclear fusion research in 1989 by the IEA countries—more than was

Table 7: Energy R&D Spending by IEA Governments, 1989

Technology	Amount (million dollars)	Share (percent)
Nuclear Fission	3,466	47
Fossil Fuels	1,098	15
Nuclear Fusion	883	12
Renewables	489	7
Conservation	367	5
Other	1,039	14
TOTAL	7,343[1]	100

[1]Column does not add to total due to rounding

Source: International Energy Agency, *Policies and Programmes of IEA Countries, 1989 Review* (Paris: Organization for Economic Cooperation and Development, 1990) spent on all efficiency and renewable technologies. Any contribution from fusion in the next 50 years is doubtful; a recent study by a U.S. Department of Energy advisory committee estimated that the first commercial fusion plant would not be operating until at least 2040.[75]

Other energy boondoggles abound. For example, the British government and the European Community are financing the development of a manufacturing process to convert coal to petroleum. The $65 million to be spent on this extremely carbon-intensive fuel is nearly three times total U.K. spending on renewable energy research in 1989. In the United States, industry and government plan to spend $5 billion in the nineties to develop so-called "clean coal" technologies. The new combustion methods lower emissions of sulfur dioxide significantly, but have little effect on carbon dioxide. At a time when coal use needs to be cut drastically, investing billions of dollars on ways to use more of it is a clear example of misplaced priorities.[76]

Sadly, most developing countries are doing no better. India, for example, has a huge and costly nuclear research establishment that for three decades has contributed almost nothing to the country's energy supply. Less than 1 percent of the Indian government's energy outlays go to renewable sources (excluding large hydroelectric dams), even though renewables, especially fuelwood, account for 40 percent of the country's energy use.[77]

The challenge in India and around the world is to reprioritize research spending so that it reflects today's needs, rather than the political clout of existing industries. In the United States, for example, the National Research Council issued a 1990 report recommending that 10 percent of the civilian energy research budget be reallocated from magnetic fusion and fossil fuel research to conservation and renewable programs. That would provide efficiency and renewables with around $300 million more each year, a 77-percent increase.[78]

In all IEA countries, only $856 million was invested in renewables and improved efficiency research in 1989, down from $931 million the previous year. Indeed, measured in real dollars, spending on these programs declined throughout the eighties, paced by drastic cutbacks in the

United States. (See Figure 3.) While research on renewables and efficiency has continued to yield many worthwhile technologies, the pace of progress has been slowed by budget cuts. However, the budgetary nadir of these programs may be past. Several countries are now planning to increase funding of efficiency and renewables research in response to environmental concerns. In the United States, for example, the fiscal 1991 budget approved by Congress included a 45-percent increase in renewables spending and a 21-percent increase for efficiency.[illegible]

With energy problems now a global issue, international energy institutions have important new roles to play. Unfortunately, many of these institutions still reflect the needs and priorities of earlier decades. For

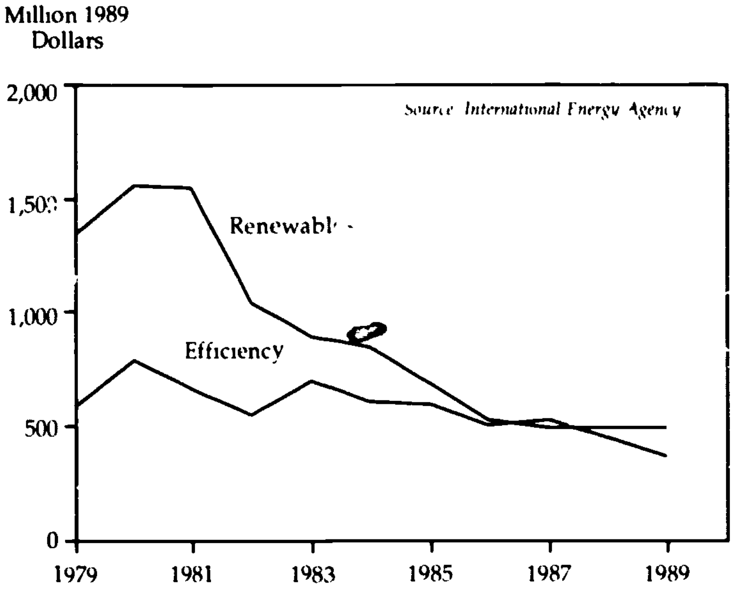

Figure 3: Energy R&D Spending by IEA Governments, 1979–1989

example, nuclear power is the only energy source with a United Nations body dedicated to its advancement. This organization, the International Atomic Energy Agency (IAEA), has a 1991 budget of $179 million, with additional voluntary contributions of $70 million expected. While the IAEA has one essential role—monitoring nuclear proliferation—it also actively promotes the export of nuclear power to developing nations. A similar organization, the Nuclear Energy Agency, exists to facilitate atomic cooperation between industrial countries.[80]

It is time to reconsider the IAEA's promotional role, which does not reflect the positions of many of the governments that fund it. The agency's programs are aimed principally at developing countries, which get 40 percent of their energy from renewables and less than 1 percent from nuclear energy. In recent years, many of these poor nations have slowed nuclear expansion, while stepping up their commitment to renewable energy sources. International institutions need to catch up with this shift in priorities.[81]

Broader reforms are also needed, such as more concerted efforts to assist developing countries improve energy efficiency and harness renewable energy resources. One way of doing this is to increase funding of energy projects by the United Nations Development Program, an organization with a $900-million annual budget. Former West German Chancellor Willy Brandt has suggested the further step of creating an International Solar Energy Agency (ISEA). This body would provide developing countries with support for research, advice on how to build production facilities, and exchanges of information and personnel on renewable technologies.[82]

The problem facing developing countries is in part a shortage of capital and in part a misallocation of funds. Multilateral lending organizations, including the World Bank and the regional development banks, provide developing countries with huge sums for energy projects—more than for any sector except agriculture. Energy accounted for 16 percent ($3.3 billion) of the World Bank's $21 billion in loans in 1990. These loans attract even more money by encouraging parallel lending by commercial banks and other development institutions. In China in particular, the failure to invest adequately in improved energy

"Only about 3 percent of the World Bank's energy and industry loans in 1989 went to improving the efficiency of energy use."

efficiency will cause carbon dioxide emissions from coal plants to soar in the years ahead.[83]

Despite the World Bank's supposed new environmental awareness, only about 3 percent of its energy and industry loans in 1989 went to improving the efficiency of energy use. Renewables (other than hydropower) received virtually nothing. Significantly increasing multilateral lending for renewables and efficiency is essential if these energy sources are to expand rapidly in developing countries during the nineties.[84]

Current lending programs also encourage energy-intensive industries and products, something that is not helpful to most poor countries. By instead promoting domestic production of efficient refrigerators, air conditioners, electric motors, and other energy-consuming devices, poor countries could cut the expected growth in their power sectors by 30 percent or more, with large economic savings. In India, for example, instead of building a factory to produce standard incandescent light bulbs, the World Bank could fund the construction of plants to make energy-efficient fluorescent light bulbs. A single $7-million factory could produce 12.3 million bulbs over seven years, enough to save India the equivalent of more than 1,500 megawatts of coal-burning electrical capacity. That translates into $2.4 billion in savings, mostly from not having to build new power plants.[85]

The process of transforming energy institutions is no less challenging than the development of new energy technologies. The transformation will take many years to accomplish, but is likely to accelerate as policy makers awaken to the environmental and economic challenges they face.

Energy and Jobs

Political leaders tend to guard the status quo, neglecting the fact that successful economies are dynamic, changing constantly over time. The evolution of technologies and of society itself naturally reshapes the economy, including the job market. With the automobile's advent, for example, service station attendants and mechanics replaced blacksmiths and wainwrights. Although this can be a painful process, it also creates new employment opportunities.

Defenders of the status quo contend that reduced energy consumption will lead to massive layoffs in energy-producing industries. To the contrary, a sustainable energy economy would likely have more jobs than one based on fossil fuels—primarily because improving energy efficiency creates more employment than supplying energy. In the future, the number of jobs in energy will probably grow, and the skills in demand shift dramatically.

Energy industries are not currently a major source of employment. In Poland, Canada, and India, for example, 4.4, 2.5, and 1 percent of jobs, respectively, are in energy and mining. Some 1.5 million Americans—1.4 percent of the labor force—worked in energy production and conversion in 1988. This includes jobs in coal mining, the oil and gas industry, and electric and gas utilities.[46]

The trend in industrial countries is toward fewer such jobs. Coal mining employment in the United States fell nearly 40 percent between 1980 and 1988, from 246,000 to 151,000, despite a 14-percent increase in coal production. The number of employees in the nation's oil and gas industry shrank from 715,000 to 528,000 over the same period. One minor exception to this trend is in electric utilities, where the number of employees, primarily service workers, rose 10 percent, to 648,000 workers. However, most of this increase likely has been offset by a loss of construction jobs as spending on new power plants declined 40 percent in the eighties.[47]

Most energy industries are capital-intensive and create relatively few jobs. The oil and gas industry in Alberta, Canada, for instance, generates 1.4 jobs for $1 million worth of capital investment, while other sectors of the economy average more than 10 jobs. Manufacturing, by comparison, yields 9.2 jobs per $1 million; agriculture, 13; and services, more than 32. The electric power industry is also capital-intensive. One-quarter of the foreign debts of Costa Rica and Brazil are from borrowing for the construction of power plants and transmission lines. Similarly, in the Soviet Union, energy accounted for nearly one-fifth of

"Each dollar invested in efficiency improvements generates more jobs than a dollar invested in new energy supplies."

all capital expenditures in the late eighties, and Poland poured almost 40 percent of its industrial investment into energy in 1986, 21 percent in coal alone.[38]

Employment in coal mining is likely to continue decreasing, especially as societies seek to limit emissions of carbon dioxide. Governments will need to compensate workers, ensure that they learn new skills, and cooperate with businesses to form new industries in the affected areas. Countries such as the United Kingdom and Germany have experience with this problem, since the number of coal miners is already falling as automation increases. Now, hundreds of thousands of Polish, Czech, and east German coal miners may lose their jobs as energy prices are deregulated. Even in China, with more than 4 million coal miners, increased automation and worker productivity ensure a leveling off of employment.[39]

There is a way, however, to meet energy needs in the future while creating jobs. Numerous studies have concluded that each dollar invested in efficiency improvements generates more jobs than a dollar invested in new energy supplies. A 1979 Council on Economic Priorities report found that investments in energy conservation and solar technologies created twice as many jobs as those in traditional energy industries such as oil, natural gas, or electric power generation. At the local level, a dollar spent on energy efficiency produces four times as many jobs as one invested in a new power plant, mainly because reduced energy bills allow investments in other job-creating businesses.[40]

Similar conclusions were reached by a 1985 European Community study of Denmark, France, the United Kingdom, and West Germany. Investments in district heating, building insulation, and biogas plants, for example, were found to save money and produce more jobs than traditional energy investments. A study in Alaska found that home weatherization created more jobs and personal income per dollar than any other investment, including the construction of hospitals, highways, or hydroelectric projects. Evaluations of existing energy-saving programs in Connecticut and Iowa found that they were less expensive and created more work than energy-supply alternatives such as electric power stations.[41]

As communities invest in energy efficiency and tap local renewable energy resources, economic benefits will ripple through the economy. An energy plan drafted by city officials in San Jose, California, for example, would create about 175 jobs during its 10-year span, with an initial city investment of just $645,000. The program includes education campaigns to show consumers how to save energy, and technical assistance such as energy audits and a home energy rating system. The plan also includes initiatives to reduce energy use in government buildings and transportation, setting an example for the community. The city investment, which would spur nearly $20 million in private spending, is expected to pay for itself in two-and-a-half years, and result in reduced carbon dioxide emissions.[92]

Even among electricity-generating technologies, there is a wide gap in employment levels. For the amount of energy produced, traditional fossil fuel and nuclear power plants employ fewer people than today's solar power systems, even when coal mining is included. (See Table 8.) As the technologies are refined and companies cut costs, however, the difference between renewable and conventional technologies may narrow. Photovoltaic companies, for example, are now reducing costs by opening fully-automated manufacturing lines, as Maryland-based Solarex did in 1990. Biomass energy also generates more jobs than fossil fuel alternatives—particularly because of the labor required for maintaining tree farms and handling fuel. A recent Canadian study found that increasing wood use in the province of New Brunswick over the next 20 years would create more income, jobs, and tax revenue than oil or coal development. Studies in the northeastern United States came to similar conclusions.[93]

In the move away from a fossil fuel economy, some of the largest employment opportunities would be in home insulation, carpentry, and sheet-metal work. Wind prospectors, photovoltaic engineers, and solar architects are among the new professions that might expand rapidly. Numbering in the thousands today, jobs in these fields may total in the millions within a few decades. Some of the skills now used in a fossil-fuel-based energy system would still be valuable. Petroleum geologists and oil-well crews, for example, could find jobs in the geothermal industry. But most of the jobs in a renewable-energy-based economy

Table 8: Direct Employment in Electricity Generation, Various Technologies, United States

Technology	Jobs (per thousand gigawatt-hours a year)
Nuclear	100
Geothermal	112
Coal[1]	116
Solar Thermal	248
Wind	542

[1]Includes coal mining

Source: Worldwatch Institute, based on DOE, EIA, *Electric Plant Cost and Power Production Expenses 1988* (Washington, D.C. 1990), DOE, EIA, *Coal Production Statistics 1988* (Washington, D.C. 1989), and other sources

would be cleaner and safer. No one would be required to clean up radioactive spills or decommission "hot" nuclear plants. Nor would workers have to toil deep underground or dispose of toxic ash.

The most profound adjustments will come in those few nations that now rely heavily on fossil fuel industries. The Persian Gulf nations, for example, have built their entire economies on oil, and Saudi Arabia in particular has worked actively to weaken international commitments to limit carbon dioxide emissions. But most of these countries eventually will have to move away from petroleum dependence. Even in the Persian Gulf, the oil will not last forever, so these nations would do well to begin diversifying their economies.[94]

Oil-importing developing countries, particularly those burdened with foreign debt, have a further incentive to follow a labor-intensive, improved-efficiency energy strategy. Most Third World nations have far more labor to spare than capital; indeed, underemployment and unemployment are creating major social problems in many developing countries. By following a more diversified energy strategy, these countries would provide more jobs while reducing expenditures on imported oil and other fossil fuels.

As energy supplies become more diverse and less dependent on conventional fuels, local economies can begin to free themselves from disruptive boom-and-bust cycles. The Iraqi invasion of Kuwait, for example, did not significantly affect the cost of solar hot-water equipment in Jordan, of sugarcane ethanol in Brazil, or of wind turbines in Denmark. Indeed, the unquantifiable benefits of a sustainable energy economy could offer stability in an otherwise volatile world.

Toward a Solar Economy

In 1976, *Foreign Affairs* journal published an article that challenged the comfortable assumptions of energy planners. In "Energy Strategy: The Road Not Taken?" physicist Amory Lovins offered a vision of a future world that relied on improved energy efficiency and renewable technologies instead of fossil fuels and nuclear power. Long before conventional energy planners were taking these new technologies seriously, Lovins was plotting the shape of a sustainable energy economy.[95]

The experience of the past 15 years has proven Lovins' vision prophetic. In the mid-seventies, conventional energy planners predicted that the United States would be using around 135 quadrillion Btus (quads) of energy in 1990, while Lovins projected just under 100 quads. However, the estimated figure for 1990 is just 83 quads, only 10 percent higher than in 1973. Once portrayed as a wild-eyed advocate of "soft energy," Lovins actually underestimated the rapidity of efficiency's gains.[96]

The world has taken the first step toward the future Lovins foresaw. However, the next step—harnessing renewable energy—has been slower in coming because of technological lag-times, government neglect, and the 70-percent decline in oil prices between 1980 and 1986. Still, renewable energy technologies are now far more mature than in the mid-seventies. Rapid commercial development of several of these tech-

"Solar, wind, and cogeneration facilities can be built at less than one-thousandth the size of a typical nuclear- or coal-fired plant."

nologies is expected during the next decade, driven not only by technical advances but by world oil and climate trends.[57]

A new energy system is beginning to emerge and, as Lovins predicted, decentralization may be its hallmark. In contrast to the huge coal and nuclear plants of today, renewable electricity sources—whether photovoltaic cells, wood-fired plants, or wind generators—can be developed economically in various sizes. Solar, wind, and cogeneration facilities can be built at less than one-thousandth the size of a typical nuclear- or coal-fired plant Some renewable energy systems can be installed, literally, at the household level.[58]

Even larger-scale renewable energy projects—such as commercial wind farms—are more modular than today's energy sources. Today, wind farms are typically composed of 100-kilowatt turbines that are less than 20 meters in diameter and cost roughly $100,000 to build and install. The manufacturing processes are more akin to today's automobile factories than to central power plants. A wind-power developer can install 10, 100, or 1,000 machines, depending on how much power is needed. The same machine could also be used by itself to supply power for a Third World village.

Given the diversity and decentralization of renewable resources, transmission and distribution losses can be minimized. Smaller scale, more decentralized energy technologies, particularly if developed at the household level, reduce the need for moving energy about However, some larger-scale distribution systems will still be needed. If hydrogen is used as a carrier, for example, energy can be moved long distances with virtually no losses. Hydrogen can also be used to power automobiles, buses, and other modes of transportation [59]

Areas where renewable sources are abundant, and the need for energy great, will likely see the arrival of a range of new technologies. Solar thermal power systems may be deployed extensively in deserts, while wind turbines proliferate in windy regions. Photovoltaics can be used virtually everywhere. No matter the energy technology, however, environmental and land use considerations need careful attention. Although many areas will remain off-limits for energy production due to environmental concerns, this will not substantially hinder renewable energy development.

Solar electric technologies do require land, but they are no more land-intensive than some of today's power sources. In fact, if the land devoted to mining coal is included, renewable systems actually require less space than coal-fired power plants. (See Table 9.) In coal-rich areas of Eastern Europe, the United States, and India, for example, vast strip mines cover huge areas. These enormous gashes in the earth's surface render large areas useless for generations.[100]

Solar technologies, in contrast, need not be spread over wide swaths of land. Photovoltaics, for example, can be deployed on rooftops. And while wind farms appear to use large tracts, only 10 percent of the land is actually occupied by turbine towers and service roads; the remainder can be used for grazing animals or cultivating crops. While land availability may be a local constraint to some renewable energy development, it seems unlikely that this will be a major limitation.[101]

Table 9: Land Use of Selected Electricity-Generating Technologies, United States

Technology	Land Occupied
	(square meters per gigawatt-hour, for 30 years)
Coal[1]	3,642
Solar Thermal	3,561
Photovoltaics	3,237
Wind[2]	1,335
Geothermal	404

[1]Includes coal mining [2]Land actually occupied by turbines and service roads

Source: Worldwatch Institute, based on Meridian Corporation, "Energy System Emissions and Materiel Requirements," prepared for U S Department of Energy, Alexandria, Va , February 1989, Paul Gipe, "Wind Energy Comes of Age," Gipe & Assoc , Tehachapi, Calif , May 13, 1990, and other sources

"Renewable energy systems actually require less space than coal-fired power plants."

Researchers at the Electric Power Research Institute in California found that all current U S electricity needs could be met by solar cells deployed over an area of 59,000 square kilometers—less than one-third of the area now used by the U.S. military Researchers at Pacific Northwest Laboratories estimate that 25 percent of current U.S. generating capacity could be provided by wind farms installed on the windiest 1.5 percent of the continental United States. Most of this is barren grazing land in the western states that hardly would be affected by wind farm development In Europe, the largest wind farms will likely be placed on offshore platforms in the North and Baltic seas.[102]

Still, no one envisions that wind power or photovoltaics alone will provide all the world's energy. Rather, a broad range of renewable technologies, deployed at many different scales, seems more likely. Within a few decades, a geographically diverse country such as the United States might get 30 percent of its electricity from sunshine, 20 percent from hydropower, 20 percent from windpower, 10 percent from biomass, 10 percent from geothermal energy, and 10 percent from natural-gas-fired cogeneration A north African country may get half its electricity from solar power, while northern Europe is likely to rely more on wind, and the Philippines on geothermal energy.

One energy source that is limited by land availability is biomass. Less than 3 percent of the sun's rays are converted to biomass in photosynthesis. Photovoltaics, by contrast, already convert 10 percent of sunlight to electricity. and solar thermal units convert 22 percent. Thus, it takes nearly one hectare of corn to provide enough ethanol to run a U.S. automobile for a year, yet the same amount of land devoted to solar thermal troughs could power more than 80 electric vehicles. Moreover, solar technologies can be placed on less valuable land. A hectare of Wyoming scrubland is worth around $100, while a hectare of Iowa farmland costs more than $3,000 Contrary to some predictions, it is unlikely that vast stretches of cropland will ever be converted to energy farms.[103]

Other environmental issues to consider include the loss of biodiversity if natural ecosystems are replaced with energy crops. In Hawaii and the Philippines, geothermal development in tropical forests already has led to environmental conflicts, while California's wind turbines have been associated with bird kills. But remedies are available. In the Netherlands, wind developers and ornithological society representatives reached agreement on areas that would be off-limits to wind development. Geothermal developers, in particular, need to locate projects with greater care, ensuring that land-use conflicts are minimized. Already, the injection of waste water into deep wells has become a mandatory practice for geothermal power stations in some areas.[104]

The pattern of human settlements, now shaped by cheap oil and the automobile, could be reshaped during the next several decades. More than half the total energy use in industrial countries is now related in some way to spatial structure—the relative location of homes, jobs, and shopping sites—according to Susan Owens, geography professor at Cambridge University. It is this placement of working and living spaces that partially drives the wasteful use of energy. Although major changes in land use will obviously take time, the early stages of that transition may begin almost immediately. Sprawling suburbs, for example, are almost certain to be supplanted. Not only do detached homes consume large amounts of energy, the suburban structure itself forces people to rely on automobiles and waste energy performing the ordinary tasks of daily life.[105]

Energy constraints are therefore likely to push societies toward more compact communities, where homes and shops are within walking or cycling distance. European cities already follow this pattern; they typically have a density about three times that of modern American cities. Compact urban designs also facilitate improved public transportation systems. Some 40 years from now, rail travel and telecommunications could replace many of the shorter trips now covered by cars and planes. Such changes in transportation would reduce energy needs, as well as diminish traffic and pollution.[106]

It also makes sense to construct new buildings so as to capture as much sunlight as possible—both for heat and electricity—and perhaps later include a hydrogen-powered cogenerator in the basement. Contrary to popular assumption, solar energy systems can easily be accommodated to compact cities. Passive solar residences can be built as densely as 35 to 50 dwellings to the hectare. A normal U.S. residential suburb, by contrast, is zoned for no more than 10 homes to the hectare. In many cities, district heating and cooling is an efficient alternative. Already in Denmark, 40 percent of the heating for buildings is provided by such plants, some using agricultural wastes such as straw for fuel.[107]

The transition to a sustainable energy system will inevitably reshape many aspects of today's societies. While some of the changes can be anticipated, others can only be guessed at. Overall, however, a sustainable energy economy promises to be cleaner and more secure. And while the energy sources themselves may be more expensive, the energy system as a whole could be far more economical. Not only is this vision preferable to the status quo, it is a vast improvement over the kind of future that would result from continuing overdependence on fossil fuels.

In the past, energy transitions have occurred on a country-by-country basis. But the next transition is one that the world as a whole must achieve, because the economic and ecological problems driving it are global in nature. By the year 2030, today's developing countries will have upward of 80 percent of the world's population. These nations have little hope of achieving their basic development goals if they follow the energy path blazed 100 years ago by the West. But they could "leap-frog" industrial countries and follow a sustainable energy strategy from the start, avoiding billions of dollars of misdirected investments.[108]

The world has in a sense already embarked on the next great energy transition—under the pressures of economic, environmental, and social limits that have made the old system unsustainable and obsolete. The main danger is that new energy systems will evolve too slowly, overtaken not only by environmental problems but the social and economic upheavals that could accompany them. Societies have only a short time to chart a sustainable energy course, and then muster the political will to follow it

Notes

1. British Petroleum (BP), *BP Statistical Review of World Energy* (London 1990)

2. Carbon emissions estimate from Worldwatch Institute, based on Gregg Marland et al , *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nations Energy Statistics and the U S Bureau of Mines Cement Manufacturing Data* (Oak Ridge, Tenn Oak Ridge National L. xoratory, 1989), and on BP, *BP Statistical Review;* "Final Conference Statement Scientific/Technical Sessions," Second World Climate Conference, Geneva, November 7, 1990, fossil fuel resources from Eric Sundquist, "Geological Perspectives on Carbon Dioxide and the Carbon Cycle," in E T Sundquist and W S. Broecker, eds , *The Carbon Cycle and Atmospheric CO_2 Natural Variations Archean to Present* (Washington, D C American Geophysical Union, 1985), conversion to carbon dioxide from Bert Bolin et al , eds , *The Greenhouse Effect, Climate Change and Ecosystems* (SCOPE 29) (Chichester, England John Wiley and Sons, 1986), and Peter Brewer, Woods Hole Oceanographic Institution, "Global Change The Relevance of Oceanic Chemical, Geological and Biological Processes," Testimony before the Committee on Commerce, Science, and Transportation, U S Senate, April 11, 1989; current CO_2 concentrations from Charles D Keeling, "Measurements of the Concentration of Atmospheric Carbon Dioxide at Mauna Loa Observatory, Hawaii, 1958-1986," Final Report for the Carbon Dioxide Information and Analysis Center, Martin-Marietta Energy Systems Inc , Oak Ridge, Tenn , April 1987, C Keeling, Scripps Institution of Oceanography, private communication, July 31, 1989

3. "Ministerial Declaration of the Second World Climate Conference," Second World Climate Conference, Geneva, November 7, 1990

4. Roger S Carlsmith et al , "Energy Efficiency How Far Can We Go?" Oak Ridge National Laboratory, Oak Ridge, Tenn , prepared for the Office of Policy, Planning and Analysis, U S Department of Energy (DOE), in support of the National Energy Strategy, January 1990, Birgit Bodlund et al , "The Challenge of Choices Technology Options for the Swedish Electricity Sector," in Thomas Johansson et al , *Electricity Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden Lund University Press, 1989), William U Chandler, ed , *Carbon Emissions Control Strategies Case Studies in International Cooperation* (Washington, D C . World Wildlife Fund and The Conservation Foundation, 1990), "Canadian Energy Ministers Fail to Agree on Reduction in Carbon Dioxide," *International Environment Reporter*, September 1989, Commission of the European Communities, Directorate-General for Energy, "Energy for a New Century The European Perspective," *Energy in Europe*, special issue, July 1990

5. "Cost of Change Could Be Great," *Financial Times*, October 13, 1989

6. Worldwatch Institute estimates, based on DOE, Energy Information Administration (EIA), *International Energy Outlook 1990* (Washington, D C 1990), and on Frank Barnaby, "World Energy Prospects," *Ambio*, Vol 18, No 8, 1989

7. Christopher Flavin, *Reassessing Nuclear Power The Fallout from Chernobyl*, Worldwatch

51

Paper 75 (Washington, D C Worldwatch Institute, March 1987), "Wackersdorf Finally Dies," *Nature*, June 8, 1989, Radio Liberty, "Ban on Nuclear Construction in RSFSR," June 29, 1990, "Soviet Nuclear Power Plant Programme Marks Time," *Nature*, January 26, 1989, California Energy Commission (CEC), *Electricity Report 1990*, final draft (Sacramento, Calif September 1990), Usha Rai, "Unique Protest Against Big Dams, *Times of India*, September 29, 1989, Kavita Singh, "Harsud Says No!" *Times of India*, October 8, 1989

8. United Nations, *World Energy Supplies 1950-1974* (New York 1976), United Nations, *1988 Energy Statistics Yearbook* (New York 1990)

9. DOE, EIA, "Weekly Petroleum Status Report," Washington, D C , October 12, 1990, BP, *BP Statistical Review*, American Petroleum Institute (API), *Basic Petroleum Data Book, Vol 5* (Washington, D C 1985), DOE, EIA, *Monthly Energy Review* (Washington, D C various issues), 1990 oil price from DOE, EIA, "Weekly Petroleum Status Report," Washington, D C , October 12, 1990

10. International Energy Agency (IEA), *Energy Policies and Programmes of IEA Countries, 1989 Review* (Paris Organization for Economic Cooperation and Development (OECD), 1990), DOE, EIA, *International Energy Annual 1989* (Washington, D C 1990), BP, *BP Statistical Review*

11. Venezuela is the main exception to the trend that all major oil discoveries during the past decade were in the Persian Gulf countries, from BP, *BP Statistical Review* (various years), Thomas W Lippman, "Saudis Come Up with Major Oil Find," *Washington Post*, October 15, 1990, "proven reserves" are those quantities of oil in known reservoirs that can be extracted under existing economic and operating conditions, these rise as new oil is discovered via exploratory drilling, and fall as oil is extracted

12. BP, *BP Statistical Review*, DOE, EIA, *Monthly Energy Review May 1990*, oil well production is Worldwatch Institute estimate based on BP, *BP Statistical Review*, and on API, *Basic Petroleum Data Book*, Vol 10 (Washington, D C September 1990), Matthew L Wald, "Effect of Fall in Soviet Oil Output," *New York Times*, September 6, 1990, A L Johnson, "Soviet Oil Outlook Less Promising in 1990s," *Oil & Gas Journal*, September 17, 1990

13. Indian data from Philip K Verleger, Institute for International Economics, "The Energy Crisis of 1990," Testimony before the Committee on the Budget, U S House of Representatives, October 24, 1990

14. BP, *BP Statistical Review*, Sundquist, "Geological Perspectives on Carbon Dioxide and the Carbon Cycle", United Nations, Department of International Economic and Social Affairs, *Global Estimates and Projections of Population by Sex and Age*, 1988 Edition (New York 1989)

15. Worldwatch Institute estimates, based on Marland et al., *Estimates of CO_2 Emissions*, and on BP, *BP Statistical Review*

16. Intergovernmental Panel on Climate Change (IPCC), "Policymakers' Summary of the Scientific Assessment of Climate Change," Report to IPCC from Working Group I, Geneva, June 1990, Roger Milne, "Pressure Grows for US to Act on Global Warming," *New Scientist*, June 2, 1990; IPCC, "Policymakers' Summary of the Potential Impacts of Climate Change," Report of the Working Group II to IPCC, Geneva, undated.

17. "Ministerial Declaration of the Second World Climate Conference"; Bill Hare, Australian Conservation Foundation, Melbourne, private communication and printout, October 17, 1990, "Austria to Reduce CO_2 Emissions 20% by 2005," *Global Environmental Change Report*, September 14, 1990; "Canada to Stabilize CO_2 Emissions at 1990 Levels by 2000," *Global Environmental Change Report*, June 22, 1990; Denmark Ministry of Energy, "Danish Efforts to Reduce Energy Consumption and the Emission of Greenhouse Gases," Copenhagen, June 7, 1990, "Country Profiles: Denmark," *European Energy Report*, May 1990; Emmanuele D'Achon, First Secretary, Embassy of France, Washington, D.C., private communication and printout, October 10, 1990, "Germany and the Greenhouse: A Closer Look," *Global Environmental Change Report*, August 17, 1990; "West German Environment Minister Proposes Tax on Carbon Dioxide Emissions," *International Environment Reporter*, September 26, 1990; "East Germany: Country will Comply with CFC Ordinance of West Germany, Seeks Smaller CO_2 Cut," *International Environment Reporter*, July 1990, Japan Council of Ministers for Global Environment Conservation, "Action Program to Arrest Global Warming," Tokyo, October 23, 1990, "The Netherlands Sets CO_2 Emissions Tax for 1990," *Global Environmental Change Report*, December 22, 1989; Bert Metz, Counselor for Health and Environment, Royal Netherlands Embassy in the United States, "The Dutch Policy on Global Warming," Testimony presented to the Canadian House of Parliament, Standing Committee on Environment, Ottawa, January 23, 1990; "New Zealand Announces CO_2 Reduction Target," *Global Environmental Change Report*, August 17, 1990, Gunnrr Mathisen, Secretariate for Climate Affairs, Ministry of the Environment, Norway, private communication, January 30, 1990; The Ministry of Environment and Energy, *Action for a Common Future: Swedish National Report for Bergen Conference, May 1990* (Stockholm: 1989); "Swiss Act on Global Warming with Major New CO_2 Tax," *European Energy Report*, November 2, 1990, United Kingdom Department of the Environment, *This Common Inheritance: Britain's Environmental Strategy* (London, September 1990), "European Councils Set CO_2 Targets and Agree Gas Transit Directive," *European Energy Report*, November 2, 1990; IPCC, "Policymakers' Summary of the Scientific Assessment of Climate Change"; Finland and Iceland also have set goals for greenhouse gas emissions, but details were not available at press time

18. IPCC, "Policymakers' Summary of the Scientific Assessment of Climate Change", U S Environmental Protection Agency (EPA), *Policy Options for Stabilizing Global Climate*, draft (Washington, D C.: EPA, 1989)

19. Christopher Flavin, *Slowing Global Warming A Worldwide Strategy*, Worldwatch Paper 91 (Washington, D C Worldwatch Institute, October 1989), Worldwatch Institute estimates, based on J M O Scurlock and D O Hall, "The Contribution of Biomass to Global Energy Use," *Biomass*, No 21, 1990, on BP, *BP Statistical Review*, on Marland et al, *Estimates of CO_2 Emissions*, and on Nigel Mortimer, "Proposed Nuclear Power Station Hinckley Point C," Proof of Evidence, Friends of the Earth U K, London, undated, Gregg Marland, "Carbon Dioxide Emission Rates for Conventional and Synthetic Fuels," *Energy*, Vol 8, No 12, 1983

20. Marland, "Carbon Dioxide Emission Rates", Michael Grubb, *Energy Policies and the Greenhouse Effect*, Volume One Policy Appraisal (Aldershot, England Dartmouth Publishing, 1990), BP, *BP Statistical Review*

21. "World List of Nuclear Power Plants," *Nuclear News*, August 1990, Christopher Flavin, "Decline of Nuclear Power The Worldwide Prospect," draft, Worldwatch Institute, August 1990

22. John F Ahearne, "Nuclear Power in the U S Is the Option Still Open?" *Forum for Applied Research and Public Policy*, Fall 1990, Alvin Weinberg, "Engineering in an Age of Anxiety," *Issues in Science and Technology*, Winter 1989-90, Mark Crawford, "Fusion Panel Drafts a Wish List for the '90s," *Science*, July 13, 1990

23. IEA, *Energy Policies and Programmes, 1989*, William U Chandler et al, "Energy for the Soviet Union, Eastern Europe and China," *Scientific American*, September 1990, José Goldemberg and Amulya Reddy, "Energy for Development," *Scientific American*, September 1990, Jose Goldemberg et al, *Energy for Development* (Washington, D C World Resources Institute, 1987)

24. Christopher Flavin and Alan Durning, *Building on Success The Age of Energy Efficiency*, Worldwatch Paper 82 (Washington, D C Worldwatch Institute, March 1988), Arnold P Fickett et al, "Efficient Use of Electricity," *Scientific American*, September 1990, CEC, *Conservation Report, 1990*, staff draft (Sacramento, Calif August 1990), Rick Bevington and Arthur H Rosenfeld, "Energy for Buildings and Homes," *Scientific American*, September 1990, Jose Goldemberg et al, *Energy for a Sustainable World* (Washington, D C World Resources Institute, 1987), Amulya K N Reddy et al, "Comparative Costs of Electricity Conservation Centralised and Decentralised Electricity Generation," *Economic and Political Weekly*, June 2, 1990

25. For renewable energy potential see Idaho National Engineering Laboratory (INEL) et al, *The Potential of Renewable Energy An Interlaboratory White Paper*, prepared for the Office of Policy, Planning and Analysis, DOE, in support of the National Energy Strategy (Golden, Colo Solar Energy Research Institute (SERI), 1990), the three U S scenarios presented in this report envision renewable energy supplies growing by approximately 300 percent, 450 percent and 600 percent over 1988 levels by 2030

26. Accessible resources are that portion of the "total resource base that can be exploited with currently available technology or technology that will soon be available," from Meridian Corporation, "Characterization of U S Energy Resources and Reserves," prepared for Deputy Assistant Secretary for Renewable Energy, DOE, Alexandria, Va , June 1989, INEL et al , *The Potential of Renewable Energy*, DOE, EIA, *Annual Energy Review 1989* (Washington, D C 1990) 55

27. Scurlock and Hall, "The Contribution of Biomass to Global Energy Use", Norwegian figure is based on Norwegian Central Bureau of Statistics, *Natural Resources and the Environment, 1989* (Oslo 1990), wherein more than 45 percent of total supply is from hydroelectric power and 5 percent from biomass

28. Carl J Weinberg and Robert H Williams, "Energy from the Sun," *Scientific American*, September 1990, INEL et al , *The Potential of Renewable Energy*, Christopher Flavin and Rick Piltz, *Sustainable Energy* (Washington, D C Renew America, 1989), DOE, *Energy Technologies & the Environment* (Washington, D C 1988), Peggy Sheldon, Luz International Limited, Los Angeles, Calif , private communication and printout, August 28, 1990, Susan Williams and Kevin Porter, *Power Plays* (Washington, D C Investor Responsibility Research Center, 1989), Nancy Rader et al , *Power Surge* (Washington, D C Public Citizen, 1989), "Country Profiles Denmark", "Spain Resurrects Funding Programme," *European Energy Report*, July 13, 1990, "West Germany Announces $3bn Plan for Research and Technology," *European Energy Report*, March 9, 1990.

29. Low-temperature heat is Worldwatch Institute estimate, based on Amory B Lovins, *Soft Energy Paths Toward a Durable Peace* (Cambridge, Mass Ballinger Publishing Company, 1977), on John Hebo Nielsen, "Denmark's Energy Future," *Energy Policy*, January/February 1990, and on DOE, EIA, *Annual Energy Review 1989*, Bevington and Rosenfeld, "Energy for Buildings and Homes", Solar Technical Information Program, *Energy for Today. Renewable Energy* (Golden, Colo · SERI, 1990)

30. Joyce Whitman, *The Environment in Israel* (Jerusalem Environmental Protection Service, Ministry of the Interior, 1988), Mark Newham, "Jordan's Solution Circles the Sky," *Energy Economist*, June 1989, Cynthia Pollock Shea, *Renewable Energy Today's Contribution, Tomorrow's Promise*, Worldwatch Paper 81 (Washington, D C Worldwatch Institute, January 1988), Eric Young, "Aussies to Test Novel Solar Energy Collector," *Energy Daily*, May 3, 1990, Solar Technical Information Program, *Energy for Today Renewable Energy*

31. Sheldon, private communication and printout, Don Logan Luz International Limited, Los Angeles, Calif , private communication, September 26, 1990, Bureau of the Census, U S Department of Commerce, *Statistical Abstract of the United States 1990* (Washington, D C U S Government Printing Office, 1990)

32. INEL et al , *The Potential of Renewable Energy*

33. Steven Dickman, "The Sunny Side of the Street ," *Nature*, May 3, 1990, "Sanyo Develops Solar Cell Shingles," *Independent Energy*, April 1989

56

34. DOE, *Energy Technologies and the Environment*, DOE, *Photovoltaic Energy Program Summary* (Washington, D C 1990), Ken Zweibel, *Harnessing Solar Power The Photovoltaics Challenge* (New York Plenum Publishing, 1990), Meridian Corporation and IT Power Limited, "Learning from Success Photovoltaic-Power Water Pumping in Mali," prepared for U S Committee on Renewable Energy Commerce and Trade (CORECT), Alexandria, Va , February 20, 1990, Maheshwar Dayal, Secretary, Department of Non-Conventional Energy Sources, New Delhi, India, private communication, July 13, 1989, "Indonesia Installs First Solar Village, Schedules Total of 2,000," *International Solar Energy Intelligence Report*, February 9, 1990, "A New Group of Sun Worshippers," *Asiaweek*, October 12, 1990

35. Zweibel, *Harnessing Solar Power*, INEL et al , *The Potential of Renewable Energy*

36. Flavin and Piltz, *Su[illegible] inable Energy*, INEL et al , *The Potential of Renewable Energy*, Danish experience from Paul Gipe, "Wind Energy Comes of Age," Gipe & Assoc., Tehachapi, Calif , May 13, 1990

37. U S Windpower, Inc , "The Design Specifications for a Wind Power Plant in Patagonia Using U S Wind Turbines," Livermore, Calif , January 1989, Christopher Flavin, *Wind Power A Turning Point*, Worldwatch Institute (Washington, D.C Worldwatch Institute, July 1981), "Minnesota Resource Greater than Previously Reported," *Wind Energy Weekly*, American Wind Energy Association, Washington, D C , July 5, 1990

38. P J de Groot and D O Hall, "Biomass Energy A New Perspective," prepared for the African Energy Policy Research Network, University of Botswana, Gaborone, January 8, 1990

39. Lester P Brown, *The Changing World Food Prospect The Nineties and Beyond*, Worldwatch Paper 85 (Washington, D C Worldwatch Institute, October 1988), Sandra Postel, *Water for Agriculture Facing the Limits*, Worldwatch Paper 93 (Washington, D C Worldwatch Institute, December 1989)

40. Biofuels and Munic[illegible] ste Technology Program, Office of Renewable Energy Technologies, DOE, *Five Year Research Plan 1988-1992, Biofuels Renewable Fuels for the Future* (Springfield, Va National Technical Information Service, 1988), Norman Hinman, SERI, Golden, Colo , private communication, August 25, 1989

41. P P S Gusain, *Cooking Energy in India* (Delhi Vikas Publishing House, 1990), Eric D. Larson et al , "Biomass Gasification for Gas Turbine Power Generation," in Johansson et al , *Electricity Efficient End-Use and New Generation Technologies*, Eric D Larson et al , "Biomass-Gasifier Steam-Injected Gas Turbine Cogeneration for the Cane Sugar Industry," presented at the Energy from Biomass and Wastes XIV conference, Lake Buena

Vista, Fla., January 29-February 2, 1990, United Nations, *1988 Energy Statistics Yearbook*

42. United Nations, *1988 Energy Statistics Yearbook*, Satyajit K. Singh, "Evaluating Large Dams in India," *Economic and Political Weekly*, March 17, 1990

43. Donald Finn, Geothermal Energy Institute, New York, private communication and printout, March 16, 1990, United Nations, *1988 Energy Statistics Yearbook*, Phillip Michael Wright, "Developments in Geothermal Resources, 1983-1988," *The American Association of Petroleum Geologist Bulletin*, October 1989, New Energy Development Organization, "The Map of Prospective Geothermal Fields in Japan," Tokyo, 1984, as cited in Michael J. Grubb, "The Cinderella Options: A Study of Modernized Renewable Energy Technologies," Part 2: Political and Policy Analysis, *Energy Policy*, October 1990

44. INEL et al., *The Potential of Renewable Energy*, "Solar Showers in Massachusetts," *Science*, September 7, 1990, J. Edward Sunderland and Dwayne S. Breger, "The Development of a Central Solar Heating Plant with Seasonal Storage at the University of Massachusetts/Amherst," University of Massachusetts, Amherst, undated

45. Christopher Hocker, "The Miniboom in Pumped Storage," *Independent Energy*, March 1990, Greg Paula, "Load Management through Energy Storage," *Electrical World*, August 1990, David Bautacoff, "Emerging Strategies for Energy Storage," *EPRI Journal*, July/August 1989, Zweibel, *Harnessing Solar Power*

46. Bautacoff, "Emerging Strategies for Energy Storage", DOE, EIA, *Annual Energy Review 1989*, Electric Power Research Institute (EPRI), "Electric Van and Gasoline Van Emissions: A Comparison," Technical Brief, Palo Alto, Calif., 1989, Mark A. DeLuchi et al., "Electric Vehicles: Performance, Life-Cycle Costs, Emissions, and Recharging Requirements," *Transportation Research*, Vol. 22A, No. 5, 1989, Bruce Fraser, "Ford Leading the Pack in Race for Electric Car," *Journal of Commerce*, October 3, 1989, "Japan Plays Catch-Up in Electric Car Quest," *Journal of Commerce*, August 30, 1990

47. DeLuchi et al., "Electric Vehicles", Zweibel, *Harnessing Solar Power*

48. Mark A. DeLuchi, "Hydrogen Vehicles," in Daniel Sperling, ed., *Alternative Transportation Fuels: An Environmental and Energy Solution* (Westport, Conn.: Quorum Books, 1989), Joan Ogden and Robert Williams, *Solar Hydrogen* (Washington, D.C.: World Resources Institute, 1989)

49. German Aerospace Research Establishment and King Abdulaziz City for Science and Technology, "Hysolar: Solar Hydrogen Energy," Stuttgart, Germany, 1989, DeLuchi, "Hydrogen Vehicles", Ogden and Williams, *Solar Hydrogen*

50. DOE, *Fuel Cell Systems Program Plan, Fiscal Year 1989* (Washington, D.C.: 1989), John Schmitt, Director of Marketing, "The Future of Fuel Cells," ONSI Corporation, South

Windsor, Conn., May 29, 1990; Paul J Werbos, *Oil Dependency and the Potential for Fuel Cell Vehic'*s, Technical Paper Series (Warrendale, Pa . Society of Automotive Engineers, 1987).

58 51. IEA, *Energy Policies and Programmes, 1989*, "World Status Report, Fusion Power," *Energy Economist*, June 1988

52. Weinberg and Williams, "Energy from the Sun "

53. Helen Berg, "China Raises Price of Domestic Coal," *Journal of Commerce*, September 10, 1990, DOE, EIA, *Monthly Energy Review May 1990*, Mark Berniker, "Labor Unrest Imperils Soviet Oil Export," *Journal of Commerce*, September 12, 1990

54. Richard Heede et al , *The Hidden Costs of Energy* (Washington, D C Center for Renewable Resources, October 1985), Energy and Environmental Study Institute (EESI), "Environmental, Energy and Natural Resources Status Report for the 101st Congress," Washington, D.C , November 1, 1990

55. Alan Tonelson and Andrew K Hurd, "The Real Cost of Mideast Oil," *New York Times*, September 4, 1990, Worldwatch Institute estimate, based on Lawrence J Korb, "We Can Afford to Fight Iraq," *New York Times*, August 21, 1990, and on Ann Devroy, "Bush Orders 200,000 More Troops to Gulf," *Washington Post*, November 9, 1990

56. "Auto Pollution Health Costs Calculated," *Washington Post*, January 21, 1990

57. Pace University Center for Environmental Legal Studies, *Environmental Costs of Electricity* (New York Oceana Publications, 1990)

58. *Ibid* , "France Introduces Tax on Emissions of Sulphur Dioxide from Industry," *European Energy Report*, May 18, 1990; "Government Proposes to Tax Emissions of Carbon Dioxide, Nitrogen Oxides, Sulfur," *International Environment Reporter*, May 1990, "Italy Raises Fuel Prices Again in Bid to Plug Budget Gap," *European Energy Report* July 27, 1990

59. Karen Treanton, Statistics Department, International Energy Agency, Paris, private communication and printout, November 2, 1990, Carbon emissions of gasoline from Gregg Marland, "Carbon Dioxide Emission Rates for Conventional and Synthetic Fuels," *Energy*, Vol 8, No 12, 1983; EESI, "Environmental, Energy and Natural Resources Status Report for the 101st Congress "

60. Geraldine C Kaye, "Global Climate Change Timeline," *Global Environmental Change Report*, July 28, 1990, Sweden instituted a "carbon tax" only on gasoline in January 1990 and a broad-based carbon tax will not be in effect until January 1991, according to Anders Boeryd, Fuel Market Division, National Energy Administration, Sweden, private communication, August 10, 1990, "Germany and the Greenhouse," *Global Environmental Change Report*; "New Norway CO_2 Tax Will Raise Petrol Prices," *European Energy Report*, October

19, 1990, "Swiss Act on Global Warming", Treanton, private communication

61. Dale W Jorgenson and Peter J Wilcoxen, Harvard University, "Global Change, Energy Prices, and U.S Economic Growth," Testimony before the National Energy Strategy Hearing, U S. Department of Energy, Washington, D C , July 20, 1990

62. U S. Congressional Budget Office, "Carbon Charges as a Response to Global Warming The Effects of Taxing Fossil Fuels," August 1990; William U Chandler and Andrew Nicholls, "Assessing Carbon Emissions Control Strategies A Carbon Tax or a Gasoline Tax?" American Council for an Energy-Efficient Economy, Washington, D.C , February 1990

63. IEA, *Energy Policies and Programmes*

64. "Pulp Plant to Produce Own Energy," *Gazeta Mercantil*, December 4, 1989, Patrick Knight, "Economies, Charges and Privatisation in Brazil," *Energy Economist*, May 1990, U S Agency for International Development (AID), Office of Energy, "Costa Rica Government Issues Executive Decree," *Private Power Reporter*, May 1989, "Country Profiles Denmark"; Sara Knight, "Fundamental Policy Change Means Premium Tariffs for Renewables," *Windpower Monthly*, October 1990, Magnar Norderhaug, Worldwatch Institute Norden, Tonsberg, Norway, private communication, November 9, 1990, M I Lashkar, "Private Sector Makes Headway," *Pakistan & Gulf Economist* March 10-16, 1990, "Lisbon's Plans for Privatisation of Electricity Gain Momentum, *European Energy Report*, September 7, 1990; "Special Report. Portuguese Energy Concerns,' *European Energy Report*, May 18, 1990, U S. AID, Office of Energy, "New Private Power Law Provides Incentives to Developers," *Private Power Reporter*, July 1990, Barbara Toman, "U.K Plan to Privatize Electric Utility Could Be a 'Monster' for Government," *Wall Street Journal*, October 24, 1990, for examples in the United States, see American Council for an Energy-Efficient Economy, *ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, Vol. 5 Integrated Resource Planning (Washington, D C.. 1990), and Nancy Hirsh, *Building a Brighter Future State Experiences in Least-Cost Electrical Planning* (Washington, D C Energy Conservation Coalition and Environmental Action Foundation, August 1990)

65. DOE, EIA, *State Energy Data Report, Consumption Estimates, 1960-1988* (Washington, D C. April 1990), DOE, EIA, *Annual Energy Review 1989*, Bureau of Census, *Statistical Abstract of the United States 1990*, Karen Griffin, CEC, Sacramento, Calif , private communication and printout, October 18, 1990; CEC, *Energy Efficiency Report 1990*, committee draft (Sacramento, Calif. September 1990), CEC, *Electricity Report 1990*, final draft (Sacramento, Calif September 1990)

66. California Public Utilities Commission (CPUC), "CPUC, Major Utilities Promote Energy Efficiency and Conservation Programs," press release, San Francisco, Calif., August 29, 1990; Armond Cohen, Conservation Law Foundation, Boston, Mass , private communication, October 29, 1990; Elizabeth Kolbert, *New York Times*, "Utility's Rates Tied

to Saving of Electricity," September 1, 1990, "NEES to 'Mine' Customers' kWh," *Electrical World*, October 1989, Oregon Public Utility Commission, "PUC Lauds PP&L's Conservation Program as an Oregon 'First'," press release, Salem, Ore , July 19, 1990, David Moskovitz, "Profits & Progress Through Least-Cost Planning," National Association of Regulatory Utility Commissioners, Washington, D C , November 1989, CEC, *Energy Efficiency Report*

67. Worldwatch Institute estimates, based on CEC, *Electricity Report 1990*, and Peter Gleick et al , "Greenhouse-Gas Emissions from the Operation of Energy Facilities," prepared for the Independent Energy Producers Association, Sacramento, Calif , July 22, 1989

68. Knight, "Fundamental Policy Change Means Premium Tariffs for Renewables "

69. IEA, *Energy Policies and Programmes*, Washington State Energy Office, "Cost-Effectiveness of Residential Building Energy Codes," Olympia, Wash , December 1989

70. Marcia D Lowe, *Alternatives to the Automobile Transport for Livable Cities*, Worldwatch Paper 98 (Washington, D C Worldwatch Institute, October 1990)

71. *Ibid*

72. "German City Lashes Out at Global Climate Change " *Multinational Environmental Outlook*, September 18, 1990, Portland Energy Office, "City Heat," Portland, Ore , Winter 1990; Susan Anderson, Portland Energy Office, Portland, Ore , private communication, May 14, 1990

73. IEA, Solar Heating and Cooling Programme, *Solar Update*, May 1990, "German City Lashes Out at Global Climate Change", "West Berlin to Support Solar," *European Energy Report*, April 20, 1990, Anderson, private communication, "Arizona Solar Village Project Gets Manager, Planning Permit Next Step," *International Solar Energy Intelligence Report*, December 15, 1989, City Manager's Office, "The Civano Report," Tucson, Arizona, July 1990

74. IEA, *Energy Policies and Programmes*, "World List of Nuclear Power Plants "

75. IEA, *Energy Policies and Programmes*, Crawford, "Fusion Panel Drafts a Wish List for the '90s"

76. "Amoco in Petrol from Coal Venture," *European Energy Report*, April 6, 1990, IEA, *Energy Policies and Programmes*, DOE, Assistant Secretary for Fossil Energy, *Clean Coal Technology The New Coal Era* (Washington, D C November 1989)

77. PPS Gusain, *Renewable Energy in India* (Vikas Publishing House Delhi, 1990)

78. Committee on Alternative Energy Research and Development Strategies et al , *Confronting Climate Change Strategies for Energy Research and Development* (Washington, D C National Academy Press, August 1990)

79. IEA, *Energy Policies and Programmes*, DOE, *Posture Statement and Fiscal Year 1991 Budget Overview* (Washington, D C January 1990); EESI, "Environmental, Energy and Natural Resources Status Report for the 101st Congress", Frank Stewart, U S DOE, private communication, November 6, 1990, Fred Glatstein, U S DOE, Washington, D C , private communication, November 6, 1990

80. International Atomic Energy Agency (IAEA), *General Conference*, Thirty-fourth Regular Session (Vienna October 1990), Marlene O'Dell, Liaison Officer, IAEA, New York, private communication, October 31, 1990; Gertrude Leitner, Budget Office, IAEA, Vienna, private communication, November 1, 1990, IAEA, *IAEA Newsbriefs*, August/September 1990, Leonard Spector, "Nuclear Exports The Challenge of Control," Carnegie Endowment for International Peace, April 1990

81. Scurlock and Hall, "The Contribution of Biomass to Global Energy Use", Flavin, "Decline of Nuclear Power"

82. United Nations Development Program, *Annual Report 1989* (New York 1989), Eurosolar, "Memorandum for the Establishment of an International Solar Energy Agency (ISEA) within the United Nations," Bonn, January 15, 1990

83. World Bank, *Annual Report 1990* (Washington, D C 1990), World Bank, *China The Energy Sector* (Washington, D C 1985), Flavin, *Slowing Global Warming*.

84. Bruce Rich, Environmental Defense Fund, "The Environmental Performance of the Public International Financial Institutions and Other Related Issues," Testimony before the Subcommittee on Foreign Operations, Committee on Appropriations, U S Senate, July 25, 1990.

85. Ashok Gadgil and Gilberto De Martino Jannuzzi, "Conservation Potential of Compact Fluorescent Lamps in India and Brazil," Lawrence Berkeley Laboratory, Berkeley, Calif , July 1989, Ashok Gadgil, Lawrence Berkeley Laboratory, Berkeley, Calif , private communication, July 17, 1990

86. Country energy employment totals are high because international statistics include energy production along with other non-energy mining activities, International Labour Organization (ILO), *Yearbook of Labour Statistics 1988* (Geneva 1988)

87. *Ibid.*, Bureau of the Census, *Statistical Abstract of the United States 1990*, DOE, EIA, *Monthly Energy Review February 1990*, Edison Electric Institute, *Statistical Yearbook of the Electric Utility Industry/1988* (Washington, D C 1989)

88. All amounts are in U S dollars, Robert L Mansell, "Economic Development, Growth and Land Use Planning in Oil and Gas Producing Regions," in J Barry Cullingworth, ed , *Energy, Land and Public Policy* (New Brunswick, N J Transaction Publishers, 1990), Robert L Mansell, University of Calgary, Alberta, Canada, private communication, September 21, 1990, Michael Philips, "Energy Conservation Activities in Latin America and the Caribbean," International Institute for Energy Conservation, Washington, D C , undated, Howard Geller, "Electricity Conservation in Brazil Status Report and Analysis," American Council for an Energy-Efficient Economy, Washington, D C , August 1990, William Chandler, Pacific Northwest Laboratories, Washington, D C , private communication, August 14, 1990, Chandler et al , "Energy for the Soviet Union", S Sitnicki et al , "Poland. Opportunities For Carbon Emissions Control," prepared for the U S EPA, Pacific Northwest Laboratories, Richland, Wash , May 1990

89. ILO, *Yearbook of Labour Statistics 1988*, "Germany to End Coal Subsidy?" *Business Europe*, London, April 6, 1990, William Chandler, Pacific Northwest Laboratories, Washington, D C , private communication, July 26, 1990, "Reduced Use of Brown Coal and Its Products Called Top East German Environmental Goals," *International Environment Reporter*, March 1990, World Bank, *China Socialist Economic Development*, Volume II (Washington, D C 1983), World Bank, *China The Energy Sector*

90. Steven Buchsbaum and James W Benson, *Jobs and Energy The Employment and Economic Impacts of Nuclear Power, Conservation, and Other Energy Options* (New York Council on Economic Priorities, 1979)

91. Olav Hohmeyer et al , *Employment Effects of Energy Conservation Investments in EC Countries* (Luxembourg Office for Official Publications of the European Communities, 1985), Steve Colt, University of Alaska, Anchorage, "Income and Employment Impacts of Alaska's Low Income Weatherization Program," ISER Working Paper 89 2, Prepared for Second Annual Rural Energy Conference, Anchorage, Ak , October 12, 1989, Meridian Corporation, *Iowa Weatherization Assistance Program Evaluation* (Alexandria, Va 1988), State of Connecticut, Office of Policy and Management, Energy Division, *An Initial Analysis of Low Income Weatherization Issues in Connecticut* (Hartford, Conn Office of Policy and Management, Energy Division, 1988)

92. Michelle Yesney, "Sustainable City Project Annual Report and Recommendation," City of San Jose, Calif , Memorandum, February 22, 1990, Skip Laitner, "Fiscal and Economic Analysis of the Proposed 1990 Energy Management Program for San Jose," prepared for the city of San Jose, Calif , Economic Research Associates, Eugene, Ore , January 30, 1990

93. Worldwatch Institute, based on DOE, EIA, *Electric Plant Cost and Power Production Expenses 1988* (Washington, D C 1990), DOE, EIA, *Coal Production Statistics 1988* (Washington, D C 1989), on Mark Sisinyak, Vice President, California Energy Company, Coso Junction, Calif , private communication, June 19, 1990, on Kathleen Flanagan,

Director of Government Relations and Public Affairs, Luz International Limited, Los Angeles, Calif., private communication, June 18, 1990, and on Paul Gipe, Gipe & Assoc., Tehachapi, Calif., private communication, April 12, 1990, "Solarex Posts Multi-Junction PV Record, Moving to Automated Line," *International Solar Energy Intelligence Report*, June 1, 1990, Neill and Gunter Limited, "A Study of the Socio-Economic Impact of Wood Energy 1988-2008 in New Brunswick," prepared for the New Brunswick Department of Natural Resources and Energy, Fredericton, N B, October 1989, Robert Chamberlin and Colin High, "Economic Impacts of Wood Energy in the Northeast 1985," Northeast Regional Biomass Program, Policy Research Center, Coalition of Northeastern Governors, Washington, D C, May 1986, Employment Research Associates, "Biomass Resources Generating Jobs and Energy," Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, Madison, Wisc., November 1985 63

94. Marlise Simons, "Scientists Urging Gas Emission Cuts," *New York Times*, November 5, 1990

95. Amory B Lovins, "Energy Strategy The Road Not Taken?" *Foreign Affairs*, October 1976

96. *Ibid.*, Energy Policy Project of the Ford Foundation, *A Time to Choose America's Energy Future* (Cambridge, Mass Ballinger, 1974), DOE, EIA, *Annual Energy Review 1989*, U S energy consumption for 1990 is a Worldwatch Institute estimate based on DOE, EIA, *Monthly Energy Review May 1990*

97. Lovins, "Energy Strategy", DOE, EIA, *Annual Energy Review 1989*, INEL et al., *The Potential of Renewable Energy*

98. Lovins, "Energy Strategy", INEL et al., *The Potential of Renewable Energy*, Weinberg and Williams, "Energy from the Sun"

99. Ogden and Williams, *Solar Hydrogen*

100. Worldwatch Institute, based on Meridian Corporation, "Energy System Emissions and Materiel Requirements," prepared for DOE, Alexandria, Va., February 1989, on Paul Savoldelli, Luz International Limited, Los Angeles, Calif., private communication and printout, July 11, 1989, on Paula Blaydes, California Energy Company, San Francisco, Calif., private communication, June 19, 1990, and on Gipe, "Wind Energy Comes of Age"

101. Gipe, "Wind Energy Comes of Age"

102. The photovoltaic panels would actually cover just 15 percent of this land area, John Schaefer and Edgar DeMeo, EPRI, "An Update on U S Experiences with Photovoltaic Power Generation," Proceedings of the American Power Conference, April 23, 1990, U S land area used by the military from Michael Renner, "Assessing the Military's War on the

Environment," in Lester R Brown et al , *State of the World 1991* (New York WW Norton, in press), based on U S Department of Defense, *Our Nation's Defense and the Environment A Department of Defense Initiative* (Washington, D C 1990), on Michael Satchell, "Operation Land-Grab,' *U S News and World Report*, May 14, 1990, on Edward McGlinn, "The Military Land Grab," *The Riverwatch*, Anglers of the Au Sable River, Grayling, Mich , Winter 1990, and on Thomas B Cochran et al , *Nuclear Weapons Databook, Vol II U S Nuclear Warhead Production* (Cambridge, Mass Ballinger, 1987), Randall Swisher, Executive Director, American Wind Energy Association, Washington, D C , press release, September 25, 1990, based on D L Elliott et al , Pacific Northwest Laboratories, Richland, Wash , "U S Areal Wind Resource Estimates Considering Environmental and Land-Use Exclusions," presented at the American Wind Energy Association Windpower '90 Conference, Washington, D C , September 28, 1990

103. J Davidson, "Bioenergy Tree Plantations in the Tropics Ecological Implications and Impacts,' Commission on Ecology Paper No 12, International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, 1987, Zweibel, *Harnessing Solar Power*, ethanol and electric car comparison is a Worldwatch Institute estimate, based on Jim MacKenzie, "Powering Transportation in the Future Methanol from Trees or Electricity from Solar Cells?" World Resources Institute, Washington, D C , March 26, 1987, on U S EPA, Office of Mobile Sources, *Analysis of the Economic and Environmental Effects of Ethanol as an Automotive Fuel* (Ann Arbor, Mich April, 1990), and on Savoldelli, private communication and printout, William Babbitt, Associated Appraisers, Cheyenne, Wyo , private communication, October 11, 1990, U S Department of Agriculture, Economic Research Service, *Agricultural Resources Agricultural Land Values and Markets Situation and Outlook Report* (Washington, D C June 1990)

104. Lena Gustafsson, "Plant Conservation Aspects of Energy Forestry—A New Type of Land Use in Sweden," *Forest Ecology and Management*, No 21, 1987, Lawrence S Hamilton, East-West Center, "Some Soil and Water Concerns Associated with Commercial Biofuels Operation," presented at Third Pacific Basin Biofuels Workshop, Honolulu, Hi , March 27-28, 1989, Timothy Egan, "Energy Project Imperils a Rain Forest," *New York Times*, January 26, 1990, Susan Meeker-Lowry, "Shattering the Geothermal Myth," *Catalyst*, Vol 8, Nos 1&2, CEC, "Avian Mortality at Large Wind Energy Facilities in California Identification of a Problem," Sacramento, Calif , August 1989, Jos van Beek, "Developers Strike Deal with Bird Societies," *Windpower Monthly*, December 1989

105. Susan E Owens, "Land Use Planning for Energy Efficiency," in J B Cullingworth, ed , *Energy, Land, and Public Policy*

106. Peter Newman and Jeffrey Kenworthy, *Cities and Automobile Dependence An International Sourcebook* (Aldershot, U K Gower, 1989), Lowe, *Alternatives to the Automobile*

107. Owens, "Land Use Planning for Energy Efficiency", Michael B Brough, "Density and

Dın. nsıonal Regulatıons, Artıcle XII," *A Unıfıed Development Ordınance* (Washıngton, D.C · Amencan Planning Assocıatıon, Planners Press, 1985)

108. Unıted Natıons, *Global Estımates and Projectıons of Populatıo ı*, Goldemberg and Reddy, "Energy for Development"

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