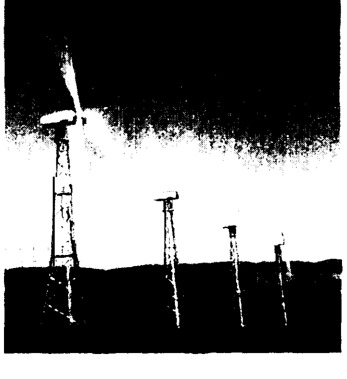
Overview 1

Since the early 1970s, U.S. energy policy has included the development of renewable energy resources—biomass, wind, solar, and geothermal—as an important long-term strategy. Renewable have exceptionally low environmental impact and reduce the nation's oil import vulnerability. They also promise significant economic benefits. These motivations remain strong today even though many factors associated with commercialization of renewable energy technologies (RETs) have changed substantially since the 1980s. In particular, increases in energy efficiency, decontrol of oil and gas prices, and changing OPEC (Organization of Petroleum Exporting Countries) politics and global oil markets have resulted in lower energy prices. At the same time, the changing regulatory framework for electricity is opening new opportunities for nonutility generation of power, which could include RETs.

RET commercial successes and failures have begun to establish a track record in technology cost and performance. As a result, capital markets are now more familiar with the potential benefits and risks of RET investments. Over the past 20 years, for example, prices of wind- and photovoltaic-generated power dropped by 10 times or more, and a small but significant industry has begun to develop around them. Growing awareness of the new opportunities presented by RETs, particularly in developing countries, has generated much interest in, and intense competition from, European and Asian countries and companies,



The costs, benefits, and risks of developing and commercializing RETs, and the time frame and scale of their contribution, depend on the relative maturity of each technology, the particular application, and the market competition. This report reviews the lessons learned in the last 20 years of renewable technology development. In addition, it describes recent advances in RETs and how they might contribute to key U.S. energy policy goals, including economic vitality, environmental quality, and national security. Finally, the report also charts alternative technology and policy paths for developing and commercializing RETs. An overview of how energy is used in the U.S. economy and how RETs fit into changing energy patterns is presented in appendix 1 -A.

It should be noted that RETs are not the only technologies that can help meet national energy goals. Energy efficiency improvements, cleaner conventional technologies, increasing use of natural gas and other lower emission fuels, and other fuels and technologies are all competing for these markets. As discussed throughout this report, RETs offer advantages as well as disadvantages in meeting market as well as national needs. The time frame and scale in which RETs are used in the future will ultimately depend on their cost, performance, and benefits compared with the cost, performance, and benefits of competitors in particular applications.

RENEWABLE ENERGY RESOURCES AND TECHNOLOGIES

Renewable energy resources include biomass, geothermal, hydro, ocean, solar, and wind energy. These resources are discussed in chapters 2 and 5. Summaries of key issues and findings are presented in boxes 1-1 to 1-5. The technical, economic, and environmental characteristics of these resources and their conversion technologies are described in the following chapters. A number of facilitating technologies are also briefly examined in the following chapters, including energy storage,[1] electricity transmission and distribution (see chapter 5), and power electronics (see chapters 4 and 5). Renewable energy resources are distributed widely across the United States, with one or more resources readily available in every region.

| what Has Changed

Crash efforts to develop RETs were initiated following the first OPEC oil embargo two decades ago. In a number of cases, commercialization was begun while the technologies were still under development; inevitably, this resulted in some technical and commercial failures. For those technologies that were successful, we now have the benefit of two decades of research development, and demonstration (RD&D) and commercialization efforts. Costs of many RETs have dropped sharply (e.g., see figure 1 -1), and performance and reliability have gone up. Numerous systems have been installed in the field, providing experience and allowing some scaleup in manufacturing (see figure 1-2). Where high-quality resources are available, a variety of RETs now offer cost-effective,[2] env ironmentall y sound energy services in numerous applications. Examples include the use of passive solar in buildings and electricity-generating technologies such as biomass, geothermal, and wind energy.[3] Several others, such as photovoltaics (PVs, are now limited to high-value niche markets, but could become broadly cost-competitive within the next decade or two (see chapter 5). Technologies for integrating renewable into systems are also substantially improved (chapter 5).

Commercialization efforts over the past two decades have shown that some technologies and policies work and some do not. Federally supported RD&D programs have found considerable value in public-private partnerships, as they main-

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1 Storage technologies include bioenergy liquids and gases; compressed air storage; electric batteries (and other chemical storage systems); thermal energy storage in thermal mass, oil, or phase change salts; pumped hydroelectric; and others not discussed in this report such as superconducting magnetic energy storage.

2 As used throughout this report, a *cost-effective* technology is one that costs less than competing technologies when they are compared on a life-cycle cost basis, using the technologies' capital and maintenance costs, market energy costs and discount rates, technology lifetimes, and other relevant factors. This does not include externalities, fuel cost risks, or other factors (see chapter 6).

3 Hydro has long been a low-cost electricity generator and is not listed here.

BOX 1-1: Bioenergy

Biomass (“stored sunshine”) IS the second most commonly used renewable resource, just behind hydropower. Biomass IS used extensively for home heating(firewood)andfor generating electricity, especially inthe forest products Industry In addition to wood burned directly for heat, agricultural residues, animal wastes, and municipal solid wastes are used as biofuels and have considerable potential The greatest potential IS from plants grown specifically for their energy content. These plants also could be burned di rectly or gasified for use in a combustion turbine for electriciy, or converted to other fuels, such as alcohol, for use in the transportation sector

The agricultural sector could produce large quantities of trees and grasses that can be converted to electricity heat, or liquid or gaseous fuels These crops could provide such as one-quarter of current national primary energy use, however, the amount of land that WiIl be available for energy crops IS uncertain

Perennial trees and grasses can protect SOiIS, improve water quality and provide habitat for a variety of animals, unlike conventional annual row crops In contrast to corn-ethanol—the most familar energy crop----these crops have high net energy returns and are potentially cost-comptitive with fossils. If bioenerg crops replace fossil fuels, they can reduce the emission of sulfur oxides (SO_x) and greenhouse gases, and also reduce U S dependence on Imported ott, which now costs $45 billion per year. Growing these crops and converting them to fuels or electricity could provide additional jobs and income to hard-pressed rural areas while potentially offsetting portion of the roughly $10 billion in current federal expenditures on SOiI conservation, commoditysupports, and certain other agricultural programs.

Bioenergy crop productivityhas increased by more than 50 percent and costs have been sharply reduced in the past 15 years, based on research on more than 125 woody and grassy species and Intensive development of half a dozen Although they are approaching cost-competitiveness in some cases, additional R&D IS needed to further Improve these crops and their harvesting and transport equipment, support agricultural extension efforts, and fully develop the fuel conversion and electricity generation technologies.

Much of the success of U S agriculture IS due to federally funded RD&D. The highly fragmented nature of the sector has precluded extensive research,and that situationalso applies to biomass In addition to RD&D, realizing the broad potential of energy crops WiIl require considerable planning and coordination among public and privateentitles Mechanisms to help broker or leverage partnerships between bioenergy farmers and processors may be useful during the commercialization process.

SOURCE Off Ice of Technology Assessment 1995

tain a commercial focus and incorporate a technology transfer process. Federal tax policy has, in some cases, begun shifting to performance-based measures such as energy production credits and away from investment-based measures such as investment tax credits. Many programs increasingly emphasize leveraging federal investment by moving Upstream to where a product is designed or produced in order to have the greatest impact per unit investment. The past two decades of commercialization experience can be a useful guide should changes in federal policies and initiatives to develop and commercialize RETs be considered.

For some RETs, a substantial industry has begun to develop. The industry downsized after tax benefits expired or were reduced beginning in 1986 and as energy prices dropped. Many large firms left renewable energy, and smaller companies closed. Other firms-many small, some medium, and a few large-continueddevelopment and have realized substantial improvements in cost and performance. Based on these advances and the many new opportunities foreseen for

BOX 1-2: Direct Solar Use in Buildings

Residentialand commercial buildings use about $18 billon worthof energy annually for services such as space heating and cooling, lighting, and water heating. Following the first oilembargo, a number of efforts were launched to use renewable energy inbulidngs despite the lack of research, development, and demonstration (RD&D). Many of these premature efforts to commercialize unproven technologies failed Two decades later, there is now a substantial base of proven technologies and practical policy experience, and many more mid-term RD&D opportunities

Passive architecture and daylighting,which require few or no additional materials, are the most cost-effective of the building RETs. Passivearchitecture uses the same elements as the conventionalbuilding—for example, walls, windows, overhangs—but reconfigures them to capture, store, and distributerenewable energy. Daylighting is a technique for integratingatural light using lightingontrols Combined with efficiency improvements, these RETs have demonstrated cost-effectwe energy savings of 50 percent in new buildings compared withtheir conventionalcounterparts. Bulldlng-integrated technologies that reduce material use by serving both as part of the roof or wall and as an energy collector are also frequently cost-effective. In contrast, technologies that require large amounts of expensivematerials, for Instance, add-on rooftop collectors to provide low-quality heat, such as for spaceheatingthe type most people think of—are often not cost-effectiveunder current conditions

Although passive architecture, daylighting, and certain other technologies have demonstrated good performance inthe field, their use remains limited due to factors such as the complexity of passivedesign, the lack of good computer-aided design tools, and the lack of trained architects/engineers Further, the construction Industry is highly fragmented inthe United States, invests little in RD&D or technology transfer, and is slow to change. The buildings market also places little premium on building energy performance, few know what their energy bills are likelyto be before purchasing a building, energy costs are generally not considered indetermining mortgage eligibility, even if energy costs are a significantfraction of owning and operating the building and landlords, for example, often do not pay energy bills and so have little reason to invest in RET features,

Tax credits have been used to encourage the application of RETs in buildings However, the credits effectively were limited to measurable add-on equipment, rather than more cost-effective passivearchitecture and buildingintegrated systems. Potentially higher leverage supports include RD&D and field validation, design assistance and education and Information programs, and energy performance-based mortages or financial incentives.Inrecent years, funding of the Department of Energy's solar buildings program has been less than $5 million, a tiny fraction of the potential savingsfrom wide-scale commercialization.

SOURCE Office of Technology Assessment, 1995

RETs due to environmental, economic, and other considerations, some large firms (including foreign firms) are now entering (or recentering) the RET industry. Wind electric companies are now beginning to emerge as strong competitors with conventional systems. Others, such as in the buildings sector and solar thermal electric systems, have not yet recovered. Still others—such as PVs—were relatively unaffected by these changes and have continued to grow at a strong pace throughout this period by concentrating on higher value niche markets (although still a small industry).

Finally, the general business practices of the RET industry have matured considerably in the last decade. The substantial changes in the business environment-declining (in real terms) fossil energy prices, international competition, new federal legislation such as the Energy Policy Act of 1992 and reauthorization of the Clean Air Act,

BOX 1-3: Renewables in the Transportation Sector

The Ford Flexible Fuel vehicle, an adaptation from a regular production Taurus, will operate on methanol, ethanol, gasoline, or any combination of those fuels

Highway transportation accounts for about one-fifth of total U S primary energy use, and over half of total U S 011 use, about half of which IS Imported These imports are expected to Increase dramatically over the next several decades, making the economy more vulnerable to the supply and price volatility of the world 011 market

Ethanol and methanol from trees or grasses, diesel 011 substitutes from oil-producing plants, electricity generated by renewable energy, and hydrogen gasified from crops or electrolyzed from water by renewable-generated electricity are the principal renewable energy fuels that might substitute for today's petroleum-based liquids These fuels could be used in a variety of vehicle technologies, Includingconventional Internal combustion engine, battery-powered, hybrid, and fuel cell vehicles Each alternative offers a different set of technical, economic, and performance tradeoffs, research, development, and demonstration (RD&D)challenges, and time frames for commercializationSubstantial technological advances have already been realized in each of these areas over the past two decades Further RD&D remains, but the wide range of renewable fuel and vehicle options greatly Improves the likelihood that one or more WiIl succeed

Even the potentially best process for converting biomass to methanol (thermochemical gasification) or ethanol (enzymatic hydrolyses) WiIl be only marginally competlive with gasoline on a direct replacement basis However, alcohol fuels also can be used in fuel cells, with significantly Improved

As Important Will be developing the necessary fuel and vehicle Infrastructure Technology paths that can take one step at a time, such as fossil fuels in hybrid and then fuel cell vehicles combined with renewable fuels in conventional and then hybrid or fuel cell vehicles, may ease the transition and allow infrastructure development

Much of the benefit of renewable fuels in the transportation sector IS public reduced 011 imports and U S vulnerability reduced pollution (for example, cleaner combustion in urban areas, little or no carbon dioxide emissions), and strengthened rural economies The primary incentive for private sector Investment in substantial R&D efforts IS regulatory, such as the low- and zero-emission vehicle requirements in Califorma Publlc-private joint ventures can leverage Investment and ensure effective commercialization.

SOURCE Off Ice of Technology Assessment, 1995

and considerable changes in the state economic and environmental regulation of the electric utilit y industry—have added complexity to making RET investment decisions. Where resources are favorable, technology cost and performance demonstrated, and environmental benefits valued, some RETs can compete and others have the potential to be competitive with additional R&D. However, establishing the conditions necessary for large-scale investment in RETs, including developing an awareness of the opportunities among potential users and the financial community and resolving institutional difficulties. remains a substantial challenge.

BOX 1-4: Renewables for Electricity Generation

Many RETs are particularly suited to the generation of electricity, a sector that consumes about 36 percent of U S primary energy Of particular interest are

- Bioenergy from plants, which can be burned directly to drive a steam turbine, much like a coal-fired plant, or gasified and burned in a combustion turbine as noted in box 1-1
- *Geothermal* energy in the earth can be exploited in areas where it is concentrated near the surface It is tapped by drilling a well and extracting hot water or steam (similar to an 011 well) to power a turbine Hydrothermal resources, the only commercial resource, are steam or hot water that can be extracted to power a turbine. Geopressurized brine, hot dry rocks, and magma are other resources that WiIl require further RD&D
- **Photovoltaic technologies** convert sunlight directly to electricity Technology and production are advancing rapidly
- ***Solar thermal technologies*** concentrate sunlight on a receiver. The heat is transferred to a fluid that powers a turbine (or is used for industroal process heat). Solar thermal trough systems have performed well, but central receivers and dishes appear more promising.
- ***Wind energy*** is captured by a turbine The technology has matured rapidly. Many applications are cost-effective. Two main types have been developed, horizontal and vertical axis

All of these technologies show great promise to contribute silgnificantly to electricity needs cleanly and cost-effectively; [1] hydropower (a mature renewable technology) has long served The cost and performance of these technologies have Improved dramatically over the past 10 to 20 years, and considerable field experience has demonstrated their long-term potential, The maturity of these technologies varies widely Some are already cost-competitive where renewable resources are favorable Others are still expensive and used primarily in niche markets. 1

All these RETs need further RD&D to improve their cost-competitiveness. Many major Improvements in technology are expected Scaling up manufacturing WiIl also help significantly in reducing costs, but this is difficult because the markets that are viable at current or near-term-achievable costs are not large enough to support Increased manufacturing For biomass, geothermal, and wind, commercialilzation efforts are probably even more Important than RD&D

[1] Not Included here are ocean thermal energy conversion, andtidal and wave energy These technologies have limited applicabili -(y for the United States and are likely to have higher costs than many alfernatives

SOURCE Office of Technology Assessment 1995

Renewable Energy Characteristics

Several characteristics substantitilly affect renewable energy technology cost, performance, and operation. These characteristics directly motivate many of the strategies and policy options discussed below.

Site Specificity

Most renewable resources are site-specific. For example, biomass is available where soils and climate provide good growing conditions for plants (see chapter 2). Geothermal resources are limited to **regions** where there are good underground hot water or steam resources, or high temperatures relatively near the surface; hydropower is available where there are adequate river flows and appropriate topography (including sites for dams); solar energy is widely distributed, but is best in the sunny and dry southwest; and wind resources are best along coastal regions, mountain passes. and

BOX 1-5: Government Supports and International Competition for Photovoltaics

U S manufacturers have led the world in photovoltaic (PV) research, development, and commercialization Today, these manufacturers are facing strong challenges from foreign competitors, which are often more strongly supported by public RD&D and commercilalization programs

The United States was a close third behind Germany and Japan in total support for photovoltaic RD&D in 1992 U S commercialization supports for PVs Include five-year accelerated depredation and a 10-percent Investment tax credit for nonutility generators Electricity buyback rates are set at the utility avoided cost, which is typically in the 3¢ to 7¢/kWh range. These supports are insufficient to pull PVs into utility markets generally The U S strategy for PVS has been to identify and aggregate high-value niche markets In contrast, Italy subsidizes up to 80 percent of the Installation costs of PVs, or provides buyback rates for peak periods of up to 28@/kWh Japan recently launched a program to subsildize up to two-thirds of the cost of household PV systems—with a goal of 70,000 systems Installed by 2000—or has buyback rates as high as 24@/kWh Germany subsidizes up to 70 percent of system capital costs Such large supports appear excessive, but may in fact be strategic these countries expect that by encouraging large-scale production, costs WiIl decline rapidly to levels more broadly competitive. This will provide domestic environmental and other benefits and Will also provide a potentially large cost advantage in International markets

In developing countries, demand for electricity is growing rapidily. Estimates of the overall market for utility power generation equipment are typically in the range of $100 billion per year, Further, many people in rural areas of developing countries are unlikely to be served by conventional electric utility grids for many years RET systems for remote applications can be quite competive with diesel generators Providing these technologies can have a powerful impact on economic development in these countries as well as offering a large market opportunity that can leverage even greater sales of other equipment

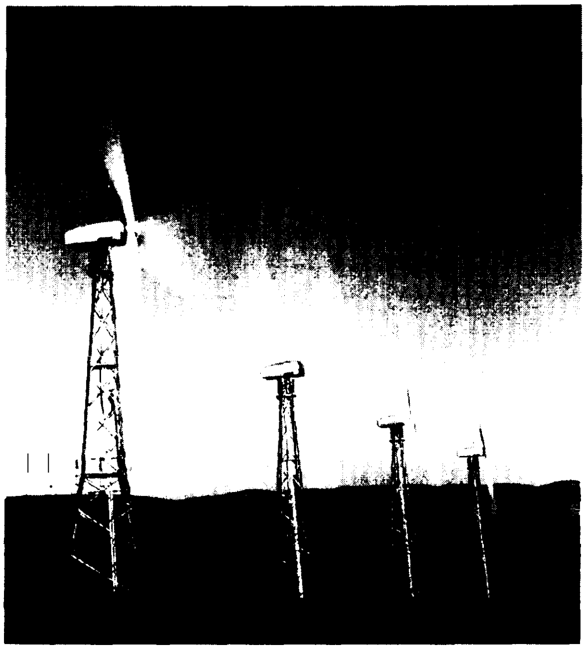
U S -based PV production accounted for about 37 percent of the global total in 1993, of this, about 70 percent was shipped abroad Whether or not U S -owned or U.S. -based firms can maintain this strength WiIl depend on both the level of RD&D conducted here and on the ability of these firms to scale up manufacturing The recent sale of Arco Solar, Solec, Mobil Solar, and others to German and Japanese firms and the joint venture by ECD with Canon (Japan) Indicates a continuing and serious problem for U S firms in supporting long-term RD&D and manufacturing Investment As a consequence, nearly two-thirds of U S -based PV production is by foreign-owned firms Other companies, especially small, innovative firms, may also be bought out if they cannot obtain funding for R&D and manufacturing scaleup On the other hand, the recently announced venture between Solarex and Enron Corp. for a manufacturing scaleup of PV production within the Nevada Solar Enterprise Zone may provide a model for privately led, publicly leveraged investment A potentially very large market is at stake

SOURCE Off ce of Technology Assessment 1995

in the plains states (see chapter 5). Some resources also vary dramatically even among adjacent locations. For example, wind resources may be very good at one part of a mountain pass. but poor on the downwind slope. This site specificity has several important implications:

- *Resource evaluation. Site-specific* (and often intermittent) resources may require extensive measurement over a relatively long period of time (years) in order to adequakly evaluate their potential.
- *Design.* Site specificity requires greater attention to the design of renewable energy systems than is the case for fossil-fueled technologies. This is particularly important in the case of passive solar buildings (chapter 3) and certain electricity generating RETs (chapter 5).

KENETECH WINDPOWER, INC



Kenetech Windpower Inc. 33M-VS wind turbines lated at Altamont Pass, California Wind turbine performance greatly improved over the past 15 years, and costs have declined

- *Energy transportation/transmission. Site specificity* may mean that economically attractive resources are located at a distance from where the energy will be used, requiring long-distance transportation/transmission of the generated energy. In turn, this may require the development of substantial infrastructure at a significant capital investment. RETs also vary considerably in their energy transportation/transmission requirements. Geothermal, wind, biomass, and some solar thermal systems tend to be relatively large centralized facilities requiring (often dedicated) high-power transmission systems, while PV and solar thermal systems can be small, widely dispersed units that can potentially be integrated into existing lower power transmission and distribution (T&D) systems.

Strategies that respond to site specificity include: conducting extensive resource valuations and developing appropriate site-sensitive analytical tools, including geographic information systems.

Intermittence

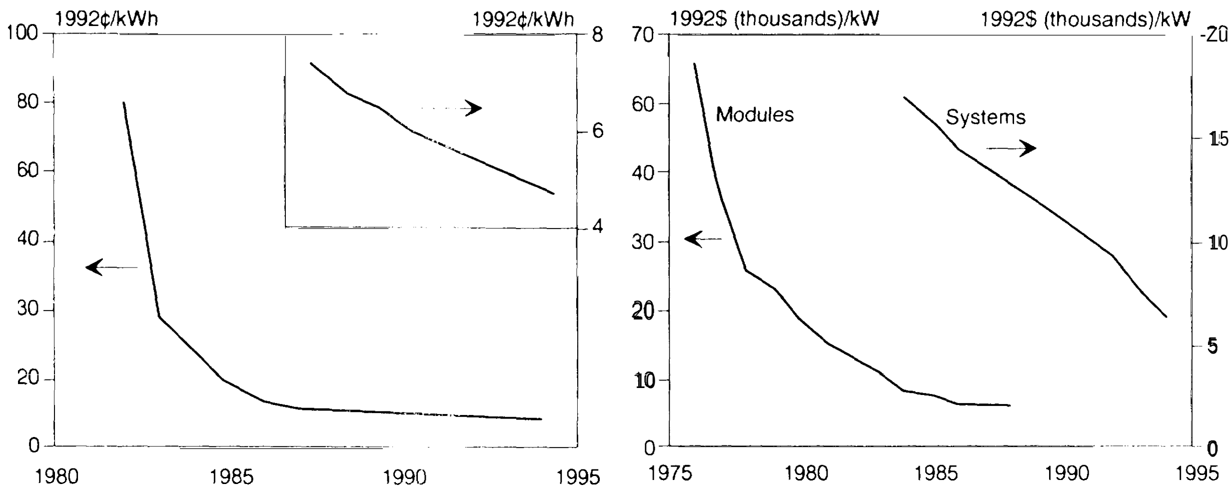
Renewable resources differ in their availability. Hydro (with dam storage) and biomass have storage built in—for example, biomass is stored sunshine—and can consequently be operated at any time of the day or night as needed. Geothermal and ocean thermal energy tap very large heat reserves that provide storage. These systems can directly offset utility fossil-fuel-fired capacity. In contrast, wind and solar systems are available only when the wind blows or the sun shines; they are intermittent. Intermittence introduces two major considerations:

- *Application, integration, and operation.* For electric power systems, the energy end use powered by an intermittent renewable resource must either not require energy on demand, such as certain remote electric power applications,

HOLLY KUPER DALLAS TEXAS

A home in the 1994 award-winning Esperanza del Sol development m Dallas For a net capital cost of $150, energy effciency and renewable energy /improvements reduce the *annual heating and cooling bill to an estiamated $300, ha/f that of s/molar convenal homes in the area*

FIGURE 1-1: Cost Reductions for Wind Energy and Photovoltaic Technologies, 1980-94



NOTE The cost of wind and photovoitaic (PV) systems and generated eleclricity DECLINED The figure or the Left shows data for wind turbines rstalied in Calfornia (which accounts for most turbines in the United States) The figure on the right shows overall U S. PV modole costs, and complete PV systems installed at the Pte PVUSA site in Davis California To conver PV system costs to an approximate cost of generated electricity divide the system capital cost by 20,000 to get c/ kWh Expanded scales show that costs continue to decline sharply

SOURCES Wind data are from Pad Gipe Paul Gipe and Associates Tehachapl CA Wind Energy Comes of Age in California, Dale Osborn. persona commumcation, April 1994 PV data for modules only are for U S based production and were provided by George Cody EYXON Corporate Research and Developmenyt Laboratory personal communication, February 1993 Paul Maycock, PV Energy Systems.Inc., January 1993 For complete PV systems data are for installations by U S PV manufacturers under the PVUSA project at Davis California, and were provide by Dan Shugar Advanced Photovoltaoc Systems Inc., personal communication, June 1994

or the system must be effectively backed up by integrating it with other power systems (such as gas turbines or hydropower) or by storage systems (such as batteries).4 At small to moderate penetration levels, intermittence poses few difficulties for system integration: at high levels there may be some operational difficulties by requiring greater ramping up and down of generation by conventional equipment in order to meet demand (see chapter 5). Similarly, using intermittent solar energy in buildings generally requires thermal storage or conventional backup for heating, and integration with conventional lighting.

. Capacity value. Capacity value refers to the conventional generating capacity (that a utility does not need when it invests in a RET. Where the match between intermittent RETs (iRETs) and utility peak load is good. as with solar radiation and summer air conditioning, the capacity value of the iRET is relatively high. Capacity value can significantly affect iRET economics. but only if the utility calculates and credits it, The full value of the iRET is determined by both the conventional capacity that it offsets and the fuel it saves (see chapter 5). Similar considerations apply to the design of passive or active systems for buildings and the

[4] Other storage systems that might be used include compressed air energy storage, pumped hydro, or possibly superconducting magnetic energy storage.

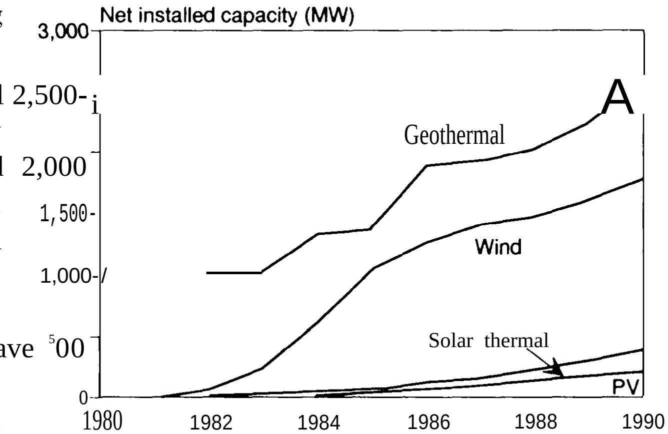
sizing of conventional heating and cooling equipment for backup (see chapter 3).

There are several strategies that may be useful in accommodating interrnittency. In electricity generation, for example, resources such as wind and solar can be collected over a larger geographic area to average fluctuations, or combined with other RETs (e.g., combining wind and solar systerns) that provide energy at different times, complementing each other. This may, however, have significant impacts on T&D systems in order to move the energy across these larger geographic areas. More generally, hybrids of conventional and renewable energy systems can be formed. A hybrid plant relies on renewable energy when available, providing environmental and other benefits, as well as extending fossil resources, and switches to fossil fuel when necessary for backup. Fossil hybrids have been particularly important fer solar thermal development in California and may have many other applications with biomass, geothermal, and other systems. There may also be opportunities to form hybrids between RETs and energy storage systems such as hydro (pumped or conventional) or compressed air (see chapter 5).

Resource Intensity

Some renewable energy resources are very diffuse. Biomass is probably the most diffuse resource (the conversion efficiency from sunlight is typically less than 1 percent), but it is an inherently stored form of solar energy that can be collected and held until needed. Solar and wind also must be collected over large areas but are not in a readily storable form like biomass or hydro.[5]

FIGURE 1-2: Installations of Renewable Electricity Generation Capacity



NOTE PV Installations are on a global basis, the others are for the United States alone Substantial amounts of RET electricity-generatmg capacity have been Installed over the past 15 years This has provided field experience and allowed some scaleup in manufacturing of particutar technologies

SOURCES Office of Technology Assessment, based on data from (PV) Paul Maycock, PV Energy Systems, Inc , personal communication, December 1993, (solar thermal) David Kearney, Kearney and Associates, personal communication, June 1993, (wind) Paul Gipe, Paul Gipe and Associates, Tehachapi, CA, “Wind Energy Comes of Age in California, ” n d , and (geothermal) Gerald W Braun and H K “Pete” McCluer, Geothermal Power Generation in the United States, ” Proceedings of the */EEE,* VOl, 81, No 3, March 1993 pp 434-448

[5]solar energy has typical energy fluxes of 150 to 250 watts/square meter (W/m[2]) as an annual average, depending on the local climate (see figure 5-6). High-quality wind energy resources are somewhat more concentrated; in good locations such as the Altamont Pass in California, typical wind energy fluxes are perhaps 450 W/m*.

TABLE 1-1: Approximate Land Areas Required for Conventional and Renewable Power Production

Plant type	Area: Hectares per MW	Acres per MW
Geothermal	0.1-03	0.25-0.75
Gas turbine	03-08	0.75-2.0
Wind	0.4- 1.7	1,0-4,2
Nuclear	O 8-1.0	2,0-2.5
Coal-steam	0.8-80	20-20,0
Solar thermal	10-4,0	2.5-10.0
Hydropower	2.4-1,000	6.0-2,500
Photovoltaics	3.0-7.0	7,5-17.0
Biomass	150-300	370-750

NOTE All values have been rounded off The value for nuclear Includes only the plant Itself, not the area required for mining or waste disposal, the value for coal includes the area for mining the value for natural gas does not include the area for long-distance pipiline transport, the value for solar thermal and photovoltaics, as well as other renewable depends strongly on the assumed conversion effociency.

SOURCES Ronald DiPippo, "Geothermal Energy, " Energy Policy October 1991, pp. 798-807, table p 804, Jose-Roberto Morera and Alan Douglas Poole, "Hydropower and Its Constraints, " *Renewable Energy Sources for FueLs and E/ectricity,* Thomas B Johansson et al (eds) (Washington, DC Island Press, 1993), and Keith Lee Kozioff and Roger C Dower, A *New Power Base Renewable Energy Policies for the Nometoes and* (Washington, DC World Resources Institute, 1993)

solar, wind, and certain other low-intensity renewable energy resources require large, capital-intensive collectors. In effect, these systems pay up front for fuel over the lifetime of the system. This eliminates the risk of fuel cost increases faced by fossil-powered systems, but raises the financial risk should the system not perform as predicted. In some cases, these front-loaded costs result in the demand for greater financial security up-front.

One strategy to moderate the high capital costs of large-area energy collection is to develop lightweight, low-cost collectors. Lowering capital costs usually requires minimizing use of materials and poses difficult engineering tradeoffs. Many renewable energy systems can be constructed in small- to moderate-sized modular units. This can reduce the financial costs and risks and the time required to demonstrate new generations of the technology compared with large-scale technologies such as coal and nuclear plants. Small modular units can also be manufactured at centralized mass production facilities, providing economies of scale to reduce costs.

Another strategy is to use systems for multiple purposes. A good example of a multiple-purpose system is the passive solar building, in which the building itself serves as the collector (see chapter 3). Such systems are design-intensive as it is necessary to effectively capture solar energy with minimal use of costly additional materials. Other examples include integrating PVs or thermal collectors directly into the building shell to serve as a part of the roof or wall and provide energy at the same time.

Despite the low resource intensity, the large land areas required for renewable energy collection do not generally appear to be a significant constraint for most RETs. For example, with the exception of biomass and, in some cases hydro, the total collection area required for RETs is comparable to that for many fossil energy resources when the land area required for mining is included (see table l-l). The best locations for solar systerns, in particular, also tend to be desert areas with fewer land-use conflicts. Thus, total U.S. electricity y needs could in theory be produced from less than 10 percent of the land of Nevada.

Technology Maturity

Renewable energy technologies vary widely in maturity. RETs such as passive solar buildings, biomass electricity, geothermal, and wind are already cost-competitive in many important applications. PVs, solar thermal-electric, and biomass fuels for transport show great promise, but require further RD&D and commercialization to become cost-competitive in key markets; they are now limited to niche applications. (Specific RD&D needs and opportunities are discussed in the following chapters). Policies designed to encourage the growth of RETs must be tailored to the unique attributes and needs of each.

Accommodating Resource and Technological Characteristics

These renewable resource characteristics are, in some respects, little different from those of conventional resources used today. For example, electric utilities have always had to consider site specificity-such as in hydropower siting, obtaining cooling water for coal or nuclear plants, or in dealing with local environmental concerns. Scheduled maintenance and breakdowns reduce the availability of all plants. Utilities integrate reserves and nonutility generators, often of small scale, into their networks.

While the operating characteristics of RETs are not very different from those of conventional technologies, the analytical tools that utilities use to plan and operate the grid (e.g., utility capacity expansion and dispatch models) are often not well-suited to aspects of many RETs, such as their site specificity, intermittence, often small scale, and T&D requirements and impacts. Developing such tools offers a potential y high leverage means of encouraging the use of RETs, especially in the buildings and electricity sectors.

Significant benefits could be realized by integrating renewable energy, conventional supply, and energy-efficient technologies. Building design and operation can benefit by combining efficiency and renewable, which can also benefit utilities through load shifting, peak-load reduction, and other demand-side management techniques (see chapter 3). Building-integrated photovoltaics have the potential to lower PV costs and T&D requirements (see chapters 3 and 5). Integrating fuel cells might have analogous benefits. Battery-powered vehicles might be recharged on a schedule that assists utility operations (see chapters 4 and 5). Hybrids can be formed of renewable and conventional electricity-generating equipment (see chapter 5). Such approaches to intra- and intersystem integration can open new, cost-effective market opportunities.

| Energy Markets and Renewable Energy Technologies

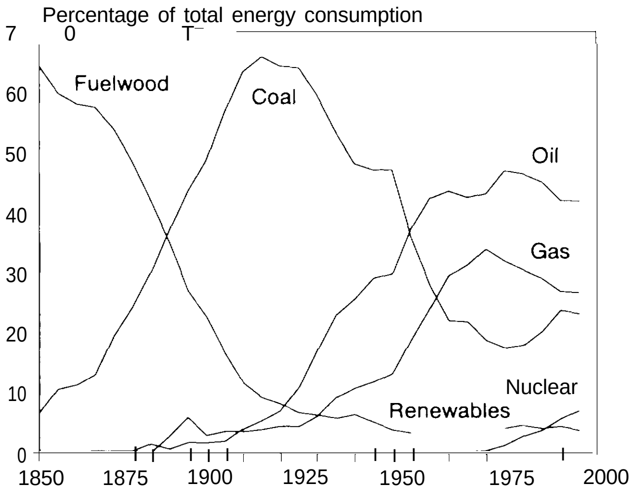
Although they manifest themselves in different ways, several market challenges appear repeatedly when commercializing RETs in the different sectors of the U.S. economy.

Competitor Prices

The price of fossil fuels is near historic lows, making them very difficult to compete against in many energy markets. Although the Energy Information Administration (EIA) projects that fossil fuel prices will increase over time (see appendix 1-A), the *risk* of sharp and/or sustained reductions in their price make it difficult for many firms to maintain a viable long-term development strategy for RETs.

Energy (oil) markets have been and may again be driven by the OPEC cartel rather than market supply and demand. The economy is highly vulnerable to energy price increases, and alternative supplies require long lead times to develop (see figure 1-3). For example, slightly higher oil prices for six months following Iraq's invasion of Kuwait raised the U.S. oil import bill by roughly $8

FIGURE 1-3: Consumption Patterns of U.S. Energy, 1850-1993



NOTE The energy resources used by the United States have changed considerably over the past 150 years Fuelwood was initially the dominant resource giving way to coal then to 011 and natural gas The time for each trarsition has been somewhat more than half a century This provides a measure of how much lead time may be required to significantly shift our energy systems over to nonfossil fuels should global warming or other environmental economic or security concerns so warrant

SOURCES Off Ice of Technology Assessment based on data in J Alterman Electric Power Research Institute "A Historical Perspective on Charges in U S Energy-Output Ratios " Report EA-3997 June 1985 and Energy Information Administration, Annual Energy Review 1993, USDOE/EIA-0384(93) (Washington, DC July 1994)

bi11ion[6]---on top of the roughly $45 billion spent annual] y for imported oil. In addition, energy markets do not now incorporate all environmental costs, resulting in imperfect market functioning.

Some observers believe that any attempts to modify the market will be worse than the problems they were intended to solve. Many such observers still support RD&D programs as a strategy for dealing with energy price volatility and other issues. A more activist strategy might include financial incentives and competitive set-asides in order to diversify supplies.

Front-Loaded Costs

As noted above, many RETs are capital -intensive. requiring large capital investment and possibly additional financial security to cover risk (see chapter 6). Many potential investors also require short payback times, further complicating investment strategies.

Strategies to deal with high capital costs include encouraging (or requiring, in some cases) purchasing decisions to be based on Iifecyclc costs; allowing utility customers to choose generation technologies through green pricing schemes;[7] placing front-loaded environmental taxes and fuel cost bonds on conventional systems: and creating innovative financial mechanisms that reduce the front-loading.

Manufacturing Scaleup

With many new technologies, including RETs. there is a frequent "chicken-and-egg" problem of needing a large market to scale up manufacturing: and thus lower costs, but needing low costs to develop a large market. There are several strategies to encourage manufacturing scaleup. Market purchases can be aggregated and coordinated across many potential customers. This is being actively pursued by electric utilities in PV markets (see chapters 5 and 6). Compatible market niches can be found that independently allow gradual scalcup: an example might be cofiring biomass with coal (see chapters 2, 5, and 6). Low-value uses as energy can sometimes be linked with high-value uses; an example is using biomass for energy (low value) or for fiber (high value) according to market demands and biomass supplies. Long-term partnerships can be formed to lower the product ion scaleup risks for both supplier and user; an example might be to partner farmers with utilities.

[6]Roughly equivalent to 200 times current federal RD&D funding for biomass transport fuel.

[7]Green pricing is discussed in the policy options section below and in chapter 6.

OAK RIDGE NATIONAL LABORATORY

Farmers m Texas discussing switch grass, a potentially Important energy crop

Finally. electricity markets can be differentiated by value, in contrast to the average pricing now common. This is already done in the case of remotc markets; structural change may also encourage such market differentiation within the electricity grid and elsewhere.

Strural Change in the Electricity Sector

Substantial structural change is now under way in U.S. (see chapters 5 and 6) and global electricity markets (see chapter 7). In the United States, this change has so far been manifested primarily by the increasing role of nonutility generators and by the use of competitive bidding in the purchase of new capacity and power. These changes are being accelerated by the Energy Policy Act of 1992 (EPACT—which allows the formation of Exempt Wholesale Generators and addresses transmission access issues) and by recent proposals by several state public utility commissions to consider opening competition for electric power sales to the retail level (see chapters 5 and 6).

These changes are likely to have mixed impacts on RETs. The purchase of RETs has been lower under competitive bidding than under approaches such as California's standard offers during the early to mid-1980s.[8] Some believe that a reduction in the purchase of RETs is inevitable due to the current low natural gas price; others believe that the bidding process fails to fully value RETs and their benefits. Structural changes and the resulting competitive pressures may also reduce electricity sector investment in RD&D, and shorten corporate and utility planning horizons. For example, the California Energy Commission estimates that investor-owned utilities will decrease their investment in advanced RD&D by 88 percent in 1995 compared with 1993 while overall RD&D will decline by one-third compared with 1992. This is likely to be particularly serious for higher risk mid- to longer term research efforts in RETs.

On the other hand, such structural change might assist the penetration of RETs into the electricity sector in the future by differentiating energy markets by value and function (unbundling). This is in contrast to the average pricing schemes widely used for electricity today. Segmenting the market may open higher value niches for which RETs can more effectively compete, allowing some market scaleup, particularly if supported by coordinated market aggregation efforts. Niche markets do have their limits, however. It is not yet known whether a strategy of pursuing niche markets will be sufficient to enable the cost reductions necessary to compete in large-scale power markets.

Leveling the Playing Field

Many have suggested that the market is sharply tilted against the purchase and use of RETs due to direct and indirect taxes, subsidies. and other factors. The Office of Technology Assessment evaluated five factors affecting RETs in the electricity

[8] The Public Utility Regulatory Policies Act establishblished a category of qualifiing facilities (QFs), which were restricted to enewable energy and cogeneration power stations. Utilities were directed to buy the power from QFs at their avoided cost of power production. The California standard offers were developed in response to this requirement. Competitive bidding not generally restricted by fuel source.

sector: powcrplant finance, full-fuel-cycle financc. direct and indirect subsidies, risk and uncertainty, and environmental costs (see chapter 6). While there appears to be some tilt against RETs overall, the nature and degree vary with the particular energy resource and technology. More significantly. the analysis suggested that some of' the policies intended to stimulate use of RETs probably have relatively little impact.

Accelerated depreciation compensates for part—but often not all--of tax code provisions that disadvantage capital-intensive RETs. Benefits such as EPACTs 10-year, 1.5c/kWh Renewable Electricity Production Credit provided to wind and closed-loop biomass systems reduce full-fuel-cycle taxes in the scenarios modeled down to or somewhat below those for natural gas, unless limited by Alternative Minimum Tax provisions (see chapter 6). In contrast, these tax benefits provide 1ittle support for RETs that now have relatively high costs, yet need to enter these large-scale markets if'they are to scale up manufacturing and and capture economies of scale sufficient to 1ower their costs to more competitive levels.

Infrastructure Development

The development of a supporting infrastructure for RETs can require large capital investments. This can be a heavy overhead before RET development can begin. Examples include establishing long-distance transmission lines for RET generating facilities sited where resources are good but far from loads. and pipelines and distribution systems for renewable fuels.

Strategies to develop supporting infrastructure involve long-term. multiple-use planning around particular technology paths. Transmission systems installed for conventional power systems r-night consider routes that would allow longer term development of RETs: gas pipelines might consider routes that would allow gas use in hybrid RET powerplants, or conversely. might allow trtinsport of renew'able fuels to load c'enters. Technologies might be chosen that are more readily adapted to a wider range of fuels, allowing use of renew'able fuels when they become cost-effective in the future.

POLICY OPTIONS

If RETs are to be further developed and commercialized. various policy options could be considered (see table 1 -2). The costs, benefits. and risks of specific strategies will vary with a particular RET, its relative maturity, its market competitors. and other factors.

■ Development

Federal funding for RET development increased since 1990 following the Bush Administration's development of the National Energy Strategy. The Department of Energy (DOE) FY 1995 RD&D budget of $344 million ($310 million in 1992 dollars) is up from its low of $119 million (in 1992 dollars) in FY 1990, but is below the funding levels of the late 1970s and early 1980s (see table 1-3).

At present, RETs are expected to penetrate energy markets slowly. Although EIA projects RET electricity generation (excluding hydro) to more than double between 1993 and 2010—from 52 billion to 118 billion kWh per year—this will account for just 3 percent of total U.S. electricity generation in 2010.[9] Continued development of these technologies will, however, lay the foundation for more rapid expansion later. The huge scale of the U.S. electricity and other energy sectors require very long times to turn over their capital stock and develop new technologies, and manufacturing enterprises to have a significant impact. RETs would be cost-effective for many additional applications—for example, passive solar buildings and electricity generation technologies such

[9] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1995*, DOE/EIA-0383(95) (Washington, DC: January 1995).

TABLE 1-2: Policy Options for Key Sectors of Energy Use

Option	Agriculture	Building	Transportation	Electricity	Comments
	Sector applicable				
Resource assessment					
Resource assessment	P	v	—	v	More extensive evaluation of renewable energy resources could be done, Including long-term analysis of the Impacts of geographic diversity, intermIttency, and correlations between renewable resources.
Research, development, and demonstration					
R&D	✓	✓	✓	✓	R&D supports could be expanded in areas with high potential returns.
Demonstrations	✓	✓	✓	✓	Expanded technology demonstrations and field validation of performance for resources and technologies with high potential returns could provide useful technical and market data and Increase confidence of potential investors.
Safe harbors				✓	Regulated industries such as electric utilities are often now constrained in Investing in promissing but not yet commercial equipment due to concerns of financial costs to ratepayers, State regulators could consider providing safe harbors for prudent Investments.
Design, planning, and information					
Design tools	✓	v	·	✓	The development of good design tools—that better account for the characteristics of renewable energy resources and technologies, such as site specificity, intermittency, low intensity, and small scale, than tools now in use--could be supported. This could Improve the capability of considering and using RETs.
Design competitions	—	✓		—	Numerous small awards for good design of, for example, passive solar buildings (which are highly design-Intensive but now poorly supported), could be provided. This could raise the visibility of RETs and encourage their use.
Planning supports	✓	✓		✓	State and local planning efforts to use RETs could be supported technically and financially.

Information	✓	✓		✓	Information programs could be broadened and extended to provide markets sufficient access to up-to-date information on the cost and performance of these rapidly advancing technologies
Ratings and standards					
Rating systems	—	✓		✓	Supporting the broader establishment of rating and certification systems in the private sector could provide greater consumer confidence in these products
Codes and standards		✓		✓	Codes and standards might be pursued where market-based approaches do not work in order to promote greater use of RETs and reduce use of conventional fuels, where financially and environmentally appropriate
Finance and commercialization					
Market aggregation	✓	✓	✓	✓	Public-prwate partnerships could be formed to aggregate markets and support large-scale, long-term purchases of RETs
Green set-asides	✓		✓	✓	Because of the difficulty of removing the various tilts in the playing field and of valuing the many benefits and costs of RETs relative to conventional technologies, technology-specific competitive set-asides might be established for RETs. Although some argue that this is simply a hidden tax on ratepayers, others note that ratepayers would benefit by reducing the risk of future fuel cost increases, environmental costs, and potentially capturing longer term cost savings by developing the RET industry and creating jobs.
Golden carrots		✓		✓	Financial awards might be given to manufacturers for the development of particularly high-performance or environmentally friendly RETs that would otherwise not receive sufficient market return to justify development
Green pricing	—	—		✓	Programs to allow customers to voluntarily pay more for environmentally sound energy resources or services, such as RET-generated electricity, could be initiated
Utility incentives		—	—	✓	State Publlc Utilityty Commissions (PUC) might allow utilities to earn slightly higher returns on Investments for RETs or purchases of renewable energy from third parties

(continued)

TABLE 1-2 (cont'd.): Policy Options for Key Sectors of Energy Use

Option	Sector applicable				Comments
	Agriculture	Building	Transportation	Electricity	
Ratepayer impact	—	@	—	P	Ratepayer impact tests (RITs) at the PUC level may not take into account risks such as future fuel cost increases and environmental externalities. State PUCs could broaden the factors considered in RITs.
Subsidies	v	✓	✓	P	Energy or other related subsidies could be reduced or adjusted on the basis of energy resource and technology potential to contribute to national goals over the long term.
Risks	✓	v	✓	P	A variety of risks, including the risk of future fuel cost Increases, environmental liabilities, and global climate change-often not now adequately considered in the choice of technology in some sectors due to regulatory procedures or other reasons-could be evaluated and incorporated in decisionmaking.
Standard contracts	v	·		P	Standard contracts provide a means of reducing transaction costs for small renewable developers Broader use of such contracts could be considered.
Federal procurement	✓	1=	v	v	Federal procurement could be more aggressively directed toward use of all cost-effective RETs, including risks and externalities.
Power Marketing Authorities	✓	—	—	v	Federal Power Marketing Authorities might be directed to increase use of RETs, as appropriate, given costs, fuel diversity concerns, and environmental externalities.
Infrastructure	✓	—	✓	J -	Support could be provided to assist in the development of infrastructure needed for RETs. This might include providing a portion of the additional costs needed to shift infrastructure (transmission and distribution, pipelines) to where it can support longer term development of renewable resources.

Taxes					
Taxes	✓	✓	✓	✓	Tax burdens per unit energy supplied or saved—which can vary widely between technologies—could be adjusted or reformulated to level the playing field across energy resources and technologies, including risk, environmental impacts, and security. Of particular importance at the local level are property taxes. For all taxes, macroeconomic, federal revenue, and equity issues must also be considered.
Externalities	✓	✓	✓	✓	Approximate environmental externality costs could be included in the planning or costing of energy-related taxes, tradable permits, environmental adders, or front-loaded bonds.
Feebates	—	✓	✓	✓	Fees could be levied on lower efficiency and/or higher polluting energy resources/technologies and then used to provide rebates to higher efficiency and/or low polluting resources/technologies. This could lower front-end capital costs.

NOTE: Additional policy options are discussed within each sector's chapter

SOURCE: Office of Technology Assessment, 1995.

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In the state of Ceara in northeast Brazil, all the homes in the willage of Cacimba have been outfitted with 50-W PV solar home power systems that provide up 4 to 6 hours of light each night from two fluorescent lights

as biomass and wind—but will not be used in many cases due to various market challenges.

The following policy options could be considered in support of RET development.

- *Resource assessment.* Additional long-term support for resource assessment would allow careful evaluation of more sites, and determination of how resources vary across geographic regions individually and with potentially complementary resources. This assessment of renewable resources and the incorporation of this data in geographic information systems would also allow longer term planning of energy infrastructures to make best use of these resources.
- *RD&D.* In addition to technology improvements, RD&D includes field monitoring, commercial demonstration, and manufacturing processes and scaleup, sometimes underemphasized in the past. Field monitoring has particular value in validating performance and providing data for researchers. Commercial demonstrations of market-ready technologies can provide valuable hands-on, kick-the-tires experience for potential builders and users. Many of these activities are best done through public-private partnerships, which can provide a commercial focus, improve technology transfer, and leverage both public and private funds.
- *Design, planning, and information.* Activities include supporting the development of design tools, holding design competitions, supporting the education of professionals in the field, providing planning support, and developing and disseminating information. By directly addressing the initial planning and design processes, these activities can have particularly high leverage.
- *Ratings and standards.*[10] Additional support could be provided to professional standards-setting organizations and/or manufacturer associations for developing ratings and standards for RET equipment and systems—for example, passive solar buildings.

If funding for support of renewable RD&D and associated measures to aid development of these technologies is reduced, costs will decline more slowly and fewer opportunities for using cost-effective RETs will be realized. In the mid- to long term, RETs will displace less imported oil and contribute less to reducing pollution, and the economy will remain more vulnerable to the risk of future energy price increases. The competitive challenge posed by Europe and Japan for interna-

[10]Ratings and standards provide confidence to potential purchasers and users that the technology will perform as indicated and/or meet minimum requirements, and that equipment can properly work with that of other manufacturers, as well as other benefits.

TABLE 1-3: DOE Renewable Energy Technology RD&D Funding (in millions of constant 1992 $)

FY 1980	FY 1985	FY 1990	FY 1991	FY 1992	FY 1993[a]	FY 1994[a]	FY 1995[a]
145.7	11 8	4 4	21	2 0	2 9	4 5	4 2
254.2	700	374	477	604	632	707	801
200.6	436	161	199	291	262	296	288
87 6	384	174	341	393	467	52 7	545
102.8	365	9 8	11 4	214	232	276	431
73.5	51	4 4	2 8	2 0	0 9	0 9	0 0
255.2	401	195	281	272	227	21 7	346
35.7	01	0 0	1 0	1 0	1 0	0 9	4 4
	–..					91	8 8
1,155	246	109	147	182	187	218	259
1,229	258	119	163	204	204	260	315
1,253	384	1,034	879	859	644	627	464

[a]A price deflator of 2.7 percent was used for 1993, and 3 percent for both 1994 and 1995

million), the National Renewable Energy Laboratory plant and equipment ($5.5 million), and program direction ($7.5 million). Not included are electric energy systems and energy storage systems, which are part of the overall solar and renewable energy programs but are not directly applicable to renewable fuels.

[c]Included for comparison. The clean coal program has $37.1 million appropriated for FY 1995, but requests $73.4 million in FY 1996 and $414 million in FY 1997, for a three-year total of $525 million. Only the $37.1 million was included in the FY 1995 estimate here.

NOTE: This table does not include related funding for advanced vehicle technologies (see chapter 4).

SOURCE: Fred J. Sissine, Congressional Research Service, "Renewable Energy: A New National Commitment?" Issue Brief IB93063, Feb. 10, 1994; Fred J. Sissine, Congressional Research Service, personal communication, August 1994; and U.S. Department of Energy, *FY 1996 Congressional Budget Request* (Washington, DC: February 1995).

tional RET markets—particularly in developing countries—might not be met effectively and could potentially cost U.S. employment and export opportunities (see chapter 7). Small U.S. manufacturers and innovative technologies will also likely be bought out by foreign competitors. If, however, energy prices remain unexpectedly low over the long term, or if the impacts of global warming prove to be below the low end of current scientific estimates, [11] then the delay in developing renewable that would result from reduced support would not be as significant, although export market opportunities would still be at risk.

Commercialization

Market challenges faced by RETs could be addressed by various strategies. Improving the competitive position of RETs in a changing market includes crediting RETs with environmental benefits, actual system capacity value even if intermittent, and potential savings in T&D capacity if used in a distributed utility mode (see chapters 5 and 6). The development and use of smart technologies and controls to determine energy value and use would permit premium prices for market segments such as peaking power. Such technologies may also allow better use of RETs, as well as energy-efficient technologies, in utility demand-side management programs. Finance and commercialization options include: identifying and tapping niche markets, including through private-public ventures; encouraging the unbundling of energy prices to create additional niche markets; supporting market aggregation and manufacturing scaleup activities; supporting green pricing systems; helping establish competitive set-asides; and establishing preference for RETs in federal procurement.

In addition, there are other strategies that could help further level the playing field and capture additional cost-effective applications of RETs. A number of financial risks and liabilities are not now fully accounted for in developing energy projects. Examples include the risk of fuel price increases in electricity generation (largely passed through to ratepayers by Fuel Adjustment Clauses), and taxpayer liability for waste cleanup in some cases. For energy markets to work better, these risks and liabilities should be identified, their value estimated to the extent possible, and these costs included in energy prices, as appropriate. The costs of environmental damage and other externalities caused by energy use are also largely not included in energy prices, limiting the efficiency of market decisions.

Leveling the playing field may not be possible in some cases. Precise values are not known for factors such as risk reduction or environmental costs and benefits. Rather than attempt to fit all conventional and renewable energy technologies—with their widely varying characteristics—into a single framework, it may in some cases be preferable to consider technology-specific competitive set-asides[12] to ensure resource diversity and promote environmentally benign technologies. This could allow consideration of RETs with widely varying maturities and, with careful design of the set-aside, could allow an appropriate scale-

[11] Intergovernmental Panel on Climate Change, World Meteorological Organization/U.N. Environment Program, *Scientific Assessment of Climate Change, Summary and Report* (Cambridge, England: Cambridge University Press, 1990); and T.M.L. Wigley and S.C.B. Raper, "Implications for Climate and Sea Level of Revised IPCC Emissions Scenarios," *Nature*, vol. 357, No. 28, May 1992, pp. 293-300. See also U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991); and U.S. Congress, Office of Technology Assessment, *Preparing for an Uncertain Climate*, 2 vols., OTA-O-567, OTA-O-568 (Washington, DC: U.S. Government Printing Office, October 1993).

[12] Competitive set-asides designate quantities of energy and/or supply capacity of certain resources—such as renewable energy—in recognition of their reduced risk of fuel cost increases, environmental damages, or other nonpriced benefits. Qualifying technologies then compete to supply the energy/capacity specified by the set-aside. Due to the significant variation in the maturity of different RETs, it may be desirable in some cases to make competitive set-asides technology-specific (e.g., photovoltaics, solar thermal).

up of manufacturing in order to reduce their production costs efficiently. At the same time, it would be important not to inadvertently restrict RETs to small market segments.

Tax benefits might be provided for those technologies that do not now receive credit for benefits such as reduced environmental costs and other externalities. Several tax policy options are listed in table 1-2 and are discussed within the respective chapters. More detailed analysis is needed of any tax policy change, including potential macroeconomic impacts, revenue impacts, and equity concerns.

The impact of such policies will vary considerably by the particular technology and will be most important for those technologies that are now or are very close to being cost-competitive. Less mature technologies that have potential for commercialization at a significant scale, but remain high in cost due to the lack of large-scale markets and manufacturing, will not be assisted nearly as much by these changes and may require other approaches. Many of these commercialization activities will be most effective if pursued through public-private partnerships.

Financial costs associated with these types of development and commercialization policies include greater budget outlays for RD&D and selected high-leverage commercialization efforts. Additional costs would vary with the activity. RD&D and high-leverage commercialization activities (such as the development of building design tools) might be increased by a few million to a few tens of millions of dollars. Large-scale demonstrations and commercialization could cost $50 million to $100 million in some cases, but the federal share would be heavily leveraged with private sector investment. For a few technologies, the higher funding levels for RD&D would need to be provided consistently for at least a decade and possibly longer in order to lower the cost of power-generating technologies such as PVs to levels comparable to those of fossil fuels. This funding would require careful allocation to high-leverage opportunities. If this path is chosen, some consideration could be given to paying for this increase in direct budget outlays by some reduction of present subsidies of conventional energy technologies. Increasing funding for RETs and related strategies to accelerate their development could lay the groundwork for earlier and more rapid expansion of use of RETs should world energy markets, environmental concerns, or other factors require it. If federal development funding for RETs is reduced, the private sector would presumably have to decide whether to provide increased funds for RET development. The prospects for this are not good (see box 1-6). If strategies to address market challenges faced by RETs are not pursued, commercialization of RETs would occur much more slowly and the competitive disadvantages would be much more difficult to overcome even in the longer term.

CONCLUSION

The policy options listed in table 1-2 and discussed throughout this report should be evaluated in the context of a long-term national strategy for the role of energy in meeting goals of economic vitality, environmental quality, and national security. In developing this strategy, factors to consider include:

- *Time frames.* Significant changes in national energy use patterns have required half a century or more (see figure 1-3). This is due in large part to the enormous amount of infrastructure that must be turned over. This time lag poses a significant problem for the United States and the world should a rapid transition from today's conventional technologies be required in the future. Laying the groundwork for such a transition is an important component of national energy policy.
- *Energy pricing.* Conventional energy systems have a variety of environmental, economic, and security impacts that are not now fully incorporated in energy prices.
- *RD&D and commercialization.* RETs vary considerably in their level of development and may require policies that account for this range of maturity. In particular, current policies do not adequately address the transition from

BOX 1-6: Funding for Research, Development, and Demonstration of Renewable Energy Technologies

What role public support of research, development, and demonstration (RD&D) and commercialization should play for any energy supply technology—fossil, fission, fusion, or renewables---is a critical question, Public support for a particular technology may be justified when there are significant public benefits that are not reflected in the market price or that cannot be fully captured by the pioneering company, or if the technology is too high risk or long term for private Investment. RET's public benefits—environmental, rural economic development, federal budget savings, national security-are not Incentives for private RD&D funding, In addition, the smaller companies that typify the renewable energy industry cannot support the long-term, high-risk RD&D that is necessary to move some RETs (e.g., photovoltaics) into the marketplace,

RD&D—both public and private-for energy supply technologies has declined over the past decade, As a percentage of gross domestic product, public support of overall energy RD&D has declined by a factor of about three since 1978. Industry support of energy RD&D has declined by a factor of about two, Restructuring of the electricity sector may also be shfting private funds away from mid- and long-term RD&D efforts, such as renewable, toward very short-term projects. Sectors such as agriculture (bioenergy) have never Invested heavily in RD&D due to their highly fragmented nature, public support has played a vital role in the development of U.S. agriculture.

Although there were substantial gains in technical performance of RETs during the 1980s, while federal RD&D supports were low, much of these gains—such as in the wind and solar thermal Industries—were actually driven (inffciently) by industry using tax credits in effect to support RD&D. With the sharp reduction in federal and state tax credits in the mid- to late 1980s, this avenue has been signficantly closed, In addition, these gains resulted in part from exceptionally large pioneering economies of scale and Iearning in mass production and field operation, and by easy, one-time transfers of technology from other sectors It Will be difficult for renewable energy firms to repeat the successes of the 1980s without dedicated RD&D, and support for this RD&D Will be difficult to obtain from industry sources.

SOURCE Off Ice of Technology Assessment, 1995

RD&D to large-scale, low-cost manufacturing coupled with large-scale commercialization.

Federal policies regarding RETs should be considered in the context of the state, local, utility, and other efforts already under way. In many areas of RET policy—including information, incentives, and regulation—states, localities, and utilities are often more active than the federal government. Renewable energy depends on the local situation, making the involvement of state and local organizations more important. Any federal efforts would be most effective if they complemented existing efforts. In most cases, states and utilities would welcome federal support and assistance, but might not welcome arbitrary federal preemption. Since, in the past, such state-local efforts have been supported in part with funds that are now in most cases expired, [13] other forms of support could be considered.

Renewable energy has significant potential to contribute to the national goals of economic vitality, environmental quality, and national security.

[13] The Petroleum Violation Escrow fund, which are funds collected on behalf of the public for pre-1981 overcharges (in excess of regulated prices) for petroleum products, is one.

The extent and timing of renewable energy pcne-(ration into energy markets will be affected by the levels of support provi ded for the research, devel - opment, demonstration, and commercialization of RETs. Policies will be most effective if they take into account the widely varying characteristics of renewable resources and differing levels of maturity of renewable energy technologies. The policies and efforts pursued over the next several years will significantly influence energy use and environmental impact during the 21 st century.

Appendix 1-A: National Energy Use and Renewable Energy

A

Total U.S. energy use in 1993 was 88 exajoules (EJ or 84 quads—see appendix A at the back of this report for a discussion of units and conversions). Oil accounts for about 40 percent of current energy consumption, followed by natural gas and coal with about 25 percent each[1] (see figure 1-A-1).

Oil is used primarily in transport; gas is used in industry, buildings, and electricity generation;[2] and coal is used to generate electricity and in some industrial processes such as steel production. Electricity is supplied by coal, nuclear, hydro, and gas and is used in buildings and industry (see figure 1 -A-2). Conversely, buildings rely primarily on electricity and gas; industry relies on all of these supplies, depending on the process; and transport is almost entirely dependent on oils

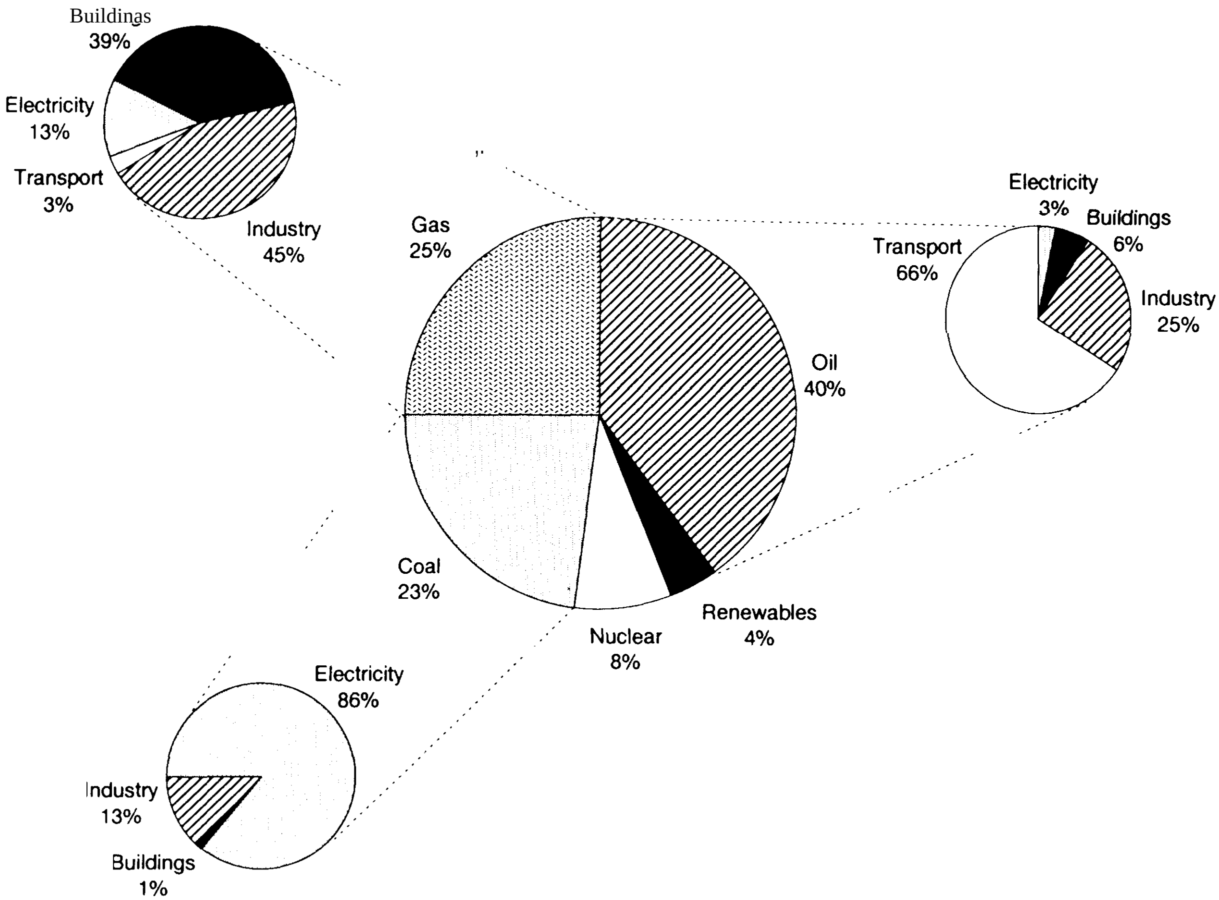
National energy supply and demand is undergoing continual change. Energy supplies shift with resource availability and cost; energy end-uses shift with technology advances and market demands; and overall energy supply and demand shift with national economic, environmental, and regulatory considerations. Economic growth, which is also a function of changing demographics (population growth creates new demands) and productivity, creates new demands for energy services, but energy use can grow

[1] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1993*, USDOE/EIA-0384 (39) (Washington, DC: July 1994), pp. 9, 165, 199, 215.

[2] Note that all electricity values are given here in terms of their primary thermal energy equivalents using a conversion factor of 33 percent.

[3] Note that natural gas for transport is used primarily in compressors for pumping natural gas through pipelines to end users.

FIGURE 1-A-1: U.S. Energy Supply and Use, 1993



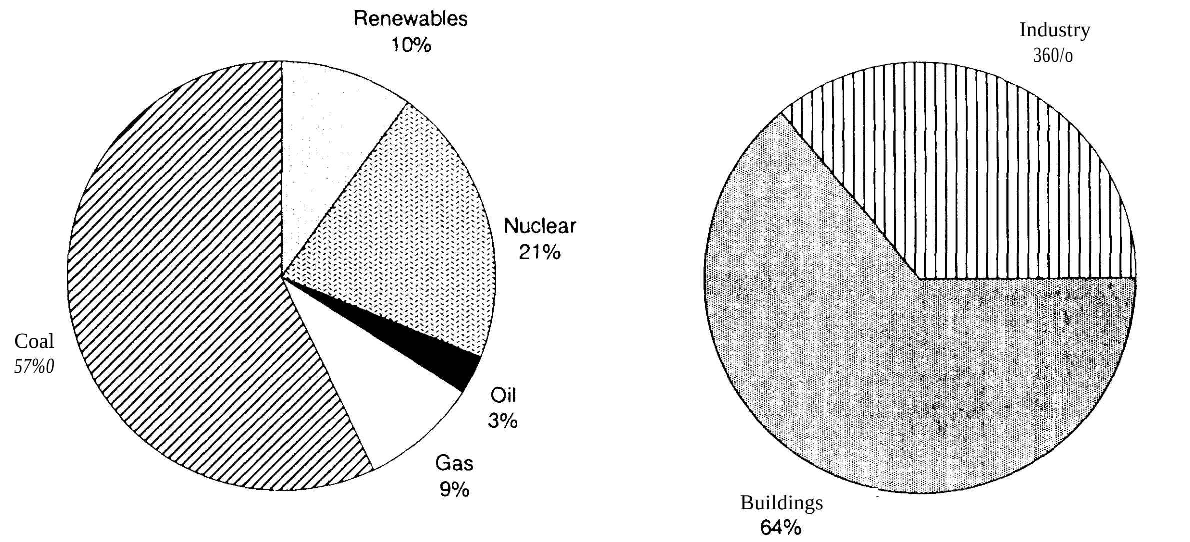
SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, 1993, USDOE/EIA-0384(93) (Washington, DC: July 1994), pp 9 165, 199, 215

either faster or slower. Important factors shaping U.S. energy use include:

- *Energy efficiency.* The energy intensity of the U.S. economy declined 30 percent between 1970 and 1990, from 29 megajoules (MJ)/$GNP to 20.6 MJ/$GNP due to efficiency gains and other factors[4] (see figure 1 -A-3). These gains greatly slowed the expansion of the U.S. energy supply infrastructure during this period. More recently, energy use has grown.
- *Electricity intensity.* The economy has become more electricity intensive, even while the total energy intensity per unit GNP has declined (see figure 1 -A-3). The electricity sector share of

[4] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1990*, DOE-EIA-0384(90) (Washington, DC: May 1991), table 8; and U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy* (Washington, DC: U.S. Government Printing Office, June 1990).

FIGURE 1-A-2: Electricity Supply by Resource and End Use, 1993



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, 1993, USDOE/EIA-0384(93) (Washington, DC: July 1994)

U.S. energy consumption has increased from 25 percent in 1970 to 36 percent in 1990 and is expected to increase further to roughly 42 percent by 2010.[5]

- *Environmental concerns.* Environmental concerns have become increasingly important at all levels. For example, the Clean Air Act Amendments of 1990 tightened various emission limits for vehicles and utilities. Some 29 states now require or are considering inclusion of environmental externalities in utility resource selection or rate-setting. Concerns about global warming and a variety of other environmental problems have also resulted in several international agreements, including the Framework Convention on Climate Change.

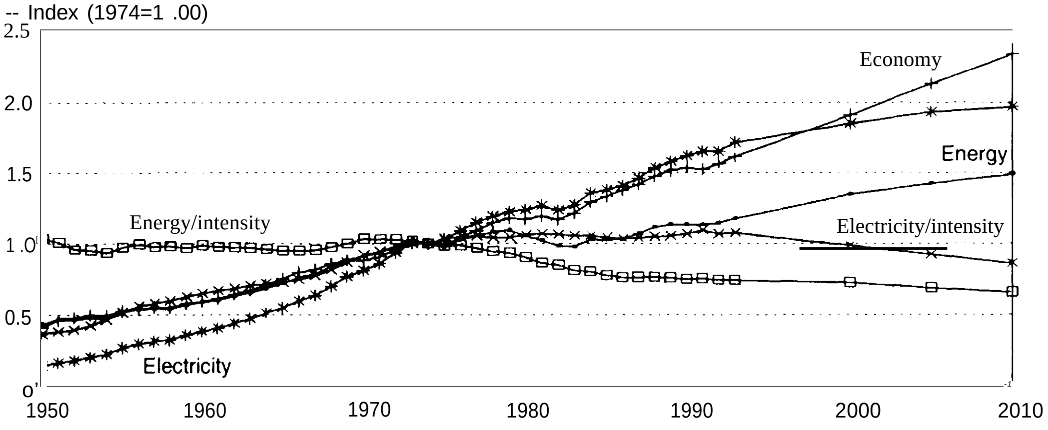
Renewable energy technologies can contribute to U.S. needs across every sector. Biomass energy resources can be used to generate heat for industry, electric it y, or liquid or gaseous fuels for transport. Geothermal energy can be used to generate electricity or for heating. Solar energy can be used directly for thermal applications such as heating, cooling, or lighting homes and offices, or it can be used to generate electricity or ultimately hydrogen. Wind energy can be used to generate electricity or for direct mechanical drive. These applications are detailed in chapters 2 through 5. Thus renewable energy can become a very important part of the U.S. energy system, contributing simultaneously to all U.S. energy goals: economic vitality, environmental quality, and national security.

1 Economic Vitality

Cost-effective, reliable supplies of energy are critical for a well-functioning economy. Fossil fuels are readily available and low in cost at the present

[5] Energy Information Administration, ibid., table 4; and U.S. Department of Energy, Energy Information Administration, *Annual* Energy *Outlook, 1992*, DOE/EIA-0383(92) (Washington, DC: January 1992).

FIGURE 1-A-3: U.S. Energy Use, Energy Intensity, and Electricity Intensity, 1950-2010



NOTE U S energy use, energy Intensity (energy dtvlded by economy), and electrlclfy Intensity (electricity divided by economy) changed course significantly in the mid-1970s following the 011 embargo and as structural changes accelerated in the electricity sector and the economy Before 1974, energy use was growing in tandem with the economy and electricity use was growing somewhat faster After the mid- 1970s, energy use substantially leveled off, while electricity use Increased at slightly more than the rate of economic growth The Energy information Administration projects that energy usewill continue to grow more slowly than the economy for the next decade and a half, and that electricity use WiIl decline as a fraction of the economy

SOURCES U S Department of Energy, Energy Information Administration, *Annual Energy Review,* 1993, USDOE/ElA-0384(93) (Washington, DC July 1994), and U S Department of Energy, Energy Information Administration, *Annual Energy Outlook,* 1995, DOE/EIA-0383(95) (Washington, DC January 1995)

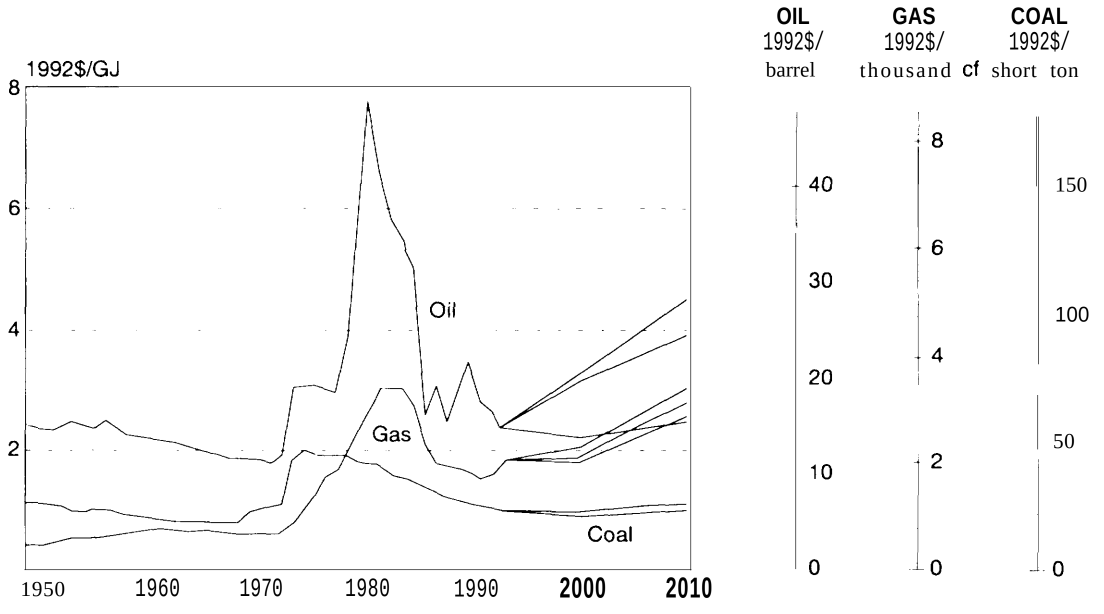
time, and have a well-developed infrastructure to support their use. Oil imports, however, now cost about $45 billion per year, equivalent to roughly half of the total U.S. international trade deficit. Further, the Energy Information Administration (EIA) projects that natural gas and oil prices may increase over time as resources decline and markets tighten[6] (see figure l-A-4), although there is much disagreement over the timing and magnitude of possible price increases. Coal prices, however, are expected to increase only slightly in the near to mid-term as there is a large resource base in the United States, but longer term costs could be affected by environmental considerations.

In contrast, in most cases the cost of renewable energy is expected to decrease over time with further research, development, and demonstration (RD&D) and improvements in production. This would significantly expand the current range of cost-effective uses of RETs, providing net economic benefits. Further, domestically produced renewable fuels can potentially offset some oil imports. Rural communities that produce renewable energy—particularly biomass-could receive significant employment and income benefits (see chapter 2), helping offset possible income losses if other federal supports in the agricultural sector are reduced.

International trade is another area where RETs can contribute to the nation's economic vitality. The United States is already exporting some RETs, including 70 percent of U.S. photovoltaic

[6] See U.S. Department of Energy, Energy Information Administration: *Annual Energy Review, 1993*, Report US DOE/EIA-0384(93) (Washington, DC: July 1994); and *Annual Energy Outlook, 1995*, Report DOE/EIA-0383(95) (Washington, DC: January 1995).

FIGURE 1-A-4: Historical and Projected Fossil Fuel Prices



SOURCE U S Department of Energy Energy Information Administration Annual energy Review 1993 USDO/EIA 0384(93) (Washington DC July 1994) and U S Department of Energy Energy Information Administration *Annua/ Energy Out/ook* 1995 USDOE/ EIA-0383(95) (Washington DC January 1995)

production in 1993. RETs are often the most cost-effective and reliable means of providing energy in rural areas of developing countries. Overall capital investment in the electricity sector in developing countries is about $ 100 billion per year; RETs could account for a significant fraction of this market in the mid- to long term. Further, these RETs have important strategic value in these markets as they can help leverage the sale of a wide range of end-use technologies, including communications, information, lighting, appliances, and electric motors. Thus. international trade in RETs and related end-use equipment could become very large. Those countries that can capture international markets will create significant numbers of jobs at home. Competition for these markets between U. S.. European. and Japanese firms is already intense (see chapter 7).

Environmental Quality

The extraction and use of fossil energy imposes a variety of environmental burdens, including mining wastes, oil spills, urban smog, acid rain, and the emission of greenhouse gases. The location, magnitude, and costs of these impacts depend on many factors, including the particular fossil resource and the extraction and conversion technologies used, For some environmental impacts, such as the extinction of species or global warming, no monetary value can realistically be placed on them. Although some RETs such as hydropower can have large-scale environmental impacts, the low environmental impacts of most RETs make them of particular interest today. For example, table 1 -A-1 shows one example of the relative emissions of various electricity generation cycles

TABLE 1-A-1: Total Fuel-Cycle Emissions for Electricity Generation

Electricity source	Carbon dioxide	Nitrogen oxide	Sulfur oxide	Trisodium phosphate	Nuclear waste
			Metric tonnes/GWh		
Coal boiler	1,000	3 0	30 .	1.6	NA
Natural gas turbine	500				NA
Nuclear	8.0	003	003	0.003	3.6
Photovoltaics	5 0	0.008	002	0.02	NA
Biomass	Small	06	0 2	0 5	NA
Geothermal	5 7 0	TR	TR	TR	NA
Wind	7 0	TR	TR	TR	NA
Solar thermal	3 6	TR	TR	TR	NA
Hydropower	3 0	TR	TR	TR	NA

KEY NA=not applicable, TR -trace

NOTE Values have been rounded off

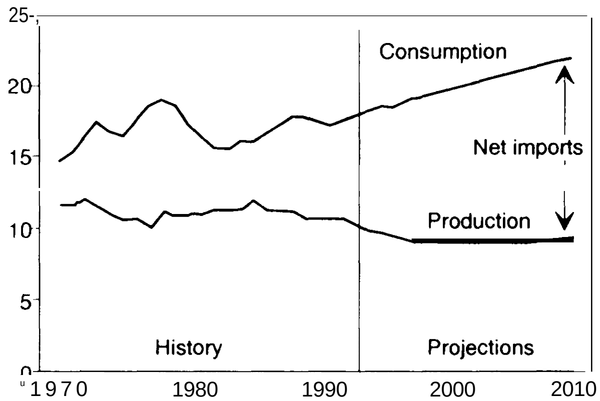
SOURCE.*Solar industry Journal,* VOl. 1, No 3, 1990, pp. 17 as adapted from U S Department of Energy *Environmental Emissions from Energy Technology Systems* The Total *Fuel Cycle* (Washington, DC 1989)

and the very low emissions possible from particular RETs.

National Security

Energy-related national security has primarily been viewed in terms of U.S. dependence on foreign oil. The United States currently imports about 45 percent of the petroleum it consumes, and according to EIA, these imports are projected to grow steadily in coming years (see figure 1-A-5).7 Renewable fuels coupled with advanced vehicle technologies have the potential to offset a significant portion of these fuel imports for transport while reducing environmental impacts (see chapter 4). An additional consideration is that the use of RETs in developing countries can promote economic growth and contribute to political stability, with corresponding benefits for U.S. national security.

FIGURE 1-A-5: Oil Production, Consumption, and Imports, 1970-2010 (million barrels per day)



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook*, 1995, USDOE/EIA-0383(95) (Washington, DC: January 1995).

[7]Energy Information Administration, *Annual Energy Outlook, 1994*, ibid