Renewing Our Energy Future

September 1995

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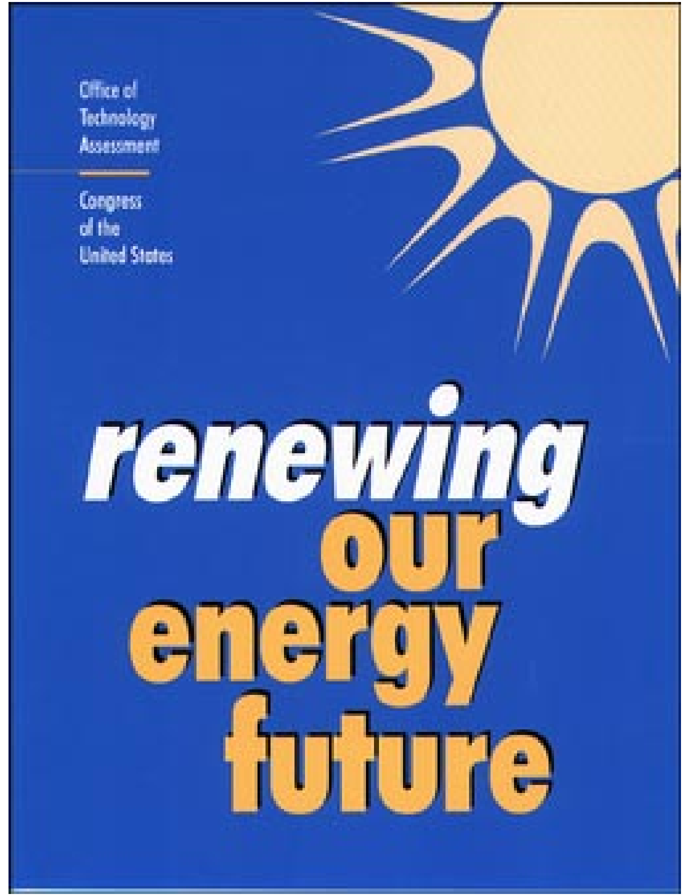

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Foreword

Various forms of renewable energy could become important contributors to the U.S. energy system early in the next century. If that happens, the United States will enjoy major economic, environmental, and national security benefits. However, expediting progress will require expanding research, development, and commercialization programs. If budget constraints mandate cuts in programs for renewable energy, some progress can still be made if efforts are focused on the most productive areas.

This study evaluates the potential for cost-effective renewable energy in the coming decades and the actions that have to be taken to achieve the potential. Some applications, especially wind and bioenergy, are already competitive with conventional technologies. Others, such as photovoltaics, have great promise, but will require significant research and development to achieve cost-competitiveness. Implementing renewable energy will be also require attention to a variety of factors that inhibit potential users.

This study was requested by the House Committee on Science and its Subcommittee on Energy and Environment; Senator Charles E. Grassley; two Subcommittees of the House Committee on Agriculture—Department Operations, Nutrition and Foreign Agriculture and Resource Conservation, Research and Forestry; and the House Subcommittee on Energy and Environment of the Committee on Appropriations.

OTA appreciates the invaluable advice and assistance of the many people who contributed to this project, including the advisory panel, contractors. and reviewers.

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Note: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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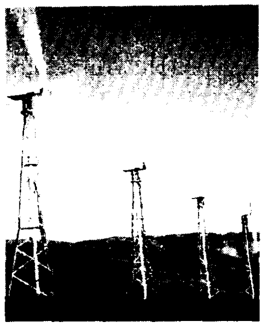
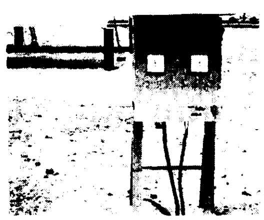
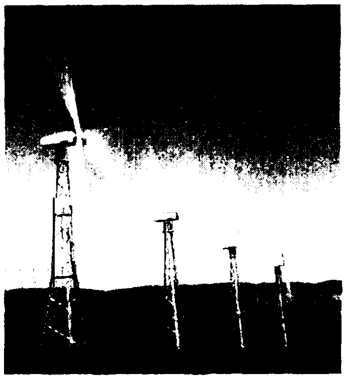




Overview 1

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-

[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 Iittle 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 mortgages 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.

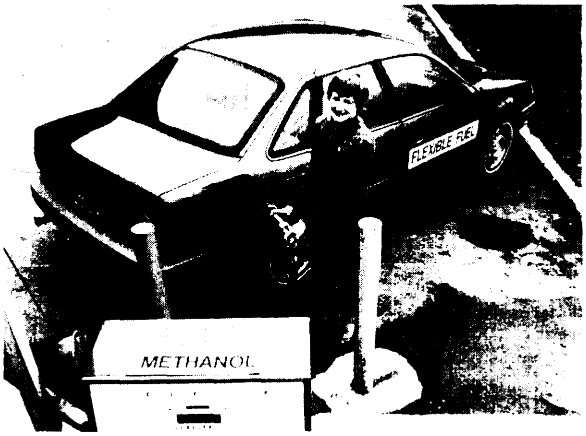
SOURCE Office of Technology Assessment, 1995

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

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



FORD MOTOR CO

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

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 Will succeed

Even the potentially best process for converting biomass to methanol (thermochemical gasification) or ethanol (enzymatic hydrolyses) Will 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 California 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 Will 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.

All these RETs need further RD&D to improve their cost-competitiveness. Many major Improvements in technology are expected Scaling up manufacturing Will 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

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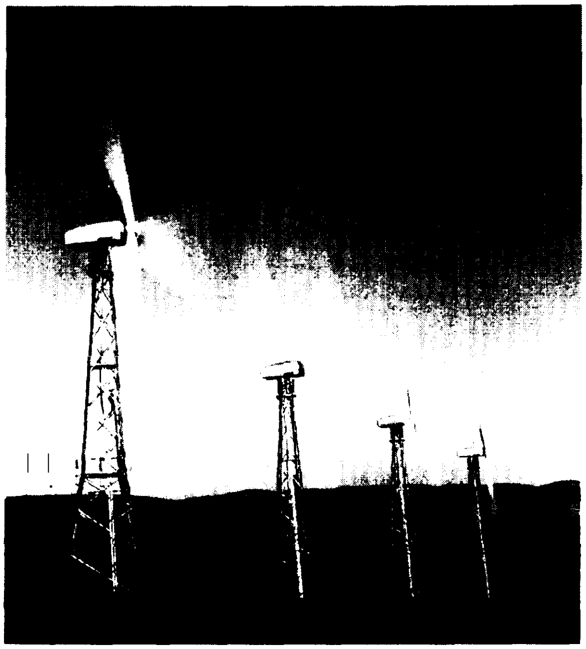
in the plains states (see chapter 5). Some resources also vary dramatically even among adjacent locations. For example, wind resources may be very good at one part of a mountain pass. but poor on the downwind slope. This site specificity has several important implications:

- *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. 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.

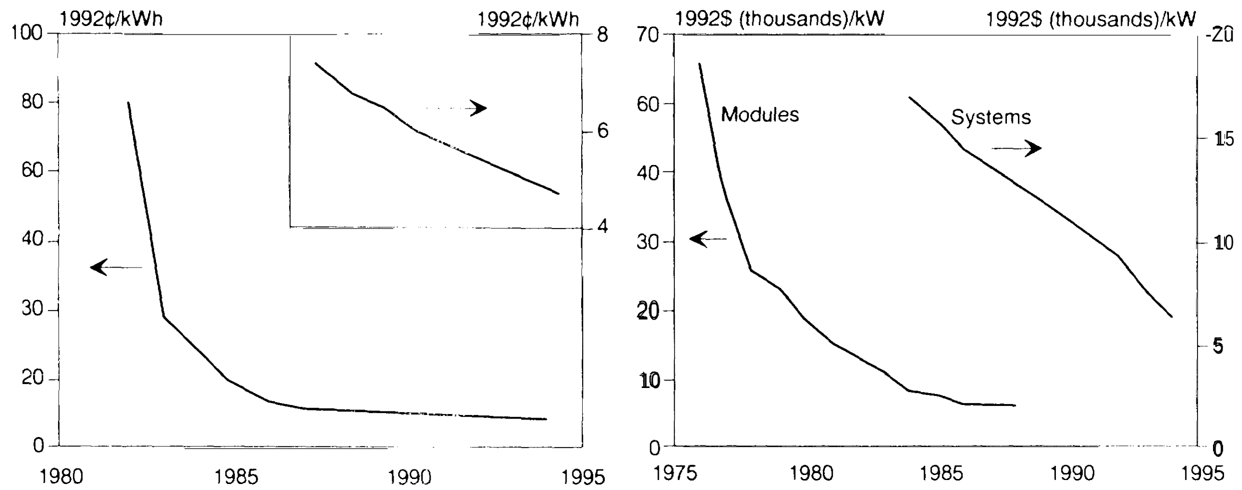
Intermittence

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,

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 elecIricity DECLINED The figure or the Left shows data for win[d] 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.

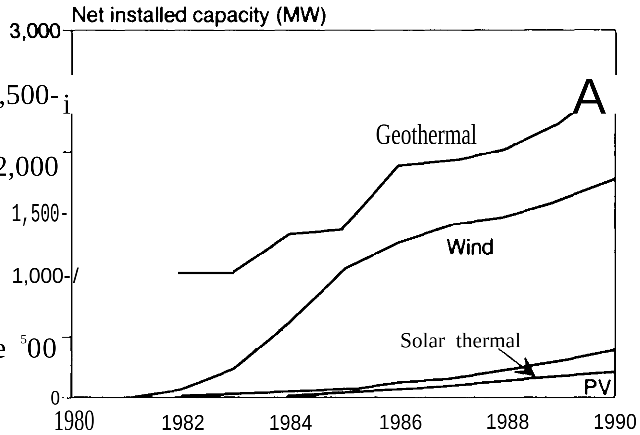
sizing of conventional heating and cooling equipment for backup (see chapter 3).

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,* VOI, 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

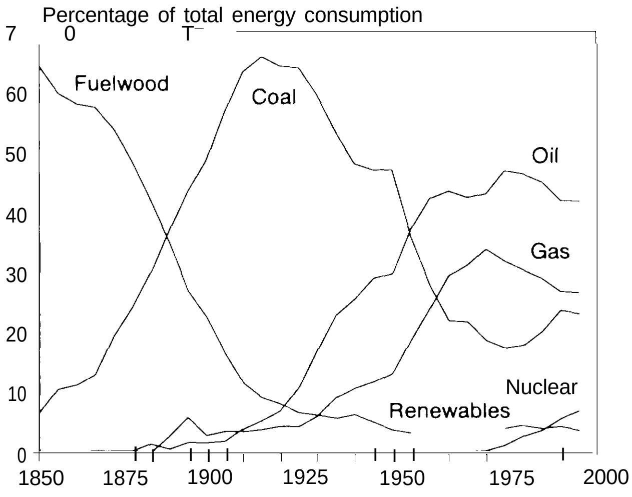
Although they manifest themselves in different ways, several market challenges appear repeatedly when commercializing RETs in the different sectors of the U.S. economy.

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 produc- t 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 evalu - ated 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

	Sector applicable				
Option	**Agriculture**	**Building**	**Transportation**	**Electricity**	**Comments**
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

	Sector applicable				
Option	Agriculture	Building	Transportation	Electricity	Comments
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.


NATIONAL RENEWABLE ENERGY LABORATORY

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 l-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 l-A-l).

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

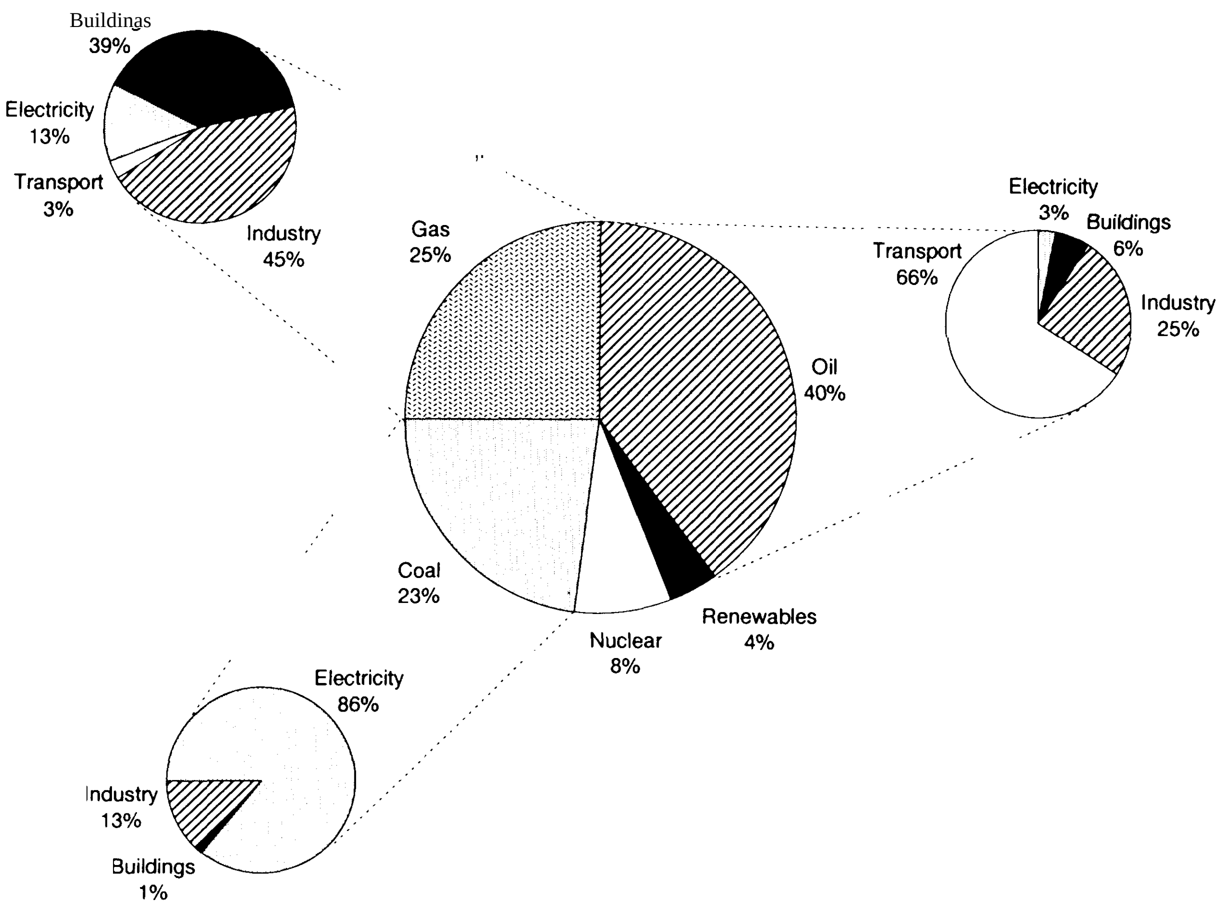
National energy supply and demand is undergoing continual change. Energy supplies shift with resource availability and cost; energy end-uses shift with technology advances and market demands; and overall energy supply and demand shift with national economic, environmental, and regulatory considerations. 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



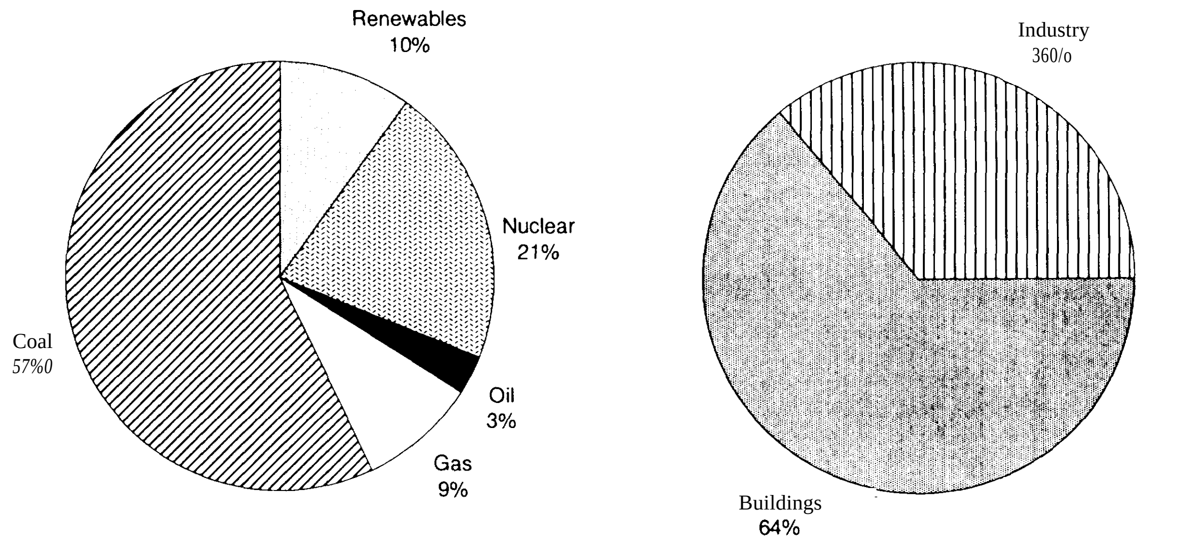
SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, 1993, USDOE/EIA-0384(93) (Washington, DC: July 1994), pp 9 165, 199, 215

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.

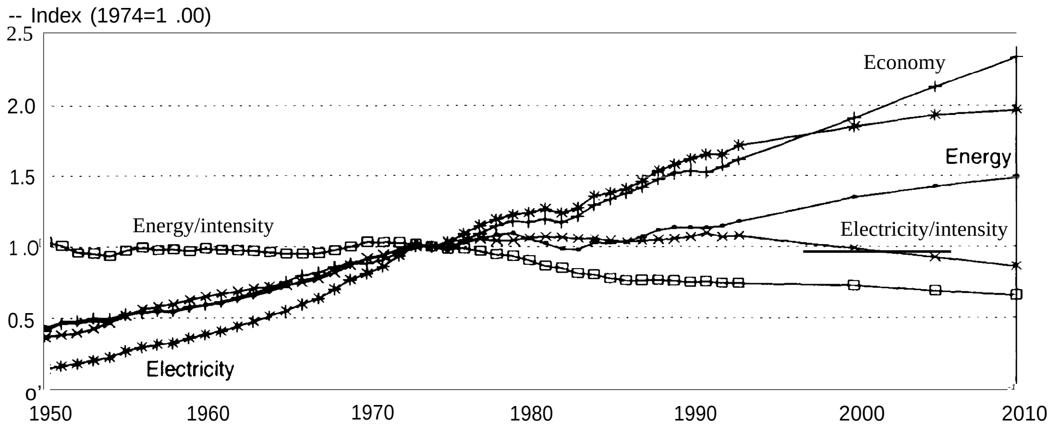
Renewable energy technologies can contribute to U.S. needs across every sector. Biomass energy resources can be used to generate heat for industry, electric it y, or liquid or gaseous fuels for transport. Geothermal energy can be used to generate electricity or for heating. Solar energy can be used directly 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)

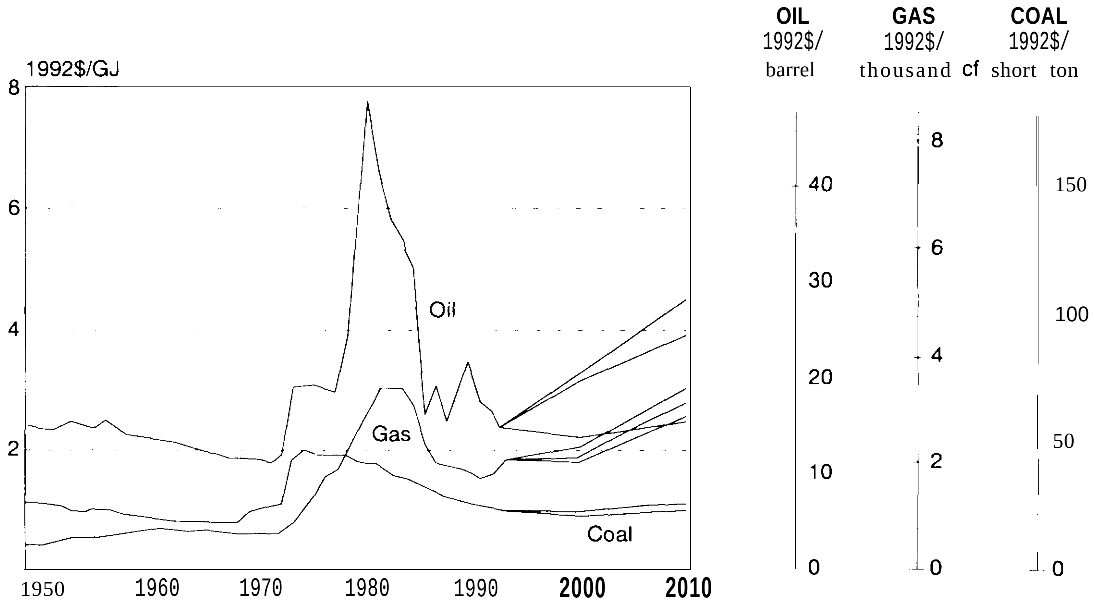
time, and have a well-developed infrastructure to support their use. Oil imports, however, now cost about $45 billion per year, equivalent to roughly half of the total U.S. international trade deficit. Further, the Energy Information Administration (EIA) projects that natural gas and oil prices may increase 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

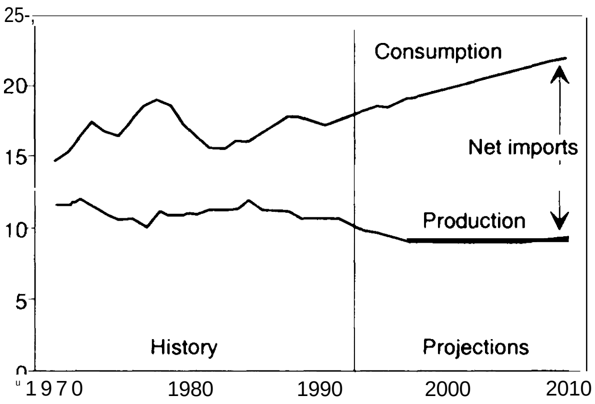
SOURCE.*Solar industry Journal,* VOl. 1, No 3, 1990, pp. 17 as adapted from U S Department of Energy *Environmental Emissions from Energy Technology Systems* The Total *Fuel Cycle* (Washington, DC 1989)

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

Agricultural Energy Crops 2

The agricultural sector has the potential to produce large quantities of renewable energy in the form of bioenergy crops,[2] which can be converted to electricity, heat, or liquid or gaseous fuels.[3] Producing these crops can potentially improve the environment, increase rural incomes, reduce federal budget expenditures, and reduce the U.S. trade imbalance. To realize this broad potential will require continuing research, development, demonstration, and commercialization efforts. It will also require considerable planning and coordination because of the numerous issues that bioenergy crops impact. Haphazardly implementing large-scale bioenergy programs without a sufficient foundation could damage the environment and reduce potential economic benefits.

What Has Changed?

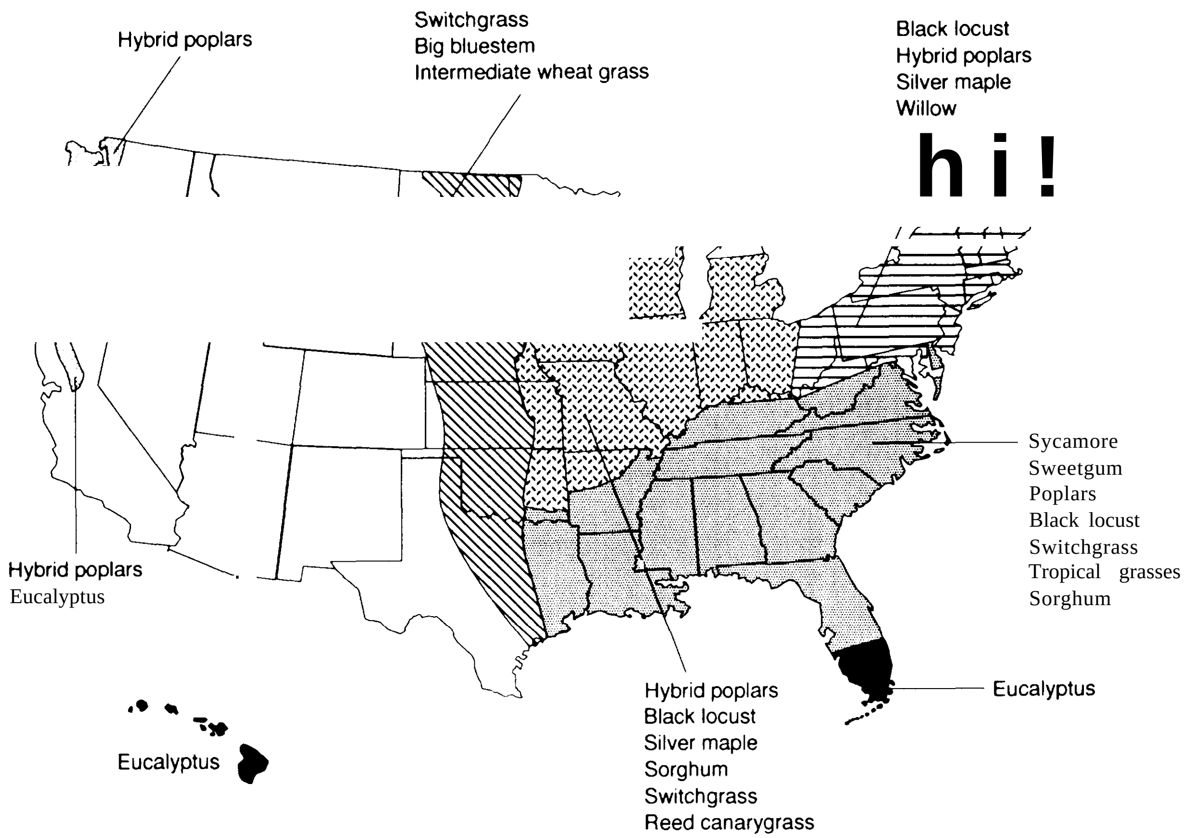
Bioenergy cropping has advanced significantly since 1980. More than 100 woody species and 25 grassy species have been examined by Oak Ridge National Laboratory and others for their suitability as energy crops; six species of woody crops and one specie of grassy crop were selected as models for intensive devel -

[1]Much of the discussion here might also be applied to the forestry sector. Because of certain differences between the agricultural and forestry sectors in environmental considerations, economic and budget impacts, market challenges, and policy issues, however, the focus here is limited to the agricultural sector. Future work should consider extending the analysis to the forestry sector.

[2]Only lignocellulosic energy crops such as trees and grasses are discussed in this chapter.

[3]See chapters 4 and 5 for a discussion of technologies for converting bioenergy crops to useful fuels and electricity.

FIGURE 2-1: Potential Energy Crops and Regions Applicable in the United States



NOTE: A limited set of potential energy crops is shown, along with willow and the regions within the United States where they might be grown. Many other species might be considered as well, including alder, ash, kenaf, mesquite, etc.

SOURCE: Oak Ridge National Laboratory, n.d.

opment.[4] Advances in genetic engineering and breeding techniques have allowed rapid improvements in crop productivity, with biomass yields increasing 50 percent and more over this period for the two principal crops, poplar and switchgrass, on which detailed work has been done.[5] Methods of establishing and maintaining these crops have also been developed and improved. In the 1970s, short rotation woody crops, which can be harvested repeatedly and regrown from the stump,[6] were little more than a scientific curiosity. Today, they are in commercial use. For example, more than 25,000 hectares (62,000 acres) of hybrid poplars have been established in the Pacific Northwest for pulp (paper) and energy use. The

[4] Lynn Wright, Oak Ridge National Laboratory, personal communication, Apr. 7, 1994.

[5] Anthony Turhollow, Consultant, personal communication, May 11, 1994.

[6] With the current rapid pace of crop improvement, replanting may sometimes be preferable to regrowth in order to realize higher yields with new crop strains.

BOX 2-1: National Policies That Influence the Use of Energy Crops

Several national policies reflect the growing interest in bioenergy, A variety of excise tax and other exemptions, tax credits, and other supports are available at both the federal and state levels. Some federal incentives for bioenergy are listed in table 2-1.

Recent legislation related to bioenergy includes

- The 1988 Alternative Motor Fuels Act encouraged the use of methanol, ethanol, and natural gas transport fuels
- The Clean Air Act Amendments of 1990 limited sulfur emissions from powerplants (potentially benefiting bioenergy because it contains little sulfur), set requirements for the use of oxygenated fuels (potentially benefiting ethanol and methanol production—see chapter 4), and established credits for the use of renewable energy,
- The Energy Policy Act of 1992 established federal, state, and private light-duty vehicle fleet mandates for the use of alternative fuels, a variety of tax exemptions and credits for alternate fuel vehicles (including electric vehicles), and a 1 5¢/kWh credit for closed-loop, biomass-fired electricity generation

Finally, the United States, along with 153 other nations, signed the United Nations Framework Convention on Climate Change at the Rio de Janeiro "Earth Summit" in June 1992, and the U. S. Senate ratified it in October 1992 This Framework Convention established the objective of stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic Interference with the climate system " The Climate Change Action Plan, announced in October 1993, has the goal of returning "U S. greenhouse gas emissions to 1990 levels by the year 2000 with cost effective domestic actions " Bioenergy can potentially play a significant role in providing energy with little or no net greenhouse gas emissions

SOURCE Off Ice of Technology Assessment 1995

costs of such energy crops are declining to the point of being competitive as energy resources, and a variety of these crops can be grown across the United States, depending on the region and climate (figure 2-1).

Bioenergy conversion technologies have also advanced significantly over the past two decades. Roughly 8,000 megawatts (MW) of bioenergy - fueled electricity generating capacity is currently connected to the electricity grid, compared with less than 200 MW in 1979; additional bioelectric capacity is operated offgrid.[7] New classes of efficient bioelectric technologies are emerging that can help make biomass competitive over a wider range of conditions (see chapter 5). Similarly, significant advances have been made in converting biomass to liquid fuels such as ethanol and methanol (chapter 4). For example, the cost of converting cellulosic biomass to ethanol has declined from $3.60/gallon ($0.95/liter) in 1980 to $1.20/gallon ($0.32/liter) in 1993.[8] Several national policies now encourage greater use of bioenergy resources (see box 2-1 and table 2-l).

[7]In comparison, total U.S. electricity generating capacity was about 700,000 MW in 1992. American Solar Energy Society, *Progress in Solar Energy Technologies and Applications* (Boulder, CO: January 1994), p. 36.

[8]Costs are based on 1990 dollars. S.R. Venkateswaran, Energetics Inc., and John Brogan, U.S. Department of Energy, personal communication, May 12, 1994.

TABLE 2-1: Selected Federal Incentives for Biomass Energy

Exemption from excise taxes on motor fuels	5. 4¢/gal
Alternative fuels production tax credit	$5,35/barrel
Tax credit for ethanol fuels	54¢-60¢/gal
Credit for small ethanol producers	10¢/gal
Electricity production credit for closed-loop biomass systems	1.5¢/kWh
Income tax deduction for alcohol fuel-powered vehicles (maximum)	$2,000 deduction

SOURCE: Salvatore Lazzari, Congressional Research Service, "Federal Tax Incentives for Biomass Energy, Including Provisions in the Energy Policy Act of 1992," n.d.

I Potential Roles

Biomass is an already stored form of solar energy and so can be used to generate electricity as needed, rather than as available as is the case for wind and solar energy. Biomass may therefore play an important role in the electricity sector, providing baseload and load following capabilities (see box 5-2), complementing intermittent generation by wind and solar systcms (see chapters 5 and 6). It can be burned directly to provide industrial or commercial process heat or space heat for buildings (chapter 3). Liquid fuels[9] from biomass offer a relatively high-energy-density,[10] high-performance alternative to imported petroleum for powering transport (see chapter 4).

| Principal Themes

Five broad themes are addressed in this chapter: 1) the potential supply and cost of bioenergy; 2) the potential environmental impacts of large-scale bioenergy production; 3) the potential economic impacts of bioenergy production; 4) research, development, and demonstration (RD&D) needs and market challenges in commercializing bioen - ergy prroduction and conversion technologies; and 5) policy issues associated with further development of bioenergy.

BIOENERGY SUPPLIES

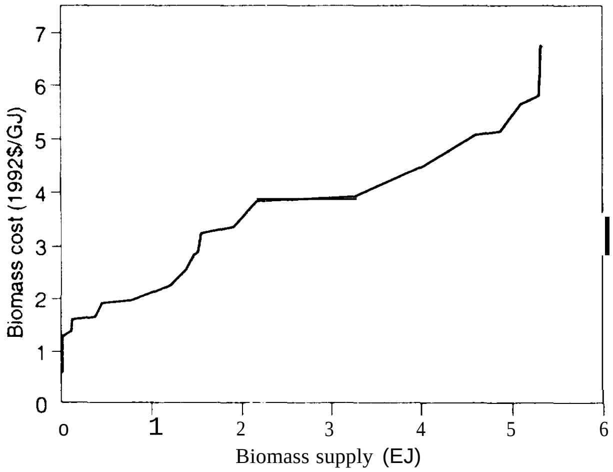
Bioenergy resources include agricultural and forestry residues (see figure 2-2), animal waste, municipal solid waste, and dedicated energy crops. Residues and wastes are often collected at central sites, such as agricultural processing plants, pulp and paper mills, animal feedlots. or municipal waste dumps; their use for energy may then be very cost-effective, particularly as an alternative to trucking them away for disposal. Although limited in quantity, these are the primary bioenergy resources now used (table 2-2). For large-scale energy use, dedicated energy crops are necessary and are the focus of this chapter.

[9]Biomass can also be gasified to produce hydrogen for fuel.

[10]Methanol and ethanol have energy densities of 17 megajoules/liter (MJ/l) (61,000 Btu/gal) and 22 MJ/l (80,000 Btu/gal) respectively, compared with gasoline's energy density of 34 MJ/l (122,000 Btu/gal) on a higher heating value basis. (See appendix A for unit conversion factors.) The fuel efficiencies of ethanol and methanol can be somewhat higher than gasoline in internal combustion engines and are potentially much higher in advanced vehicle technologies such as fuel cells. Higher efficiencies can offset part or all of the impact of lower energy densities on vehicle range. In contrast, gaseous fuels such as methane (natural gas) and hydrogen have much lower energy densities, even in pressurized cylinders. See chapter 4 for details.

[11]For a discussion of bioenergy from agricultural and forestry residues, animal waste, municipal solid waste, and other sources, see the following: U.S. Congress, Office of Technology Assessment, *Energy from Biological Processes*, OTA-E-124 (Washington, DC: U.S. Government Printing Office, July 1980); *Energy from Biological Processes: Volume II—Technical and Environmental Analyses*, OTA-E-128 (September 1980); *Energy from Biological Processes: Volume III—Appendixes Part A: Energy from Wood* (September 1980); *Energy from Biological Processes: Volume III—Appendixes Part C: Select Conversion Technologies and End Use* (September 1980); and *Facing America's Trash: What Next for Municipal Solid Waste*, OTA-O-424 (October 1989). Also see K.H. Lee et al., *Biomass State-of-the-Art Assessment*, Report GS-7471, 2 volumes (Palo Alto, CA: Electric Power Research Institute, September 1991).

FIGURE 2-2: Supply Curve for Whole Tree Chips



NOTE Biomass supplies from conventional wood sources (whole tree chips, logging residues, mill resdues, and others) are estimated to be from 13 EJ (1 2 quads) at $2/GJ ($2 10/MBtu) up to 56 EJ (5 3 quads) at $5/GJ ($5 25 MBtu) Most mill residues shown as part of this supply curve are already used for energy The estimates for whole tree chips were made in the mid- 1980s and more strict environmental rules and scrutiny may lead to decreased availability of this resource Excluded from these supplies is fuelwood used in the residential sector, which amouted to about O 8 EJ (O 75 quads) in 1990

KEY EJ = exajoules (1 EJ = O 948 quads) GJ = gigajoules (1 GJ = 0948 mllion Btu)

SOURCE Anthony F Turhollow and Steve M Cohen, Oak Ridge National Laboratory Data and Sources Biomass Supply, " draft, Jan 28, 1994

Bioenergy crops include annual row crops such as corn and sorghum, perennial grasses (herbaceous energy crops, or HECs)[12] such as switchgrass, and short rotation woody crops (SRWCs)[13] such as poplar and willow.[14] HECs are analogous to growing hay, with the crop harvested for energy rather than for forage. SRWCs typically consist of a field of closely spaced—2 to 3 meters (2 to 3 yards) apart on a grid-trees that are harvested on a cycle of three to 10 years. After harvest, HECs regrow from the remaining stubble and SRWCs regrow from the remaining stumps. Such harvesting may continue for 10 to 20 years or more without replanting; fertilizer, other inputs, and maintenance may be required more regularly, however. HECs, because they are grown like forage crops, may be grown by farmers with only modest changes in farming practices. SRWCs use conventional farm equipment for site preparation and weed control, but they require specialized equipment for harvest.[15] Only HECs and SRWCs are considered here for energy cropping.[16] Typical growing regions for selected energy crops are shown in figure 2-1.

The conversion of sunlight to biomass energy is an infficient process typically with an efficiency of less than 1 percent under field condi-

[12] HECs are typically grasses (e.g., switchgrass, big bluestem, intermediate wheatgrass, tall fescue) that are planted, maintained, and harvested like hay. Grasses such as these are currently used in the Conservation Reserve Program to provide erosion control and wildlife habitat. These crops regrow from their roots and stubble and require replanting only every 10 or more years. Because they are hay crops, they can be grown by farmers with only modest changes in farming practices, and equipment is relatively low cost.

[13] SRWCs are typically hardwoods (e.g., poplar, cottonwood, sycamore, silver maple) with planting density ranging from 1,600 to 5,000 trees/hectare (650 to 2,000 trees/acre). The silvicultural management of SRWCs is typically more intense than conventional forestry, but less intense than conventional agriculture. To obtain good yields requires site preparation, weed control during the first two years after establishment (before canopy closure), and the application of fertilizers. These operations employ conventional agricultural equipment. Harvest requires specialized equipment. Coppicing (i.e., regrowth from the stumps after harvest) is possible. Currently, some SRWCs are grown for pulp.

[14] Other potential bioenergy crops include microalgae.

[15] Such equipment might be owned and leased out by the conversion facility purchasing the bioenergy feedstock, by harvest equipment vendors, by cooperatives, or through other arrangements.

[16] Annual row crops used for energy (such as corn) are grown in essentially the same manner as their food crop counterparts and consequently offer few or no environmental benefits over conventional agricultural practices, For this reason, they are not examined further in this report. There are also energy crops (often annual row crops) that produce starches, sugars, oils, and other specialty plant products for energy. Nationally, however, their energy production potential is much lower and their costs are likely to be higher in the long term than those for HECs or SRWCS. Consequently, they are not considered further in this report. Some of these crops and fuels, such as biodiesel, may nevertheless offer important opportunities and have potentially valuable roles to play.

TABLE 2-2: U.S. Biofuel Production and Use, 1989

Fuel	Energy production (in exajoules)
Wood	2.6 EJ
Industrial	17
Residential	0 9
Utility	001
Biofuels from waste	036
Municipal solid waste combustion	O 23
Manufacturing waste	0.10
Landfill gas	003
Ethyl alcohol	0075
Total	3.04

NOTE EJ - exajoules, 1 EJ -0948 quads

SOURCE U S Department of Energy Energy Information Administration *Esfimates of U S Biofuels Consurnption 1989* (Washington DC April 1991)

tions. As a result, biomass must be collected from large areas.[17] For example, Producing 15 to 20 EJ (14 to 19 quads) of biomass energy annually would require energy cropping on 45 to 60 mill ion hectares (110 to 150 million acres) of land, if a high average yield is assumed. Sixty million hectares (150 million acres) is equivalent to roughly one-third of current total U.S. cropland; it is about 1.7 times more than the 36 million hectares (89 million acres) of cropland currently idled through various conservation and other programs. Crop productivity, harvest, handling, and transport are therefore important determinants of overall bioenergy costs [18] and key areas for further RD&D. Large collection areas also raise the specter of land-use conflicts: fuel versus food, fuel versus wildlife habitat, and others (see below).

Estimates of potential bioenergy crop production typically range up to around 25 EJ/year (24 quads/year) by 2030. '9 Projections based on current policy, however, are that nonliquid biomass fuels will provide 4 to 8 EJ per year (or 3.8 to 7.6 quads/year) in 2030.[20]

The specific land used for energy crops, however, may in some cases be prime cropland rather than currently idled or marginal lands. The use of any particular parcel of land will depend on its highest value use (food, feed, fiber, or fuel), environmental considerations, market access and conditions, and other factors. For example, prime crop land near a powerplant might best be used for producing energy crops in order to minimize transport needs. These factors will be determined by the respective markets operating within the agricultural sector. In many cases, multiple uses will be served.

Although producing large amounts of bioenergy will thus require large land areas (potentially greater than currently idle cropland), some argue that additional cropland will be idled by productivity improvements over the next several decades. For example, in the Intenmediate Future Scenario of the Second Resources Conservation Act (RCA) Appraisal, productivity increases are

[17] These large areas can consist of many small patches, depending on economic. env ironmental, and other considerations.

[18] Obviously land Prices are also important, but they are outside the range of issues considered here.

[19] Additional bioenergy resources are available from other sources such as municipal sol id waste and agricultural or forestry residues. Lower or higher production levels are possible. Various estimates are g iven by: J. W. Ranney and J.H. Cushman, "Energy from Biomass," *The Energy Sourcebook: A Guide to Technology, Resources, and Policy.* Ruth Howes and Anthony Fainberg (eds.) (New York, NY: American Institute of Physics, 1991); and Solar Energy Research institute et al., *The Potential of Renewable Energy: An Interlaboratory White Paper,* SERI/TP-260-3674 (Golden, CO: March 1990).

[20] Oak Ridge National Laboratory, Resource Modeling and Technology Economics Group, "Projections of Wood Energy Use In the United States," draft, July 2, 1990.

projected to allow an additional 46 million hectares[21] (114 million acres) of current cropland to be idled by 2030 for a net idled capacity of 64 million hectares (158 million acres) .22 In addition, some of the 54 million hectares (133 million acres) of pasture or other lands might be suitable for energy crops (see table 2-3).

Alternatively, some have recently argued that the Uruguay Round under the General Agreement on Tariffs and Trade (GATT), the North American Free Trade Agreement (NAFTA), and other factors could increase the demand for agricultural products and largely absorb lands currently idled through various agricultural programs in the near to mid-term.[23] In this case, energy crops would then be competing more directly with conventional agricultural commodities, and the market penetration of energy crops would depend on their relative return to the grower, the level of agricultural supports for their competitors, the credit given for their environmental benefits, and other factors. In the longer term. it is not known how competition for use of this land to produce food, feed. fiber. or fuel might evolve, particularly given technological advances, increasing crop productivities, and growing agricultural trade.

Figure 2-3 illustrates one estimate of the cost—for planting, maintenance, harvest. transport, etc.-of bioenergy as a function of crop yield and total production (see box 2-2). In the high-yield case of 18 dry metric tonnes/hectare (8 tons/acre) per year, roughly 10 EJ (9.5 quads) of biomass are available for $2/GJ ($2.10/million Btu—MBtu) or less and 17 EJ (16 quads) for $3/GJ ($3.15 /MBtu) or less. In comparison, the low-yield case gives essentially no biomass for less than $2/GJ and 10 EJ for $3/GJ or less. Thus, costs are quite sensitive to crop productivity, reaffirm ing the importance of RD&D into improved crop varieties to increase yields and decrease produc-

TABLE 2-3: Major Cropland Usage, 1992

Crop	Area planted (million hectares)
Corn	308
Wheat	259
Hay	25.5
Soybeans	235
Other small grains	77
Cotton	57
Sorghum	49
Other field crops	53
Orchards	20
Vegetables	16
Total active	1329
Idled	138
Short-term set-aside	77
Long-term set-aside	142
Total cropland	170.4
Total pastureland	539
Total rangeland	1644
Total agricultural land	3887

NOTE 1 hectare -247 acres

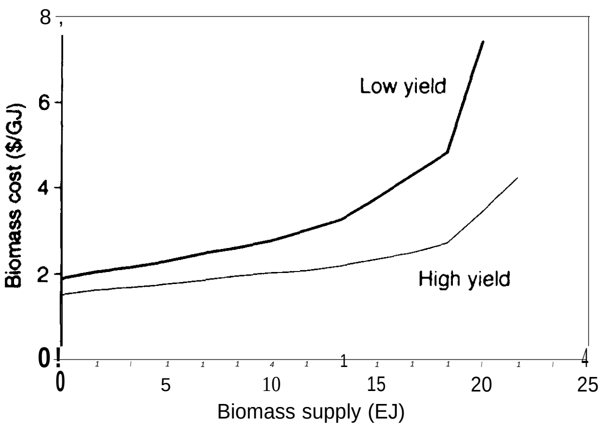
SOURCE Steven Shafer Air Quality Impacts from Agriculture Biomass Production and Residue Utilization as Energy Feed Stocks report prepared for the Off Ice of Technology Assessment May 13 1993

[2]'Ctilculated by assuming a base cropland area of 170 million hectares, minus the 36 million hectares currently idled and the estimated (intermediate scenario) 88 million hectares actively cropped by 2030. See U.S. Department of Agriculture, *The* Second *RCA Appraisal: Soil, Water, and Related Resources on Nonfederal Land In the United States, Analysis of Conditions and Trends* (Washington, DC: U.S. Government Printing Office, June 1989), figure 4, p. 10.

[22]Conversion of cropland to urban uses reduces the gross available area from 82 million hectares by another 18 million hectares, leaving roughly 64 mi II ion hectares of idled cropland. Total potentially available idle croplands, not including losses (o urban ization, are estimated at 30 to 105 million hectares (ibid.).

[23]See, e.g., U.S. Department of Agriculture. Office of Economics, Economic Research Serv ice, *Effects of the Uruguay Round Agreement on U.S. Agricultural Commodities* (Washington, DC: March 1994).

FIGURE 2-3: Biomass Supply Curve for Energy Crops on Agricultural Lands



NOTE The potential supply and cost of energy crops grown on agricultural lands are shown The low-yleid case assumes an average productivity of 13.4 dry metric tonnes/hectare/year (6 tons/acre), the high-yield case assumes an average productivity of 179 dry metric tonnes/hectare/year (8 tons/acre) These productivities are believed to be readily attainable, particularly in the Southern United States, by 2020 or sooner with continued RD&D and have already been realized in a number of experimental plots

SOURCE Burt C English and Anthony Turhollow, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville, "Estimation of the United States Potential To Produce Biomass for Energy, 2005 " 1994

(ion costs. This comparison also suggests that the economics of bioenergy crops may be less attractive on lower quality land.[24]

These estimates are preliminary. The unique local conditions for biomass production, detailed field demonstrations, and commercial purchase and use patterns have largely not been rigorously evaluated. Numerous questions remain concerning bioenergy crop management, procurement, regulatory constraints, market development, scaleup, and other factors. Nevertheless, these preliminary estimates and current fieldwork suggest a substantial bioenergy potential.

In comparison with the bioenergy crop costs shown in figure 2-3, current wholesale costs of coal, natural gas, and oil, respectively, are roughly $ 1.30/GJ ($1 .40/MBtu), $3.70/GJ ($3,90/MBtu), and $3 .00/GJ ($3. 15/MBtu), and are destined to increase over time (see box 1-1).[25] Total national energy use is roughly 87 EJ (83 quads), of which bioenergy currently accounts for roughly 4 percent, or about 3 EJ (2.8 quads) (see appendix 1 -A). Thus 20 EJ (19 quads) of bioenergy would be a substantial contribution to national energy needs.

Some of this bioenergy could potentially be converted to fuels for transport, which would reduce U.S. dependence on imported oil. Unless coupled with very aggressive efforts to improve vehicle fuel efficiency, however, biomass fuels will not be sufficient to completely displace imported oil (see chapter 4). Alternatively, biomass can be converted to electricity (chapter 5).

POTENTIAL ENVIRONMENTAL IMPACTS

Intensively cropping large areas for energy inevitably raises concerns about potential environmental impacts. A detailed review of potential soil, water, air, and habitat issues by the Office of Technology Assessment (OTA) shows that the net environmental impacts depend on the previous use of the land, the particular energy crop, and crop management.[26] For example, as a substitute for conventional agricultural row crops such as corn or soybeans, properly managed HECs and SRWCs can help stabilize erosive soils and

[24] This, of course, will also depend on whether some consideration or credit is given bioenergy crops for the extent to which they provide environmental or other benefits, or offset other subsidies or supports.

[25] The difference in cost between fuels reflects the additional processing or different conversion equipment that may be required, depending on each case. The costs are substantially lower than those charged to the final consumer.

[26] U.S. Congress, Office of Technology Assessment, *Potential Environmental Impacts of Bioenergy Crop Production+-Background Paper*, OTA-BP-E-1 18 (Washington, DC: U.S. Government Printing Office, September 1993).

BOX 2-2: Developing Energy Crop Supply Curves

The energy crop supply curves shown in figure 2-3 are calculated by using a linear programming model of the U S agricultural sector called the Agricultural Resources Interregional Modeling System The model is currently operated from the University of Tennessee

In this model the country is divided into 105 crop production regions, and each crop production region has eight land quality classes Crops Included in the model are barley, corn grain, corn silage, cotton, legume hay nonlegume hay oats, sorghum, sorghum silage, soybeans, wheat, and the energy crops switchgrass and short-rotaton hybrid poplar Grains, silage and hay also serve as inputs for livestock—beef hogs and milk and poultry production Switchgrass serves as a proxy for all warm-season thin - stemmed grasses, and hybrid poplar as a proxy for all hardwoods grown on a short (three- to 12-year) rotation using agricultural-type practices

Land available for crop production is restricted to exsting cropland, and cropland avaiability is assumed to decrease over time Demands for crops and livestock for food, industrial use, and export are he'd constant

The objectve functon of the model is to minimize the cost of producing food, livestock and energy crops, by varying the type and quanity of crops grown in each region

To develop a supply curve energy crop production levels (after losses in harvest and storage) were varied from O 16 to 24 EJ Supply curves were estimated for two energy crop national average yields, 134 dry metric tonnes hectare (6 tons 'acre) and 179 metric tonnes/hectare (8 tons 'acre), before losses Estimated losses ranged from 19 to 24 percent National average yields were determined by modeling energy crops with the EPIC (Erosion Productivity Index Calculator) model and setting average yields across all regions and land quality classes Over this range of production, delivered prices for energy crops varied widely from $1. 30/ GJ ($1 37'MBtu) for very small quantities up to $7/GJ ($7.40/MBtu) for very large quantities At higher production levels, yields make a significant price difference

SOURCE Office of Technology Assessment based on Burt C English and Anthony Turhollow, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville "Estimation of the United States Potential To Produce Biomass for Energy 2005" 1994

perhaps act as filters to prevent agricultural chemicals and sediments from rcaching water supplies .[27] They may help provide habitat directly or serve in buffers around, or corridors between, fragments of natural forest, wetlands, or prairie. (Such habitat benefits will. however. also depend on the particular animal species.) In contrast, substituting energy crops for hay, pasture. or well-managed Conservation Reserve Program lands will generally have r-nixed environmental impacts, both positive and negative. Positive impacts include offsetting fossil fuel use; negative impucts include possibly greater use of agricultural chemicals and habitat disruption during harvesting. At the global level. when grown on a closd-loop basis.[28] these bioenergy crops would make little or no net contribution to rising levels

[27] To serve as a filter and to be harvested periodically for energy, energy crops may require more complex and careful management than is typical for energy crops that do not serve such demanding multiple functions.

[28] *Closed-loop* means that new biomass is grown at the same rate at which it is harvested for use as energy. Thus, carbon dioxide will be taken up by new plant growth at the same rate that it is released by using the harvested biomass for fuel.

OAK RIDGE NATIONAL LABORATORY

Switchgrass growing near Auburn, Alabama This fast-growing, high-ytetd grass can be harvested once or twice each year over many years, whale its deep roots help protect soils and ground water

of atmospheric carbon dioxide ($C0_2$)—a key greenhouse gas.[29]

The potential environmental benefits of energy crops compared with conventional agricultural row crops are due to several factors. The energy crops considered here are perennials; agricultural crops are annuals. Perennial crops require tillage only when being established—perhaps every 10 to 20 years—and then maintain a year-round protective cover over the soil. This greatly reduces soil erosion, which occurs primarily when soils are uncovered during heavy storms, and can reduce compaction as well because of the less frequent use of heavy equipment on the soil. These energy crops also have the potential to be more efficient in the use of fertilizers (i.e., some nutrient retention and cycling occur between growing years that do not occur with annual crops).

The overall inputs required by energy crops are generally lower than in conventional agriculture for several reasons. Energy crops often have heavier and deeper rooting patterns than conventional agricultural crops, which allows the soil to be utilized to a greater depth for water and soil nutrients and provides more time to intercept fertilizers or other agricultural chemicals as they migrate down through the soil. This can also give energy crops greater capacity to intercept fertilizers or other agricultural chemicals flowing from adjacent areas. This capacity may make energy crops a valuable new tool in addressing certain nonpoint water pollution problems; further research on this subject is needed.[30]

Heavier rooting also puts more carbon into the soil and so assists in creating more productive soil conditions, such as enabling the slow continuous release of nutrients or the binding of chemicals so that they are not leached.[31] Energy crops are also selected on the basis of their production of cellulosic biomass, which consumes less input energy (e.g., light) per unit of energy stored than many specialty plant components.

Finally, energy crops can provide greater structural diversity especially if grown in polycultures in the longer term-than conventional agricultural crops, which emphasize large agricultural blocks devoted to a few monoculture cash crops. In general, the more complex the vegetation (with many species, sizes, shapes, and ages of

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[29] Currently, some fossil fuel—typically S to 15 percent of the energy value of the bioenergy crop—is used in the form of agricultural chemicals or diesel fuel. Energy crop cycles such as com to ethanol have much lower net energy production and consequently higher net emissions of carbon dioxide than the SRWC and HEC crops discussed here (see ch. 4). The potential contribution of biomass energy crops to other greenhouse gases, such as methane and nitrous oxide, needs to be examined.

[30] Office of Technology Assessment, op. cit., footnote 26.

[31] This also sequesters additional atmospheric carbon, thereby slightly slowing the increase in atmospheric CO_2 levels.

plants) in an area, the more complex is the community of animals--+, g.. insects,[32] spiders,[33] birds,[34] mammals[35]—that it will support. Conversely, as vegetative structure is simplified, the community supported becomes progressively poorer. For example, the number of insect species in typical agricultural ecosystems such as corn can be half that found in pasture and one-third to one-tenth that found in deciduous forests.[36] It is. in part, the structural poverty of conventional agricultural monoculture that opens an opportunity for using energy crops to improve habitat and biological diversity in a region.

Properly designed, energy crops can be used to manage or direct the regional landscape ecology—potentially serving as buffers around natural habitat, as corridors between fragments of natural habitat, or as habitat in themselves, How effectively the energy crop serves these roles depends on the particular crop, how it is managed (including use of chemicals, equipment, and harvesting cycle), and how the species that it is designed to assist actually respond. There are very few field data on which to base conclusions at this time; further research is required.

Energy crops are not, however, a substitute for natural habitat.[37] Instead, their impact depends on the particular case. In terms of local habitat value, it would often be preferable to let much of the idled cropland or other land return to a more natural state. Should global warming occur as currently projected, however, much of the habitat in the United States and elsewhere may be subject to sufficiently rapid climate change that the species and habitat intended to be protected may be unable to adjust quickly enough for the changed circumstances[38] (figure 2-4). To avoid this and out of more general concern for potential global warming, it may be preferable to use idled cropland to produce greenhouse-gas-neutra1[39] biomass energy. Energy crops are therefore of particular interest to the extent that they can be designed as a compromise between local habitat concerns and greenhouse gas concerns with global habitat implications.

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[32] D.R. Strong et al., *Insects on Plants* (Oxford, England: Blackwell Scientific Publications, 1984).

[33] C.L. Hatley and J.A. MacMahon, "Spider Community Organization: Seasonal Variation and the Role of Vegetation Architecture," *Environmental Entomology, vol.* 9,1980, pp. 632-639.

[34] R. H. MacArthur and J.W. McArthur, "On Bird Species Divers ity," *Ecology*, vol. 42, 1961, pp. 594-598; and G.S. Mills et al., "The Relationship Between Breeding Bird Density and Vegetation Volume, " *Wilson Bulletin, vol.* 103, 1991, pp. 468-479.

[35] M. Rosenzweig and J. Winakur, "Population Ecology of Desert Rodent Communities: Habitats and Environmental Complex ity," *Ecology, vol.* 50, 1966, pp. 558-572: and R. Il. Dueser and W.C. Brown, "Ecological Correlates of Insular Rodent Diversity," *Ecology, vol.* 61, 1980, pp. 50-61.

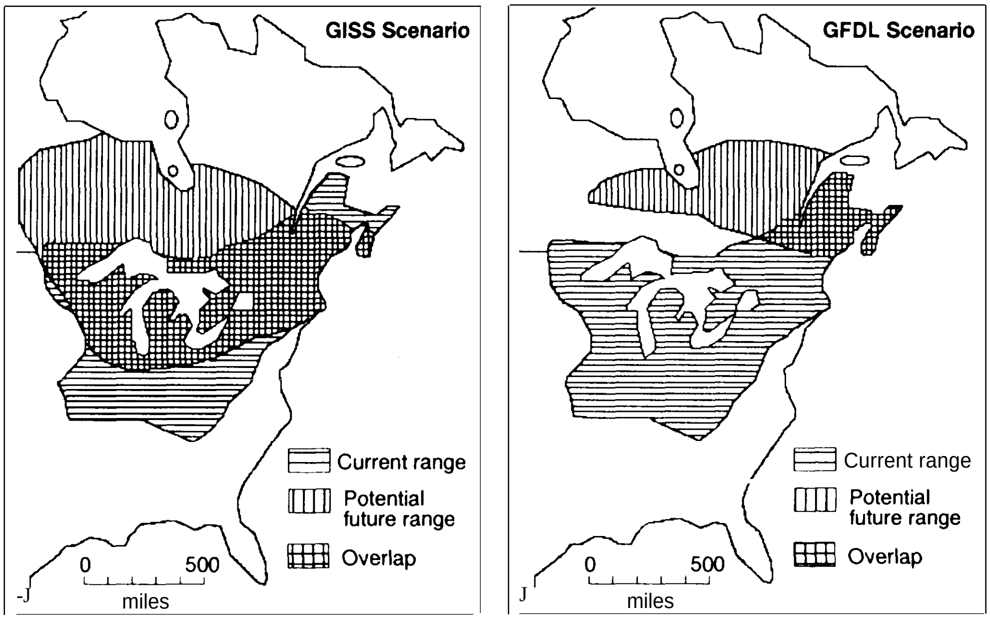
[36] David Pimentel et al., "Conserving Biological Diversity in Agricultural/Forestry Systems," *BioScience, vol. 42, No. 5,* May 1992, pp. 354-362; and M.G. Paoletti et al., "Agroecosystem Biodiversity: Matching Production and Conservation Biology," *Agriculture, Ecosystems and Environment, vol. 40,* 1992, pp. 3-23.

[37] Defining *natural habitat* may be difficult and controversial] because the past decades to centuries of clear cutting, selective harvesting of economically valuable trees, and tire suppression, for example, have altered many U.S. forests, often leading to an increased concentration of plant species with lower economic or ecological value. Similar alterations have occurred over many other U.S. landscapes, including prairie and wetlands. Although defining how much modification still qualifies as "natural " is thus challenging, the term is used broadly here to include all lands that support a significant quantity and variety of indigenous plants and animals. For this report, only current or former agricultural lands or highly degraded lands are considered for energy crops.

[38] U. S. Congress, Office of Technology Assessment, *Preparing for an Uncertain Climate*, vols. *1* and 2, OTA-O-567, OTA-O-568 (Washington, DC: U.S. Government Printing Office, October 1993).

[39] I f fossil- fuel. based agricultural chemicals, fertilizers, or transport fuels are used, bioenergy is not strictly greenhouse gas neutral. Typically, however, the net energy return (or greenhouse gas equivalence) for HECs and SRWCs varies from 6: 1 to 18: l for biomass energy to fossil energy inputs. In contrast, current com to ethanol production has much lower net energy gains.

FIGURE 2-4: Current and Projected Range of Sugar Maple Under Two Models of Global Warming



NOTE GISS = Goddard Institute for Space Studies, GFDL = Geophysical Fluid Dynamics Laboratory

SOURCE Office of Technology Assessment, 1993, adapted from M B Davis and C Zabinski, "Changes in Geographical Range Resulting from Greenhouse Warming Effects on Biodiversity in Forests," *Global Warming and Biological Diversity* B J Peters and T E Lovejoy (eds) (New Haven, CT Yale University Press, 1992)

Although large land areas would be devoted to bioenergy crops, in most cases they are not likely to dominate the landscape. For typical electricity or ethanol production facilities with processing capacities of 1,000 to 2,000 dry metric tonnes (1 ,100 to 2,200 short tons) of biomass per day, roughly 4 to 8 percent of the land in a 40-kilometer (25-mile) radius around the plant would be required.[40] In terms of land area, energy crops would then rank third or fourth in overall importance in most areas.[41]

Bioenergy can potentially also improve urban and regional air quality by reducing sulfur oxide (SO_x) and other emissions. SO_x emissions can be reduced by cofiring biomass with coal or by substituting biomass-fired for coal-fired powerplants. If poor-quality equipment or controls are

[40] This assumes the high yield of roughly 18 dry metric tonnes/hectare (8 tons/acre) shown in figure 2-3. At lower yields, the percentage of land devoted to energy crops would increase proportionately.

[41] R.D. Perlack et al. Oak Ridge National Laboratory, "Environmental Emissions and Socioeconomic Considerations in the Production, Storage, and Transportation of Biomass Energy Feedstocks," ORNL/TM-12030, 1992.

used, however, emissions of particulate and certain organic compounds could be increased by the substitution of bioenergy for conventional fuels.

Under the Clean Air Act Amendments of 1990, oxygenates arc required in gasolines used in urban areas that exceed carbon monoxide and ozone limits. Ethanol and methanol, which can be derived from renewable resources,[42] could serve that purpose. However, a 1994 government directive that 30 percent of oxygenates be derived from renewable fuels was recently overturned by a federal court. More importantly. by developing an infrastructure in support of ethanol or methanol fuel in the near term, mid- and longer term use of advanced vehicle technologies may be possible, with much greater potential reductions in emissions and substantial increases in fuel economy (see chapter 4).

Biomass can be used in place of fossil fuels to avoid the emission of carbon dioxide from fossil fuel combustion.[43] In addition, biomass energy crops may provide a net increase in soil carbon as well as in standing biomass, depending on the previous use of the land.[44] The ability of bioenergy to offset the emission of greenhouse gases is an important potential benefit from its use. Details of these issues are discussed elsewhere.[45]

Conversely, the potential impact of likely climate change on energy cropping is uncertain and may require some adaptation. These issues have been explored in depth in a recent OTA publication.[46]

ECONOMIC IMPACTS[47]

Rural economies in the United States have been hard pressed for many years. Between about 1980 and 1990, the U.S. share of the world total agricultural trade dropped from 28 to 21 percent. At the same time, the European share grew from about 13 to 19 percent. China is now the world's second largest corn exporter and Brazil is a major exporter of soybeans. Some expect that parts of Eastern Europe and the former Soviet Union could become food exporting powerhouses in the future.[48] In late 1992, roughly half of the shiploading grain terminals in the United States were reportedly closed, about to close, or for sale.[49]

[42] Again the focus here is on ethanol and methanol from cellulosic biomass. Ethanol from Com presents a different set of issues and is not examined here.

[43] D.O. Hall et al., "Alternative Roles for Biomass in Coping with Greenhouse Warming." *Science and Global Security*, vol. 2, 1991, pp. 113-151.

[44] L.L. Wright and E.E. Hughes, "U.S. Carbon Offset Potential Using Biomass Energy Systems," *Journal of Water, Air and Soil Pollution*, in press.

[45] For more information, see Off Ice of Technology Assessment, op. cit., footnote 26.

[46] Office of Technology Assessment, op. Cit., footnote 38.

[47] The primary source for this section is K, Shaine Tyson and Randall A. Reese, Windy Peaks Associates, "Economic Impacts of Biomass Energy," report prepared for the Office of Technology Assessment, Jan. 15, 1994. For other reviews of the economic impacts of bioenergy crops, see: Southeastern Regional Biomass Energy Program, Tennessee Valley Authority, and Meridian Corp., *Economic Impact of Industrial Wood Energy Use in the Southeast Region of the .0'. S., 4* vols. (Muscle Shoals, AL and Alexandria, VA: November 1990); J.W. Onstad et al.. National Renewable Energy Laboratory and Meridian Corp., *Analysis of the Financial and Investment Requirements for the Scale-Up of Biomass Energy Crops (Alexandria,* VA: September 1992); Ed Wood and Jack Whittier, "Biofuels and Job Creation: Keeping Energy Expenditures Local Can Have Very Positive Economic Impacts," *Biologue*, vol. 10, No. 3, September-December 1992, pp. 6-1 I: Meridian Corp. and Antares Group, Inc., "Economic Benefits of Biomass Power Production in the U.S.," *Biologue, vol. 10, No.* 3, September-December 1992, pp. 12-18. R.L. Graham et al., "Biomass Fuel Costs Predicted for East Tennessee Power Plant," *Biologue*, vol. 10, No. 3, September-December 1992, pp. 23-29; and U.S. Department of Energy, Office of Solar Energy Conversion, Solar Thermal and Biomass Power Division, *Electricity from Biomass: A Development Strategy*, DOE CH 10093-152 (Washington, DC: April 1992).

[48] In the longer term, population growth in some developing countries may surpass agricultural productivity growth and increase the demand for food imports. Some of this demand may be supplied by the United States. No one knows, however, what the net effect is likely to be.

[49] Scott Kilman, "U.S. Is Steadily Losing Share of World Trade in Grain and Soybeans," *Wall Street Journal*, Dec. 3, 1992, p. Al.

These pressures have resulted in a growing need to find alternative crops and/or markets for U.S. agricultural communities: to provide employment, to stabilize rural incomes, and to maintain the rural infrastructure of equipment and supply distribution and service. Bioenergy crops offer one such alternative.

The rural economy faces several trends: bioenergy may be able to moderate some of their impacts. Domestic demand for conventional agricultural products is likely to increase slowly: U.S. population growth is low[50] and the U.S. consumer is reasonably well fed. At the same time, foreign demand is uncertain and will depend on how fast agricultural productivity increases compared with population growth, the impacts of trade agreements such as GATT and NAFTA (see above),[51] and other factors. Foreign demand might also be met in the future by new export powerhouses, particularly Eastern Europe and the former Soviet Union. Latin America. and elsewhere.[52] Efforts in those regions will bc strongly aided by adoption of the modern agricultural techniques and crop varieties pioneered by the United States. Thus, U.S. farmers are not assured of a continuing comparative advantage. at least not of the magnitude they have enjoyed in the past.

The trend to farming as an agribusiness is likely to continue as well. This is an inevitable result of the need to maintain some competitive advantage, and it will require increased use of modern chemistry, biology, and computer and telecommunication technologies, creating a production unit with sophisticated stocks and flows of goods and scrvices.[53]

The production of bioenergy may also be impacted by such agribusiness considerations. For example, large conversion facilities requiring an assured supply of feedstock might: 1) buy or lease land sufficient to supply their biomass feedstock needs; 2) negotiate a limited number of larger contracts to provide the feedstock while minimizing overhead; and 3) use these supplies to keep market prices down and supplies up—all of which could significantly influence bioenergy markets in a region. This scenario is a rather different vision from that of many small farmers entering a huge market. Further analysis of the possible evolution of these markets would be useful.

Environmental considerations may play an increasing role in farming practice as well. Indirectly, increasing attention to environmental considerations on public lands may push fiber and other production activities more to private and marginal lands.[54] At the same time, increasing attention to environmental issues on private lands (e.g., soil erosion, water quality, habitat) may also have an impact on cropping practices.

Energy crops may provide alternative sources of income and help diversify risk for the farmer. Energy crops have the potential to redirect large financial flows from foreign oil or other fossil energy resources to the rural economy while simultaneously reducing federal agricultural expenditures. Realizing this potential, however, will require further development of economically and environmentally sound energy crops; their successful commercialization; and carefully crafted federal, state, and local policies to ease the transi-

[50] U.S population growth is one of the highest in industrial countries. however.

[51] U.S. Department Of Agriculture, 0p. cit.. footnote 23.

[52] Of course, this will require heavy investment to develop the needed infrastructure of farming equipment, roads, storage facilities, and shipping terminals. Such investment capital is now very limited in these countries.

[53] U.S. Congress, Office of Technology Assessment, *A New Technological Era for American Agriculture, OTA-F-474* (Washington, DC: U.S. Government Printing Office, August 1992); and William E. Easterling, "Adapting United States Agriculture to Climate Change," report prepared for the Office of Technology Assessment, February 1992.

[54] This is beginning t. occur in the pacific Northwest now, with SRWCs being grown on pasture or cropland to supply fiber for paper products.

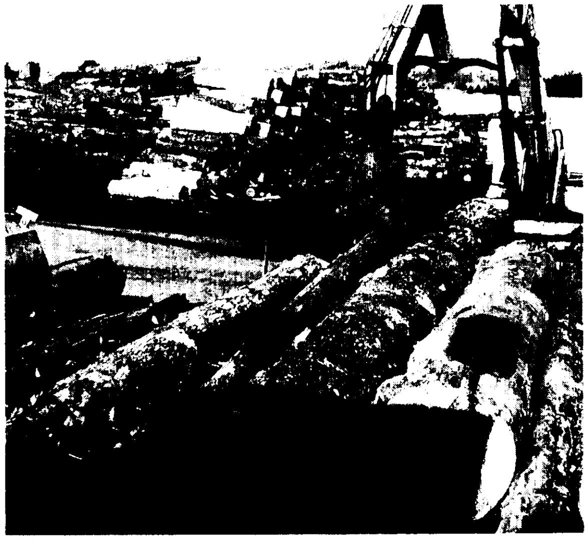
(ion to energy crops without injuring the farm sector or exposing it to undue risk during this period. It will also depend on the relative value of other uses of this land and the costs and benefits of other fuels and technologies.

Electricity

Several efforts have been made to model the potential economic impacts of bioenergy crop production.[55] For the electricity sector. job creation in rural agriculture must be measured against fewer jobs created or even job losses in coal production.[5b] Various estimates place net job creation—including both direct and indirect impacts across the entire economy—with bioenergy development at about 9,500 to 13,000 jobs per GW of electricity-generating capacity in the year 2010 and net income generation at $170 million/GW to **$290** million/GW. Much of the projected job creation would be in rural agricultural areas.

These models project bioelectricity capacity in the year 2010 in the range of 12 to 18 GW. Factors influencing this capacity expansion include the design of the particular econometric model and assumptions concerning the costs of competing fuels, the continued availability of tax credits, the growth in electricity demand, and technological advances.

Estimates of federal and state tax revenues on the direct and indirect economic activity stimulated by the bioelectricity generation vary, but typically range in the neighborhood of $70 million/GW before tax credits or other financial supports. In addition, there is the potential to offset some of the roughly $10 billion that the federal government now pays in agricultural commodity support and conservation programs (see below).



WARREN GRETZ NATIONAL RENEWABLE ENERGY LABORATORY

Wheelabrator Shasta Energy Co , near Anderson, California, uses the bark to generate electricity and se//s the hfgh-quality wood chips to a nearby paper mill.

Installing 12 to 18 GW of bioelcctricity-generation capacity by 2010 is a substantial challenge. Feed stock production and powerplant demonstrations must be developed and completed to show the financial viability of these technologies. Detailed business plans must be developed and financial markets tapped. Large-scale dedicated energy crops must be established, infrastructure developed, powerplants built, and regulatory and institutional issues addressed. For capacity on this scale to be installed by 2010, power companies should already have a significant amount of bioenergy powerplant construction in their 10-year plans: they do not.[57] In the longer term, however, bioelectricity production on a very large scale (50 to 100 GW or more) appears feasible with expected crop land availability and bioenergy crop productivity, and with expected advances in

55 Tyson and Reese op. cit., footnote 47; Southeastern Regional Biomass Energy Program, Tennessee Valley Author-it). and Meridian Corp., op. cit., footnote 47; Wood and Whittier, op. cit., footnote 47; and Meridian Corp. and Antares Group, Inc., op. cit.. footnote 47.

56 Over a particular time there may be net increases in jobs in the coal sector even with aggressive bioenergy development, depending on the overall growth of the electricity sector, coal share of electricity) generation, and other factors. Further. other factors such as automation may reduce the number of jobs in coal mining as well as in bioenergy. For example. according to one estimate the coal industry cut its workforce by a net 70,000 jobs between 1980 and 1990 as a result of productivity increases. See Meridian Corp. and Antares Group. Inc., op. cit., footnote 47.

57 Kurt Yeager Electric Power Research Institute, personal communication, Mar. 11, 1994.

biomass-powered electricity-generating technologies (see chapter 5).

Liquid Fuels

Technologies are under development to convert energy crops such as HECs and SRWCs to liquid fuels such as ethanol and methanol that can be used for transport[58] (see chapter 4). The econom ic impacts of large-scale production of liquid fuels are similar to those for the production of bioelectricity. Net income and job gains in the agricultural sector must be weighed against possible long-term slower growth or even job losses in the oil and refinery sectors. The impact of biofuels on the oil and gas sector is, however, likely to be far less important than that of ongoing changes within the oil and gas sector: declining domestic resources in many areas, refinery operations shifting offshore, volatile prices impacting independent developers, and many others. Further, because oil and petroleum products have a well-developed global market, a large share of any domestic oil production or refinery capacity displaced by the production of biofuels may ultimately be redirected toward other markets, with little overall job or income loss. Additional investment in infrastructure may be required, however, to move these products efficiently to new markets.

Estimates of direct and indirect job creation in the agricultural and conversion sectors are roughly 20,000 jobs per billion gallons of ethanol (BGOE) and $350 million of direct and indirect income per BGOE.[59]

Potential production levels of ethanol and methanol vary widely with assumptions about the cost of oil, the availability of tax credits and other financial supports, constraints on the availability of manpower and finance, growth in the demand for transport fuels, technological advances (see chapter 4), and many other factors. One model projects production levels of 15 to 50 BGOE per year by 2030, depending on these and other factors.[60] A level of 50 BGOE is the equivalent of roughly 2 million barrels of oil per day, or about 10 percent of our current total oil use. Before 2010, the potential for producing ethanol is limited by the need for continued RD&D of the technology and the lead time required for large-scale commercialization. Further work to understand the potential economic impacts of biomass-ethanol strategies would be useful.

Fluctuations in the price of oil have been a significant risk for ethanol producers. Between 1979 and 1987, the corn-ethanol industry constructed some 140 facilities of which 60 percent failed and were closed, at least in part due to the oil bust in the mid-1980s. Oil price fluctuations similarly pose substantial risk to future development of biomass-to-ethanol production.

Federal Budget Impacts

Federal agricultural expenditures play a noted role in the rural economy. The federal budget is under great pressure, however, and agricultural programs—like everything else—are undergoing increased scrutiny for savings. Currently, federal programs to prevent soil erosion[61] and various commodity support programs to strengthen crop prices together cost roughly $10 billion per year, and considerable debate about the future of these programs is under way. If, for example, the Conservation Reserve Program (CRP) is reduced in scope in the future, unintended costs may be im-

[58] These energy crops have a much greater resource potential than com to ethanol, much better overall energy *Conversion ratios,* and fewer (or beneficial) environmental impacts.

[59] Tyson and Reese, op. cit., footnote 47.

[60] Ibid.

[61] An example is the Conservation Reserve program (CRP), which pays farmers to take lands out of production of a marketable crop for 10 years in order to protect more erodible or fragile soils with permanent cover. Similar soil protection can be obtained from bioenergy crops on CRP land, but harvesting of energy crops may reduce the wildlife habitat value of this land.

posed on the commodity support programs as farmers put previously idled CRP lands back into production. More generally, as agricultual productivity continues to increase, means of idling additional acreage may be necessary.

Bioenergy crops area potential alternative cash crop that could protect fragile soils or could be grown on lands previously idled in order to strengthen commodity crop prices. If grown on fragile soils or marginal lands. however, energy crop productivities would 1ikely be low and might require additional supports to be cost competitive. Bioenergy represents a huge potential market. Americans use food at the equivalent of roughly 100 watts,[62] while energy is used at the rate of 10,000 watts. U.S. energy demands are far greater than the energy likely to be produced by bioenergy crops.

Earnings from energy crops might then be used to ease federal supports while maintaining farm income. Of course, the relative environmental benefits of energy crops versus current soil conservation programs such as CRP would again depend on the specific energy crops grown and how the land was managed. The relative economic and budgetary value of producing bioenergy crops would have to be compared with potential alternative uses of the land. Designing federal programs to achieve such ends while minimizing disruption and risk to farmers presents challenges.

The federal government also provides significant crop insurance support in response to flood, drought, or other natural disasters. Some bioenergy crops may be naturally more resistant to such disasters than food or feed crops. For example, in contrast to food or feed crops, certain trees normally found in frequently flooded bottonlands-sweetgum. sycamore, willow, and others-may survive partial inundation for weeks without significant damage. Harvesting of food or feed crops must also be done within a narrow window of time; severe weather or natural disasters may limit such harvesting. In contrast, the harvest of SRWC bioenergy crops can be delayed for months with no damage to the crop. The extent to which such bioenergy crops can cost-effectively substitute for traditional food or feed crops while potentially reducing federal crop insurance expenditures needs to be examined in detail.[63]

Trade Balance Impacts[64]

U.S. expenditures on foreign oil are currently running about $45 billion per year and are destined to increase sharply as domestic oil production continues to decline. Several U.S. electric utilities are also now importing low-sulfur coal. As noted above, bioenergy crops could potentially offset some of these imports. Although biocnergy by itself is unlikely to eliminate fuel imports unless combined with dramatic improvements in vehicle efficiency (see chapter 4), it could make a substantial contribution to our energy needs.

RD&D AND COMMERCIALIZATION

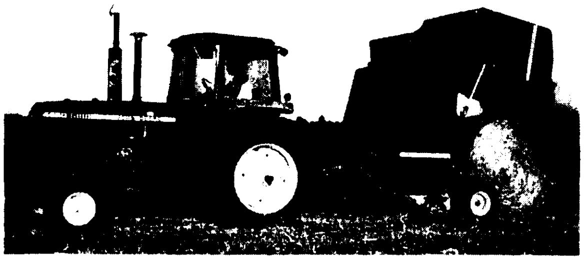
If bioenergy is to make a substantial contribution to the U.S. energy mix, several issues must be addressed. Examined briefly here are RD&D of environmentally sound energy crops and market challenges that may substantially slow commercial adoption of these technologies.

[62]This does not account for transport, storage, processing, and other losses, or for the low conversion efficiency of feed to meat. In addition, only a small portion of the plant is useful food, while most of the plant carl be converted to energy.

[63]This might include consideration of both the risk of crop loss and the offsetting of federal or other crop insurance payments.

[64]Some note that Japan imports all of its oil, yet still maintains a sizable trade surplus for various reasons. Thus, the role Of energy in the trade balance is just one facet of a very complex issue. Reducing the (). S. trade deficit mayor may not be a worthwhile goal at this time, depending on a variety of factors; reducing the trade deficit and creating jobs at home--all else remaining the same—are likely [o help domestically.

LAB



Baling switchgrass near Auburn, Alabama.

Research, Development, and Demonstration

Research, development, and demonstration may be useful at all levels of biomass energy systems, including high-productivity crop varieties; their planting, maintenance, and harvesting; their environmental impacts; their transport and storage; and their conversion to fuels or electricity (see chapters 4 and 5).

- *High-productivity crop varieties.* RD&D to improve energy crop productivity and performance remains in its infancy. Crop productivities have increased 50 percent in the past decade, but substantial further improvement appears possible. Because of the sensitivity of biomass costs to crop yield (figure 2-3), improving crop productivity can play a particularly important role in the economic viability of energy crops. In the longer term, the development of complementary polycultures may also be of interest (see below).
- *Crop operations.* Crop planting, maintenance, harvesting, transport, and storage represent the bulk of the costs—and thus opportunities for cost reduction—in producing biomass. Much research remains to be done in these areas, but early indications suggest substantial opportunities for productivity improvement and overall cost reduction in several of these steps.
- *Environmental impacts.* Relatively little R&D has been done on the environmental impacts of energy crops in the United States. Most studies have been short term, limited in scope, and confined to small scales. Although careful studies have been conducted at a handful of sites across the United States, the results tend not to be readily transferable to significantly different sites, crops, or management practices. Consequently, most practices in the field have been developed by analogy with conventional agriculture or forestry. This approach has significant limitations: for example, energy crops can have much deeper and heavier rooting patterns than conventional agricultural crops, affecting soil carbon balance, water balance, and the fate of agricultural chemicals. Even less is known about the habitat impacts of energy crops; some of the first studies are just under way at a few locations. Virtually all proposed habitat practices are based on ecological theory and by analogy with conventional crops. A detailed list of possible environmental RD&D is provided in box 2-3, and prototype principles for structuring energy crops are provided in box 2-4.
- *Demonstrations.* There have been few demonstrations to establish pilot energy conversion facilities such as bioenergy to electricity or to liquid or gaseous fuels (or to other petrochemical substitutes); to clarify issues of how best to develop supporting infrastructure and to address overall management and regulatory issues; or to determine how to structure energy crops for maximum environmental (soil, water, air, habitat) value or determine what their environmental value actually is by field observations. Demonstrations are most useful if they are of sufficient scale to clarify the characteristics of a fully functional infrastructure and thus to reliably and cost-effectively link feedstock production activities to energy conversion processes.[65]

[65] The U.S. Department of Energy is making awards for feasibility studies for bioenergy crop and conversion demonstration projects.

The structure of the farm sector also plays a role in determining environmental impacts and needs to be examined carefully. For example, roughly one-third of farms having fertilizer expenditures and one-quarter having pesticide expenditures in 1986 paid for some custom application procedures. Training such specialists in the timing and application of agricultural chemicals to minimize misapplication, potential groundwater leaching or runoff, or other problems may require one set of extension activities; reaching the two-thirds or more of the farms that use on-farm hired laborers to do it may require a different approach.[66] Extension efforts will also vary between very large farms and small part-time farms. Tenants and part-owners are operating an increasing proportion of farms and farmland acres, and may be less concerned about the environmental costs and benefits of various crops and management systems than owners.[67]

Some research is already under way for many of the above and related topics. In addition, the Electric Power Research Institute. National Audubon Society, and others have organized a National Biofuels Roundtable to develop a set of principles and guidelines for minimizing negative environmental and socioeconomic impacts associated with the development of bioenergy crops and conversion facilities.[68]

Energy crops must be cost-effective to producers and users. This will require careful balancing of environmental considerations—including near-term local and long-term global environmental impacts—within the overall bioenergy economics. It may also require trading off local versus global environmental impacts. Detailed integrated analyses of the economics and environmental impacts of various bioenergy fuel cycles are needed. The economics of bioenergy crops might also be improved if the potentially significant environmental services of energy crops were recognized and valued, where appropriate. This may be quite difficult in practice.

Finally, and as noted above, energy crops may also provide greater habitat value than con\' entional agricultural monoculture. Providing habitat has traditionally been of 1ittle concern to and is largely not addressed by conventional agriculture. In contrast, the National Biofuels Roundtablc has identified habitat improvement as a guideline for bioenergy development.[69] The extent to wh ich the habitat value of bioenergy crops is actively encouraged is a policy choice, however, and will be influenced by a variety of factors. including the particular region, crop, and wildlife species; overall bioenergy crop economics: and the value (if any) credited the energy crop for its habitat benefits. The extent to which bioenergy crops can address habitat concerns without significant} reducing their economic viability —particularly vis-à-vis agricultural crops or fossil fuels. wrhich carry little or no such consideration-is unknown.

If the potential habitat value of energy crops is identified as an important policy goal, several issues are then raised, including the follow in::

- *Disrupting life-cycle processes.* Biomass planting, maintenance, harvesting, and other activities may sometimes interfere with key

66 New technologies ma\ also help a\ oid some Of these problems. For example, the development Of time-re!e~ie fertilizer\ (or other agricultural chemicals) would allow farmers to continue the common labor-sa\ ing practice of spreading fertilizer (or other chemicals) onl\ once per year while reducing the amount that must be applied to ensure that the nutrients arc available late in the growth cycle. See David O. Hall et al . "Biomass for Energy: Supply Prospects," *Renew able Energy: Sources for Fuels and Electricity*, Thomas B. Johansson et al. (eds.) (Washington, DC': Island Press, 1993).

67 U.S. Congress, Office of Technology Assessment, *Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemi '()/ [']) ttami-nation of Groundwater*, OTA-F-418 (Washington, DC: U.S. Government Printing Office, November 1990).

68 National Biofuels Roundtable, Electric Power Research Institute, and National Audubon Society, "Principles and Guidelines for the De-~ elopment of Biomass Energy Systems " draft, May 1994.

69 Ibid.

BOX 2-3: Environmental Research and Development Needs for Energy Crops

Energy crops raise a variety of Important environmental concerns Research to understand and minimize potential environmental Impacts IS needed across a breadth of Issues, Including the following

- Soil qualify. Key areas of RD&D Include the development of a "minimum data set" of key soil physical, chemical, biological, and other parameters as a means of monitoring soil quality over long periods of time for different crops and management regimens. nutrient cycling, particularly of biochemical processes, the return of organic matter to the soil under various intensive energy crops and cropping systems, and the impacts of necessary equipment and various tillage systems on soil quality It may also be necessary to conduct this RD&D in parallel with the study of adjoining land uses to improve understanding of the interaction of energy crops with the larger environment.
- Agricultural ***chemicals.*** Research on the impact of agricultural chemicals on soil flora and fauna and on wildlife is needed. This includes research on the Impacts on wildlife behavior and reproductive processes Chemical pathways, decay processes, and Impacts need to be better understood, particularly when they affect more than the target species or when they move out of the target area The dynamics of chemical use on energy crops, how to reduce the movement of chemicals offsite, and how to reduce their use generally are important Issues.
- ***Water quality.*** Research is needed on the impact of erosion/sedimentation and agricultural chemicals from energy crops, especially on riparian zones, and on the potential of various energy crops to serve as filters and buffers for riparian areas Studies are also needed on how to best minimize potential Ieaching of agricultural chemicals into groundwater. Energy crops might be a useful tool for reducing nonpoint agricultural pollution, but data are needed to verify this and to provide better crop guidelines for realizing that end,
- Air ***quality.*** Research on the total fuel cycle emissions of various bioenergy crops, conversion, and end-use systems is necessary to minimiae impacts on air quality This Includes better understanding of both rural and urban air quality issues and how to best trade them off to maximize benefits Comparing the potential air quality Impacts of bioenergy systems with those of a wide range of other fuel and energy technology options is a key issue
- ***Habitat.*** Box 2-4 Iists a number of prototype principles for structuring energy crops to maximize their value as habitat, buffers, or corridors Each of these principles needs to be examined through extensive research in dedicated large-scale field trials and modified as necessary Such research must consider the impacts of energy crops in the context of the regional landscape ecology over the near and the long term Establishing overall goals for the desired habitat impacts (which species should be helped) of energy crops in the larger landscape WI I also require extensive analysis.

life-cycle processes for wildlife. If such potential conflicts are to be minimized, biomass harvesting and other activities may need to be restricted during nesting and other critical times. (Harvesting may also be limited at times, for example, during peak growing periods or inclement weather.) This could require storage of sufficient biomass to keep the conversion plant operating during this period: it may also require idling capital equipment and labor used for harvesting and transport. Alternatively, electricity generation, for example, might be powered during such periods by the use of natural gas (chapter 6). On the other hand, a well-established biomass industry may have a sufficient variety of crops and rotation cycles to moderate this disruption. Field trials arc needed to determine the extent of these potential disruptions and means of moderating them.

BOX 2-3 (cont'd.): Environmental Research and Development Needs for Energy Crops

- ***Restoration of degraded soils and ecological functions.*** Energy crops may reverse soil deterioration from human abuse in certain cases This might Include problems of soil structure, loss of topsoil or organic content, salinity, acidity or alkalinity, or even chemical or heavy-metal pollution. [1] It might also Include restoration of some water purification or wetland functions, including moderating flood damage. Research is needed to Identify such opportunities, to design systems that make the best use of this potential, and to verify performance in the field Realizing the possible restorative potential of energy crops while providing landowners with adequate income (where yields are low) poses additional challenges
- ***Greenhouse gases.*** The total fuel cycle (from crop production to end use) impact of energy crops on greenhouse gases (including carbon dioxide, methane, isoprenes, and nitrous oxide) needs to be evaluated for various energy crops, conversion processes, and end uses. The development and use of a "minimum data set" of key emission factors would be useful for determining these Impacts. Related effects (e g , on soil carbon balances or vehicle refilling station volatile organic compounds emissions) should be Included These fuel cycle emissions can then be compared for agricultural or energy crops and for fossil or biomass fuels
- ***Crops and multiple cropping.*** The potential risks and impacts of various genetically modified energy crops Will need to be examined A variety of multiple cropping systems should be evaluated to determine how to ensure soill quality, habitat benefits, crop productivity, crop disease resistance, and other key economic and environmental criteria At the same time, research is needed to determine how to convert agricultural lands to tree crops and vice versa, the soils and microflora and fauna are often quite different

[1] Growing plants will take up a variety of chemical or heavy metal toxins, depending on the precise substance and the particular plant species This poses a problem for food crops because it concentrates the toxins and allows them to enter the food chain In contrast for energy crops these toxins may be removed in the energy conversion process (e g destroyed by combustion or remaining in the ash) and so may allow a gradual cleansing o! the soil

SOURCE U S Congress, Off Ice of Technology Assessment *Potential Environmental Impacts of Bioenergy Crop Production*, OTA-BP-E-1 18 (Washington DC U S Government Printing Off Ice September 1993)

Polycultures. In the longer term, it may be useful to research the value of polycultures (a mixture of species as well as various ages. sizes, and shapes) to provide both energy and environmental benefits. According to ecological theory and a few limited field tests, a mixture of species can have higher biomass productivity and greater resistance to environmental stress than a monoculture.[70] From this perspective, a polyculture would benefit bioenergy production. On the other hand, it may be easier and cheaper to maintain a monoculture and to harvest, transport, and convert a uniform size

[70] Peter Kareiva, "Diversity Begets Productivity," *Nature*, vol. 368, Apr.21, 1994, pp. 686-687; Shahid Naeem et al., "Declining Biodiversity Can Alter the Performance of Ecosystems." *Nature*, VOI. 368, Apr. 21, 1994, pp. 734-737; and Yvonne Baskin, "Ecologists Dare To Ask: How Much Does Diversity Matter'?" Science, vol. 264, Apr. 8.1994, pp. 202-203.

and type of feedstock.[71] Research in the conversion of polycultures could be useful, particularly if it can be coupled with field research on the habitat and other environmental benefits of particular combinations of crops.

- *Regional landscape planning.* Realizing the benefits of energy crops as habitat, buffers, and corridors may in some cases require a level of regional landscape planning not often seen in this country. This will require much more RD&D on regional landscape ecology and its sensitivity to imperfections. Considerable effort will also be required to develop new policy instruments for encouraging participation in such landscape formation across many public and private properties. These issues are examined further in box 2-4.

Finally, once a substantial market develops for wood fuels, there is the potential risk that owners will be encouraged to harvest poor-quality timber—spared up to that point because of its low commercial value—that is serving as important wildlife habitat, or to plant energy crops on wetlands that are fertile but inappropriate for conventional agriculture. These matters are particularly important in regions such as the Northeast where forests are the primary biomass resource. Means of addressing such unintended side effects maybe needed.

These many issues form a substantial near-, mid-, and longer term RD&D agenda. Which of these issues should be pursued and when depend on the policy goals that are established.

Commercialization

As for any new technology, agricultural production of energy crops faces a variety of market challenges that may slow the speed of adoption.[72] These challenges include slow technology adoption in the agricultural sector, competitor prices (low and/or volatile fossil fuel prices), production scaleup, ways to level the playing field, and infrastructure development. Energy crops also must contend with a variety of existing support programs for other crops (box 2-5). Each of these factors may play an important role in determining the pace of market penetration by bioenergy crops. Issues unique to bioenergy crop development and commercialization are discussed here.

Technology Adoption

Technology adoption in the agricultural sector has been relatively slow in the past. This is changing, however, as agricultural production becomes increasingly technology-based and business-oriented,[73] and because of the competitive pressures and rigid market fluctuations farmers have experienced in recent years.

Farmers typically make *production* decisions within short timeframes while maintaining flexibility, which discourages investments in potentially longer term and less flexible energy crops. Market prices, support levels, credit availability, and debt load are critical considerations at the individual farm level.

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[71] For example, some species in a polyculture may not be easily converted to ethanol by current enzymatic hydrolysis processes. In the near term, it maybe more important to verify the cost and performance of these conversion processes by using R&D already in progress for narrowly specified (monoculture) feedstocks. For the longer term, it may be useful to begin R&D now to adapt these enzymatic hydrolysis processes to mixed feedstocks as needed in order to increase habitat benefits. Some research on mixed feedstocks is under way at the National Renewable Energy Laboratory. It tends to focus, however—and rightly so at this early stage-on a few common farm species that might be mixed with the primary feedstock by accident, rather than on a much wider range of plants that might be considered on the basis of their habitat value. Arthur Wiselogel, National Renewable Energy Laboratory, personal communication, Sept. 8, 1993.

[72] The specific issues of commercializing transport fuels are addressed in chapter 4 and of commercializing electricity-generation technologies in chapters 5 and 6. See also U.S. Congress, Office of Technology Assessment, *Replacing Gasoline." Alternative Fuels for Light-Duty Vehicles, OTA-E-364* (Washington, DC: U.S. Government Printing Office, September 1990).

[73] U.S *Congress,* Office of Technology Assessment, *A New Technological Era for American Agriculture, OTA-F-474* (Washington, DC: U.S. Government Printing Office, August 1992).

BOX 2-4: Prototype Ecology-Driven Principles for Structuring Energy Crops

Plant species under consideration for use as bioenergy crops are primarily native species that evolved in the regions where they may be used These crops can provide greater structural diversity on a landscape level than typical agricultural crops and thus can enhance wildlife habitat The extent to which such habitat benefits are realized, however, depends on the careful application of ecological principles, as outlined below These principles should be considered merely a starting point, requiring much further research Further, these principles are drawn from studies of natural ecosystems and of highly simplified agricultural systems there are few or no empirical data for energy crops themselves Conducting dedicated field trial research on the ecological Interact Ions of natural systems with energy crops would be useful in guiding the development of large-scale energy cropping Finally, the extent to which these principles can be pursued WiIl be highly dependent on the local situation and the economics of the particular energy crop

Ecology-driven principles for structuring energy crops might Include the following

- Site. Energy crops should be concentrated on current, idled, or former agricultural, pasture, or other "simplified" or "marginal' lands Energy crops should not be grown on naturally structured primary - growth forest land, wetlands, prairie, or other natural lands [1]
- Species. Energy crops should combine two or more species in various ways to improve species diversity. This would preferably include the use of leguminous species or others with nitrogen-flxlng capabilities to reduce the need for artificial fertilizers, and other comb; nations to reduce potential losses from disease or Insects and thus reduce pesticide use Noninvasive species that will not escape from cultivated plots are also preferred
- ***Structure.*** Energy crops should combine multiple vegetative structures to enhance landscape diversity as needed by particular wildlife species This could include various combinations of SWRCs, perennial grasses, and other dedicated energy crops, Ieaving small to large woody debris and other ground cover, as well as Inclusions of natural habitat, as needed These energy crops could also be used to provide structure to conventional agricultural monoculture through the addition of shelterbelts and fencerow plantings Similarly, monoculture of energy crops should have shelterbelts or fencerows of other types of vegetation
- ***Lifetime.*** Landscape structure can also be made more diverse by harvesting adjacent stands on different rotation cycles, Including Ieaving some stands for much longer periods if possible.
- ***Native species.*** Energy crops should use locally native species rather than exotics to the extent possible Native species or close relatives wiIl harbor richer insect and other faunas
- Chemicals. Crops should be chosen to minimize application of agricultural chemicals such as herbicides, insecticides, fungicides, and fertilizers, as discussed earner
- ***Unique features.*** Unique habitats and features such as small natural wetlands, riparian or other corridors, "old-growth" inclusions, and shelterbelts should be preserved and enhanced by the energy crop
- Habitat ***assistance.*** Artificial nesting structures and other additions to or supplements of habitat features should be provided where appropriate
- Research. Energy crops should be studied carefully at all appropriate scales and on a long-term basis to better understand the means of Improving appropriate habitats for desired species both for the energy crop itself and for related agricultural, managed forest, and natural lands This should also be done on a regional basis, as appropriate

[1] See footnote 37 in this chapter on defining *natural habitat*

SOURCE U S Congress Off Ice of Technology Assessment *Potential Environmental Impacts of Bioenergy Crop Production* OTA BP-E-1 18 (Washington DC U S Government Printing Off Ice September 1993)

BOX 2-5: Existing Farm Support Programs

Most farmers participate in federal farm commodity programs, These programs have a significant influence on which crops farmers plant and how the crop is managed, Program crops include wheat, corn, sorghum, barley, oats, cotton, and rice. Depending on how many acres a farmer has planted with such crops and the crop yield, a farmer establishes "base" acreage and yield over a period of time. Each year, farmers receive deficiency payments based on the difference between the market price and the target price (established by Congress and the Administration) and the number of base acres and program crop yields. Farmers are required to grow the specific program crop on the appropriate number of base acres or lose a portion of their base acreage (with some exceptions)

Some flexibility has been added in recent years. With flexible base acreage (15 percent mandatory and 10 percent optional), a farmer may plant any crop (with some exceptions) including trees. On the mandatory flexible base, deficiency payments are received; if another crop is planted there are no deficiency payments, but also no loss of base,

The economic attractiveness of energy crops to the farmer is potentially much greater on the mandatory flexible base acres than on other base acres Under the 0/85 program for wheat and feed grains (corn, sorghum, barley, oats), producers with base acres plant 15 percent or more of their maximum payment acres (base acreage minus conservation reserve acreage—base acres that farmers are required to take out of production—and mandatory flexible base) to a conserving use. The producers maintain their base acres and can receive 85 percent of the deficiency payments on land planted with the conserving crop as if it were planted with the program crop, Energy crops would have to be declared a conserving use for this to apply

Because soil conserving energy crops would be perennial, farmers would need some assurance that the 0/85 program would continue for a number of years Haying is presently not allowed during the five months of the principal growing season to avoid competing with forage markets No trees are allowed on 0/85 land,

SOURCE Office of Technology Assessment, 1995

Outside their normal range of cropping practice, farmers prefer to make changes slowly. Farm *management* changes, even relatively minor ones, are not decisions made overnight. The adoption of relatively simple, highly profitable technologies such as hybrid corn has taken as long as nine years on average. The decision to change farming practices requires a considerable degree of deliberation, and maintaining new practices frequently necessitates on-farm experimentation and adaptation beyond that conducted during initial technology development.

Some energy crops may reduce the flexibility of farmers. For example, typical SRWC stands require 3 to 10 years to mature. Farmers may then be reluctant to make the investment because of this long lead time and the need for interim cash flow, particularly with current low and uncertain prices for other forms of energy. It may be difficult to quickly plow under a tree crop and plant the land with something else should crop productivity, market conditions, or other factors limit the return on the farmer's investment of labor, land, and capital.

Thus, although the Conservation Reserve Program encouraged U.S. farmers to convert 12 million hectares (30 million acres)[74] of marginal

[74]The total now stands at approximately 15 million hectares (37 million acres). Thyrele Robertson, U.S. Department of Agriculture, Soil Conservation Service, personal communication, Aug. 26, 1993.

BOX 2-6: Conservation Compliance Programs

Conservation compliance was enacted under the 1985 Food Security Act as amended in 1990, which requires all farmers cultivating highly erodible land to fully Implement an approved conservation plan by 1995 or risk Iosing certain farm benefit programs At the same time, the Conservation Reserve Program pays farmers with highly erodible or otherwise environmentally fragile or sensitive land to take it out of production under 10-year contracts At present, some 15 million hectares (38 milllion acres) are enrolled in the CRP, with annual payments averaging roughly S124~hectare ($50/acre) At the end of the contract, land that IS highly erodilble must meet conservation compliance conditions

Failure to comply with the conservation plan results in the potential loss of a variety of benefits, including eligibility for price supports and related programs, farm storage facility loans, crop Insurance, disaster payments, storage payments, certain Farmers Home Administration loans, and several other types of ass stance

Conservation compiance affects some 57 milionon hectares (140 million acres), more than one-third of U S cropland A key aspect of about three-quarters of the conservation compliance plans to date is the use of agricultural residues to control erosion Use of such residues for energy may then confilict with SOiI erosion concerns

SOURCE Jeffrey A Zinn *Conservation Compliance Status and Issues*, 93-252 ENR (Washington, DC Congressional Research Service, Feb 24 1993)

corpland to permanent cover during the 1986-89 period, only 1 million hectares (2,5 million acres) of this was planted with trees (box 2-6).[75] More gcnerally, of land planted in tree crops, the majority has been in the southern United States, where relatively short tree rotation ages and some longer landowner planning horizons have intersected.[76] Conversely, grasses generaly do not reduce flexibility.

On the other hand, farm labor needs are determined largely by the intense effort required to plant, harvest. and transport conventional agricultural crops during a narrow window of time, usually spring and fal1. Once planted, however. perennial herbaceous or woody energy crops may last 10 to 20 years, and harvesting may take place over a relatively long period of time. Adding such energy crops to the farmer's portfolio might then case the burden during spring and fall, allowing better use of labor and capital equipment overall and thus increasing certain aspects of farmer flexibility.

Farmers are most likely to adopt technologies with certain characteristics. Favored technologies are those that: 1) have relative advantage over other technologies (e.g., lower costs or labor, higher yields): 2) are compatible with current management objectives and practices: 3) are easy to implement: 4) are capable of being observed or demonstrated; and 5) can be adopted on an incremental or partial basis. The complexity of systems-oriented changes will likely slow their adoption. which may pose particular problems if regional landscape planning is pursued to maximize the habitat benefits of energy crops. Mechanisms for incrementally realizing habitat benefits may be needed should these programs go forward.

[75] R Neil Sampson, "Biomass Opportunities in the United States To Mitigate the Ef'feet\ of Global Warm " *Energy from Biomas s and Wastes XV*, Donald L. Klass (ed.) [Chicago, IL. Institute of Gas Technology). 1991).

[76] Thomas Kroll, Minnesota Department of Natural Resources, personal communication. Apr. 13, 1994.

Individual and farm characteristics appear to explain only a small portion of behavior associated with adopting new crops or farming practices; institutional factors (e.g., farm programs, credit availability) are highly influential. Research on individual farm characteristics (e.g., size, specialization, land tenure) and farmer traits (e.g., age and education) and their relation to conservation adoption has yielded mixed results. Most researchers consider institutional factors to be much more influential, but few studies have been conducted on these to date.

Finally, farmers are a heterogeneous group with unequal abilities, access to information, and resources for decisionmaking; different degrees of willingness to take risks; and a wide range of objectives in practicing farming. For example, farmers objectives may include the following: making a satisfactory 1iving (as either an owner-operator, a tenant, or an employee); keeping a farm in operation for family inheritance or other personal reasons, perhaps while working at an off-farm job; obtaining a satisfactory return on investments in land, labor, and equipment; obtaining tax benefits; and obtaining recreation or aesthetic enjoyment. These objectives influence the portfolio of crops, including energy crops, that a particular farmer chooses to grow.

Strategies to encourage bioenergy crop adoption might include the following:

- *Demonstrations.* Local demonstrations would allow area farmers to observe first-hand what works and what does not and thus provide some familiarity with the technology in the local context. Demonstrations are similarly important for bioenergy feedstock users such as fuel producers (chapter 4) or electricity generators (chapter 5).
- *Long-term contracts.* The development of long-term contracts with local feedstock users, such as electric powerplants or ethanol producers, would provide greater market certainty to the farmer (see below).
- *Business plans.* The development and demonstration of high-quality business plans and related supporting materials might improve the credit worthiness of bioenergy cropping and assist farmers in gaining needed financial support.

Competitor Prices

As noted in chapter 1, fossil fuel prices are very low and can be quite volatile. These factors make it difficult to compete against fossil fuels in the near term and increase the risk of long-term investments in alternative energy systems. Strategies for dealing with low fossil fuel prices and high volatility might include the following:

- *RD&D.* Maintaining stable long-term RD&D programs in bioenergy crops irrespective of low or volatile energy prices might allow more rapid development of competitive bioenergy crop and energy conversion technologies.
- *Nonmarket values.* Recognizing and valuing the potential environmental and energy diversity benefits of bioenergy crops could improve their competitiveness. Environmental benefits potentially include reducing soil erosion, improving water quality by reducing sedimentation and agrichemical runoff or leaching from adjacent food and feed crops, improving air quality, reducing the emission of greenhouse gases, and providing habitat benefits. Energy crops might be used to help restore degraded lands, providing some financial incentive to plant and maintain the land.[77] Energy diversity benefits result from increasing the variety of energy resources that can be tapped and thus limiting the dependence on any one resource (see chapter 6). Approximate values for these benefits might then be incorporated through

IT@ degraded lands, yields are likely to be lower. Remaining economically competitive with low yields may then necessitate valuation Of some of the environmental or other benefits that the energy crop offers.

various environmental taxes on fossil fuels and/or credits for biofuels. When even crude financial valuations of these bcnefits (s prove difficult, techniques such as point systems or competitive set-asides may be useful (see chapter 6).

- *Federal supports.* The competitiveness of bioenergy crops might be improved by including a portion of the federal soil conservation and/or agricultural commodity support payments that would be offset by producing the bioenergy crop. Properly structured. it might then be possible to make the bioenergy crop competitive, improve farmer income. and reduce federal agricultural expenditures. Careful examination of the potential costs and benefits of such an approach is needed.

Production Scaleup

As noted in chapter 1, a key difficulty faced by many new technologies is the chicken-and-egg problem of developing a market. In the case of biomass energy, farmers cannot afford to grow biomass unless electric power or fuel conversion facilities---g.,., producing electricity and liquid fuels—are in place to purchase it. Conversion facilities cannot be built unless the biomass feedstock is available at a reasonable price and an end-use market is ready. An end-use market is difficult to develop without assured supplies of fuel.

Strategies to enable production scaleup might include the following:

- *Niche markets. Niche* markets for bioenergy crops might include cofiring biomass with coal in conventional power-plants. Cofiring works well for perhaps up to 5 to 15 percent wood input into the powerplant fuel mix. Cofiring is also a means for utilities to reduce their emission of SO_x. Cofiring can provide an early market, begin the development of biomass infrastructure, and provide electric utilities with early experience in procuring. transporting, and using biomass. As a substitute for coal in a conventional powerplant, however, the delivered costs of bioenergy should be roughly comparable to those of coal. limiting the quantity of biomass that can be tapped economically. Credits for SO_x reduction may improve these economics. (See also chapters 4 and 5.)
- *Partnerships.* As noted above, long-term contracts might be developed between farmers and end users such as electric utilities, ethanol/methanol producers. or others such as pulp and paper producers. This would provide greater certainty to both partners. The high levels of capital investment required of feedstock users might also encourage them to be the prime movers of such a strategy. Such partnerships may also help address the ● ’nuisance” factor of needing numerous (small) contracts to provide sufficient feedstock.
- *Multiple uses.* Bioenergy crops might best serve a variety of end uses simultaneously. In particular, the initial establishment of bioenergy crops might be assisted by coupling energy production with higher value uses of the feedstock. For example, an energy crop might be established initially to serve a higher value purpose such as the production of pulp and paper and only secondarily for energy .[78] The experience gained through such multiple uses may provide a foundation for further energy crop development and cost reductions.

Bioenergy crops will naturally move to their highest value use. This might be as a transport fuel. as a baseload backup to intermittent renewable, for industrial chemicals or fiber, or perhaps for environmental benefits. Evaluating more completely the full range of costs and benefits for each potential use of bioenergy crops, including budget and trade balance impacts. across the entire production and use cycle would be an important next step in determining the potential competitiveness of these crops vis-à-vis various competing uses of the land and other sources of energy.

[78]Even if SRWCs are used for pulp and paper, roughly 25 to 40 percent of the harvested biomass would be available for energy use.

OAK RIDGE NATIONAL LABORATORY

Eight-year old hybrid poplars grown by James River Corp. in Oregon These fast-growing trees can be harvested repeatedly and regrow from the stump More than 25,000 hectares (62,000 acres) of these trees have been established in the Northwest to provide both fiber and energy

Studies of how best to address these issues might be conducted in parallel with demonstrations.

Leveling the Playing Field

Existing soil conservation and commodity support programs, as well as other factors. may discourage financial investment in alternatives such as energy crops. The extent to which this occurs needs to be examined and is an important area for further analysis.

Infrastructure Development

A wide range of infrastructure development is required to support bioenergy programs. This includes, in particular, harvesting and transport equipment, energy conversion facilities (electricity generation, ethanol production), energy transmission (high-voltage electric power lines) and transport (pipelines or tanker trucks) systems, financial services, extension services, trained manpower, and many others.

Much of this infrastructure will develop with the industry. In some cases, however, existing infrastructure—such as electricity transmission systems or liquid or gaseous fuel pipelines—might be used effectively if plants can be sited appropriately. Geographic information systems could assist such analysis.

POLICY OPTIONS

Several economic incentives and other supports of biomass fuels are already law (box 2-1; table 2-1). These supports target primarily the transport fuel and electricity sectors, however, and tend to ignore the substantial market challenges at the crop production stage. As a consequence, a significant share of the near- to mid-term opportunities for producing and using biomass energy might not be realized because of the market challenges described above and current resource constraints. There has been a significant increase in overall program support for bioenergy in recent years.[79] Bioenergy crop development is, however, a small portion of the total. For feedstock development, the fiscal year 1995 budget is about $4.6 million in 1992 dollars.

Under current funding levels, the ability to develop and demonstrate energy crops and related harvesting and transport hardware is quite limited. Development of high-productivity crop species currently accounts for about half of the Depatiment of Energy (DOE) feedstock development funding. With total costs for developing a single feedstock species in a single region of about $1 million per year, feedstock development has been limited to poplar at three centers[80] and switchgrass at two centers[81]---even with heavy cost-sharing with the private sector, states, and others. At present funding levels, detailed feedstock development is not taking place on other tree spe-

[79] Most of this funding is for feedstock conversion processes such as lignocellulose to ethanol (ch. 4) or electricity generation (ch. 5).

[80] Located in [he pacific Northwest, the Midwest, and the Southeast.

[81] Located in the Midwest and the Southeast.

cies, such as silver maple, black locust, sycamore, and sweetgum, and on grass species, such as big bluestem and wheatgrass. Funding levels of perhaps $6 million to $10 million (1992 dollars) over an extended period (e.g., 10 to 15 years) would provide adequate to good species development for the various regions (see below).

Current DOE funding levels provide essentially no support for the development of harvesting and transport hardware. Since these activities constitute a significant fraction of bioenergy crop costs, development of high-performance hardware is essential if costs are to be reduced to more widely competitive levels. Funding of $1 million to $2 million per year over an extended period (five years or more) maybe sufficient to catalyze private sector interest and cost-sharing to develop such hardware.

Substantial field demonstration and environmental monitoring of these energy crops will be needed, at a scale sufficient to demonstrate the performance and characteristics of a fully functioning crop production, infrastructure, and feedstock conversion system. Such demonstrations may be needed at some level for each species and region. As an example, a dedicated 50-MW powerplant will require production from perhaps 20,000 hectares (50,000 acres) of energy crops. At a typical cost for crop establishment of $740/hectare ($300/acre), this will have a front-end cost of $15 million, not including the powerplant (see chapter 5). The private sector would share the cost of the demonstration, and a portion of the funds will also be recovered with the sale of electricity or fuel from the faci lit y. To reduce risk further, early demonstrations could be limited to obtaining 15 to 30 percent of their fuel needs from biomass; the rest could be obtained from natural gas or coal.

Environmental monitoring of such demonstrations will also be needed, with costs running into several million dollars per year, to monitor species such as birds and mammals, soil quality, groundwater quality and quantity, and landscape-level impacts.[82]

Thus, while the current funding level provides support for the detailed development of a single tree and a single grass species; it does not support significant development of key harvesting and transport hardware, and it supports only minimally the field demonstration and environmental monitoring of these crops. As a consequence, the development of energy crops is likely to be relatively slow and haphazard, and several current or near-term cost-effective applications of bioenerg y are unlikely to be captured. These include some coal cofiring and biomass-fired electricity-generation opportunities. A significant demonstration program would give farmers, electricity sector planners, financiers, and regulators the confidence to move these biomass-fueled systems forward.

To the extent that current funding fails to fully capture the cost-effective use of bioenergy crops, it misses the opportunity of using these crops to offset federal budget expenditures for soil conservation, commodity support, and/or crop insurance.[83] Maximizing cost-effectiv e production and use of energy crops could also improve the rural economy and generate jobs, while reducing environmental problems such as soil erosion and emissions of greenhouse gases.

The development and demonstration of these energy crops can also reduce farmers' risks by diversifying their crop portfolios and providing more robust crops for flood- or drought-prone re-

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82 For example, current monitoring of the environment] impacts of several small 400-hectare (1,000 acres in 8 to 15 plots) sites costs about $200,000 to $300,000 per year. Scaleup by a factor of 15 to 25 to a demonstration system of 20,000 hectares would not increase costs commensurately because only portions of this area would have to be sampled. There would. however, be additional environmental monitoring costs associated with landscape-level impacts on habitat diversity and other factors.

83 The extent t. which these budget expenditures actually occur will depend strongly on the impact of trade agreements—the Uruguay Round of GAIT and NAFTA-and many other factors.

Harvesting hybrid poplars at the James River Corp. in Oregon, using a "feller buncher "

gions. Energy crops may similarly reduce national energy risks by diversifying the national energy portfolio. For example, large-scale use of these energy crops could offer a mid- to long-term alternative to imported oil.

To capture high-leverage opportunities to significantly expand the production and use of bioenergy, it would be necessary to increase expenditures to some extent. For example, crop development support could be increased to $6 million per year (1992 dollars), providing at least $1 million per year for harvesting and transport hardware development, and supporting several larger scale demonstration and environmental monitoring efforts. This funding would necessarily be leveraged against private sector supports to carry out these efforts adequately.

These costs should be balanced against potential savings in federal expenditures in areas such as soil conservation, commodity support, and crop insurance programs. The timing and magnitude of these potential costs and savings, however, depend on numerous technical, economic, and institutional factors and remain to be determined.

The 1995 Farm Bill may be a potentially useful vehicle for addressing many of the policy options involving higher expenditures than current levels, which are described below. Among other options, a title might be included within the Farm Bill that focuses on energy crop RD&D, planning, commercialization, information, crop insurance, and other programs. Attention could also be given to joint programs between associated departments and agencies, such as DOE, the Department of Agriculture, and the Environmental Protection Agency.

Policies that could be considered as part of a bioenergy development strategy are listed below. RD&D programs might include the following:

- *Collaborative research, development, and demonstrations.* Continuing and expanded support could be provided for high-leverage RD&D opportunities across the breadth of crop production, harvesting, transport, environmental impacts, and other aspects discussed above. These efforts may be significantly leveraged to the extent that they can be conducted in collaboration with private organizations, and they could include the development of multiuse crops to reduce farmer risk. In addition, this might include analysis of the potential infrastructure development requirements and economic impacts of large-scale energy cropping. Various forms of support, particularly through cooperative efforts with the private sector, could be provided for a variety of biomass electric or transport fuel project demonstrations,

Planning and information programs include:

- *Planning.* Support, including the development of geographic information systems and other tools, could be developed in cooperation with state and local governments to establish a local and regional landscape planning capability for optimal design of energy crops. Support could also be provided for the development of local approaches that minimize possible environmental or other impacts of energy crops. Some work in this area is now beginning and could be strengthened.
- *Information programs.* Information programs, including extension efforts to farmers, electric utilities, financiers, and others, might be expanded. Conversely, much information could

be gathered from farmers so as to better design biocnergy programs. Current funding for information and a number of other activities through the Regional Biomass Program is about $4 million per year. These programs conduct regional biomass resource assessments. facilitate technology transfer to the private sector, support public-private projects, and assist other activities. As their scope and outreach activities increase, greater support will be needed for these and related programs. In certain cases, however, it may be possible to capture some savings by combining these with other agricultural information and planning programs.

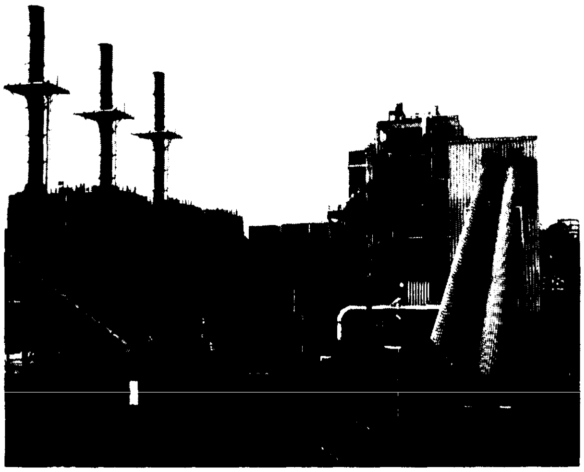
Bioenergy programs might complement existing agricultural programs as follows:

- *Conservation Rrserve Program lands.* Contracts on CRP lands begin to expire in 1995. If Congress decides to alter the CRP, consideration might be given to achieving a transition to bioenergy cropping on some of these lands in order to reduce federal CRP expenditures while increasing farm income and minimizing farmer risk. This, together with commodity support and insurance program considerations listed below. represents a key opportunity that requires further analysis.
- *Commodity support programs.* Energy crops might be considered as substitutes for program crops with a modified or transitional payment schedule so as to reduce federal expenditures and farmer risk. while allowing the farmer to maintain or increase income through energy crop sales. Additional flexibility in commodity support programs might also be considered to allow the growth of energy crops without penalty or risk to the farmer's enrollment in other farm programs.
- *in.surance programs.* Federal crop and other insurance programs for flood. drought, and other natural disasters might be examined to determine if biocnergy crops offer a lower risk alternative to conventional agricultural crops in particular areas. If so, growers in high-risk areas might be encouraged to switch to these crops.

Finance and commercialization programs could include the following:

- *Partnerships.* Mechanisms for brokering or leveraging partnerships between bioenergy growers and users might be examined, including modest financial or institutional support from the federal government in early demonstration or commercialization efforts. Partnerships are also examined in chapters 4 and 5.
- *E.xternality taxes and incentives.* Mechanisms for recognizing and valuing the potential environmental and energy-diversity benefits of bioenergy crops might be examined, including appropriate financial credits,[84] points or other value systems for including environmental and other potential bioenergy benefits when choosing technologies for expanding electricity y capacity, and green set-asides. These mechanisms are examined in chapter 6 for the electricity sector. Such considerations could allow bioenergy's range of costs and benefits-including environmental—to be considered more fully in comparison with those of con\' entional energy systems.
- *Energy production credits.* The National Energy Policy Act of 1992 established a 1.5¢/kWh energy product ion tax credit for electricity y generation with closed-loop bioenergy crops. This credit is available only for plants placed in service before July 1, 1999. Because of the long lead times required to establish many energy crops, such as SRWCs, and powerplants, few will be able to make use of this tax credit. Congress might consider extending the period of eligibility sufficiently for such closed-loop systems to be fully tested and markets to be initiated.
- *Federal procurement.* The federal government. including the Power Marketing Authorities, could establish bioenergy power facilities

[84] Alternatively, various combinations of social cost taxes on conventional energy resources might be considered (see ch. 6).



Wheelabrator biomass electric plant in Mt. Shasta, California.

where cost-effective or near-cost-effective biomass supplies might be obtained. These could serve as useful demonstrations and provide valuable design and scaleup data for commercial efforts. Federal procurement complements the above policy tools by being a more direct mechanism for initiating bioenergy projects.

A strategy involving higher levels of funding could include the following elements:

- *Financial mechanisms.* Innovative financial mechanisms might be examined that reduce farmers' risks in shifting to energy crops while minimizing public costs. These could include interest rate buydowns, cost-sharing, longer term farmer-feedstock-user contracts or risk-sharing agreements, or explicit codevelopment of bioenergy with the expansion of pulp and paper or other facilities. For utilities, this might also include safe harbor rules, cofiring of biomass with coal to provide SO_x reductions, recognition of fuel diversity benefits, and competitive set-asides for biomass energy (see chapter 6). Many of these would be private initiatives with modest federal support. The relative costs and benefits of such mechanisms need to be evaluated to determine which are the most cost-effective.
- *Competitor pricing.* Mechanisms might be considered to protect an embryonic biomass energy industry from short-term fossil fuel price drops below certain thresholds. Effectively, this would be the bioenergy counterpart to agricultural commodity support programs. Again, the relative costs and benefits of such mechanisms would have to be evaluated, mechanisms to minimize and cap costs explored, and means developed for ensuring their phaseout within a reasonable period.

The multiplicity of sectors affected by energy crops--e. g., agriculture, energy, environment, forestry—poses a substantial and, in some ways, unique institutional challenge in developing coherent policy goals, processes, and effective coordination. For any bioenergy strategy, effective means of communication and policy coordination among the many institutional and private-sector participants are required.

CROSSCUTTING ISSUES

Integrating biomass crops with energy conversion facilities and end uses requires careful consideration of total fuel cycle cost, performance, environmental impacts, and other factors, Current bioenergy crop and conversion systems already show considerable promise in simultaneously providing energy, economic, and environmental benefits.

In the longer term, additional gains maybe possible with advanced bioenergy crop and conversion systems, although much research remains to be done. Compared with monoculture, for example, polycultures may provide more wildlife habitat benefits as well as other possible environmental benefits. If polycultures are pursued, energy conversion technologies such as gasifiers may then be preferred for their ability to easily handle a variety of input feedstocks. In turn, gasifiers are better suited to the production of methanol than ethanol, and methanol may allow the use of low-temperature steam reformers and proton exchange membrane fuel cells to power transport (chapter 4).

Conversely, advances in solid oxide fuel cells may encourage the use of ethanol for transport. Capturing the habitat benefits of polycultures may then require further research on the enzymatic hy -

drolysis of polyculture feedstocks. Chapter 4 examines some of these alternative technology paths for transport, including fuel cells and internal combustion engine hybrids. At this early stage, it is important that a broad portfolio of energy crop and conversion technology RD&D and environmental analysis be maintained.

The extent to which such paths can be pursued depends strongly on the relative long-term economics of bioenergy polycultures versus monoculturcs, the value placed on habitat and other benefits, and the means by which these are weighed against the economic or environmental costs and benefits of agricultural crops and/or fossil fuels. These long-term questions should not obscure the potential benefits of currently conceived monoculture energy crops.

CONCLUSION

Energy crops may help address some of our national energy, economic, and environmental problems. Depending on the direction of global agricultural markets, they can potentially provide a significant amount of energy, perhaps 20 EJ (19 quads) or more---equivalent to one-quarter of current U.S. energy usc. The y have potential environ - mental benefits compared with conventional agricultural crops. Energy crops are no substitute, however. for natural habitats on contiguous landscapes. The regional impacts of energy crops will be mixed. Not all crops can be readily grown everywhere. The overall national economic and job impacts of bioenergy cropping may be quite positive, particularly for rural areas.

Energy crops thus show promise to help meet several national needs---conomic. environmental, budgetary, and national security. The extent to which the potential of bioenergy can be realized wil1 depend on how wel1 the many compcting eco - nomic/environmental. rural/urban, and other interests can be balanced. Realizing this potential will require a long. dedicated effort in terms of research, development, demonstration, and commcrcializaticm of these technologies. Implementing large scale bioenergy programs without such a foundation could damage the environmcnt and reducc potential economic- or other benefits.

Residential and Commercial Buildings 3

Revidential and commercial buildings in the United States use about $180 billion worth of energy per year for space heating and cooling, lighting, water heating, and other energy services. Passive solar architecture,[2] daylighting, and certain other renewable energy technologies (RETs) can cost-effectively reduce energy use in new buildings by 15 to 20 percent. Together with energy efficiency improvements,[3] these technologies can provide roughly 50 percent energy savings in new buildings compared with their conventional counterparts (see figure 3-1). These RETs can save money, reduce the need for new energy supplies, and provide substantial environmental benefits.

What Has Changed?

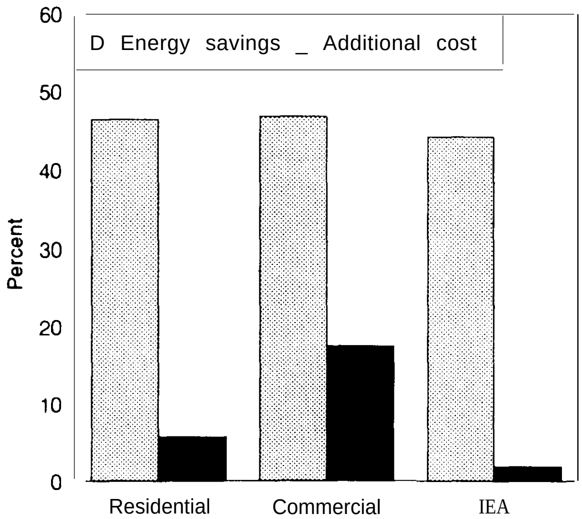
In the early 1970s, energy was not a very important consideration in building design or operation. Relatively little was known about building energy flows, market challenges to use of RETs, or effective policy responses. Following the 1973-74 oil embargo, build-

[1] U s Department of Energy, Energy Information Administration, *Annual Energy Review 1993*, DOE/EIA-0384(93) (Washington, DC: July 1994), pp. 55, 77.

[2] A more descriptive term is *building-integrated solar energy*, but the traditional term *passive solar* is used here.

[3] In comparison, previous work by the Office of Technology Assessment showed that cost-effective, commercially available efficiency improvements by themselves could reduce new building energy use to two-thirds that of conventional buildings. When the provisions of the Energy Policy Act of 1992 are fully implemented, a portion of these efficiency improvements will be captured. See U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, *OTA- E-5 18* (Washington, DC: U.S. Government Printing Office, May 1992); "Energy Policy Act of 1992," Conference Report 102-1018, Oct. 5, 1992.

FIGURE 3-1: Energy Savings and Additional Construction Costs of Passive Solar Designs Compared with Conventional Forms



NOTE Average energy savings are depicted for 20 residential buildings and 12 commercial buildings studied in the United Slates as well as 40 buildings studied by the International Energy Agency The buildings were experimental models use of the data obtained from these studies now allows better performance and lower costs than those shown here

SOURCES Solar Energy Research Institute Passive *Solar Homes 20 Case Studies SERI/SP-271 -2473* (Golden, CO December 1984), Burt Kosar Rittelmann Associates and Min Kantrowifz Associates *Commercial Vuilding Design Integrating Climate, Comfort, and Cost (New*York NY Van Nostrand Reinhold Co 1987) and International Energy Agency *Passive and Hybrid Solar Commercial Buildings Basic Case Studies,* Task XI (Washington DC U S Government Printing Off Ice 1992)

ing energy research, development. and demonstration (RD&D) was launched in parallel with supports such as tax credits for commercializing largely unproven technologies. Much was learned from both the failures and the successes that followed.

Two decades later, we now have a substantial base of proven technologies and practical policy experience of what works and what does not. Many valuable technologies are in the RD&D pipeline. The design and construction of well-performing passive solar buildings have been conclusively demonstrated. Window technology has improved dramatically in recent years as multiple glazings, low-emissivity coatings, and other technologies have penetrated the market: further improvements such as gas- filled[4] glazings are now appearing. Sophisticated lighting controls that integrate artificial lights with daylight are now available commercially. Improved materials and designs are appearing in solar water heaters. These are only a few of the many advances. Some estimate that more than 200,000 residential and 15.000 commercial buildings using passive architecture have been built[5] and 1.8 million solar water heaters have been produced.[6] Although there arc serious market challenges hindering adoption of these technologies. they are now better understood and policies have been developed to deal with them (see box 3-1). Many, however, still primarily remember the frequent overselling of the technology during the 1970s and early 1980s.

| Potential Roles

The residential and commercial sectors use roughly 35 percent of U.S. primary energy and 65 percent of U.S. electricity (see box 3-2). In addition to potential direct energy and financial savings to the building owner,[7] incorporating RETs for space heating and cooling, water heating, and daylighting may shift and or reduce peak loads on utilities, potentially providing important demand-side management (DSM) benefuts and cost savings for the utility. Reducing fossil energy use can also provide environmental benefits.

[4]Including either argon or krypton.

[5]J Douglas Balcomb (cd,), *Passive Solar Buildings* (Cambridge, MA: MIT press. 1992).

[6]Kenneth G. Sheinkoff, *Progress in Solar Energy Technologies and Applications: An Authoritative Review* (Boulder. CO: American Solar Energy Society, January 1994).

[7]Where time-of-use metering is used, the building owner may capture some of the demand-side management peak load reduction benefits.

BOX 3-1: National Policy Influencing Renewable Energy Use in Buildings

Several federal acts currently Influence the use of RETs in buildings Section 912 of the Housing and Community Development Act of 1992[1] established the Solar Assistance Financing Entity (SAFE) to help finance the use of renewable and energy-efficient technologies in buildings. This law also established the energy-efficient mortgage pilot program under sections 513 and 914

The Energy Policy Act of 1992[2] requires consideration of RETs in energy standards for new federal buildings, in residential energy efficiency guidelines, in lighting, and in the energy-efficient mortgage pilot program

Many other programs, including Community Development Block Grants and Comprehensive Housing Assistance Plans, Influence energy use in buildings and might greate greater consideration to RETs in the future

[1] U S Congress House of Representatives *Housing and Community Development Act of 1992* Conference Report 102-1017 (Washington DC U S Government Printing Off Ice, 1992)

[2] U S Congress House of Representatives, *Energy Policy Act of 1992*, Conference Report 102-1018 (Washington DC U S Government Printing Off Ice 1992)

Principal Themes

Three broad themes are addressed in this chapter:

1. the principles and performance of various RETs[8] for heating and cooling, ventilation, lighting, water heating, and other energy needs in new[9] residential and commercial buildings[10];
2. market challenges in the design, construction, sale, and ownership of buildings using RETs, and past experience in addressing these challenges; and
3. policy options associated with further RD&D and commercialization of RETs for buildings.

INTRODUCTION

Renewable energy has been used to heat, cool, and light buildings since humanity first moved indoors. Clerestories[11] were used more than 3,000 years ago by the Egyptians to daylight their temples at Karnak. The Remans designed their buildings with a variety of passive solar features: windows to capture sunlight for heating in the

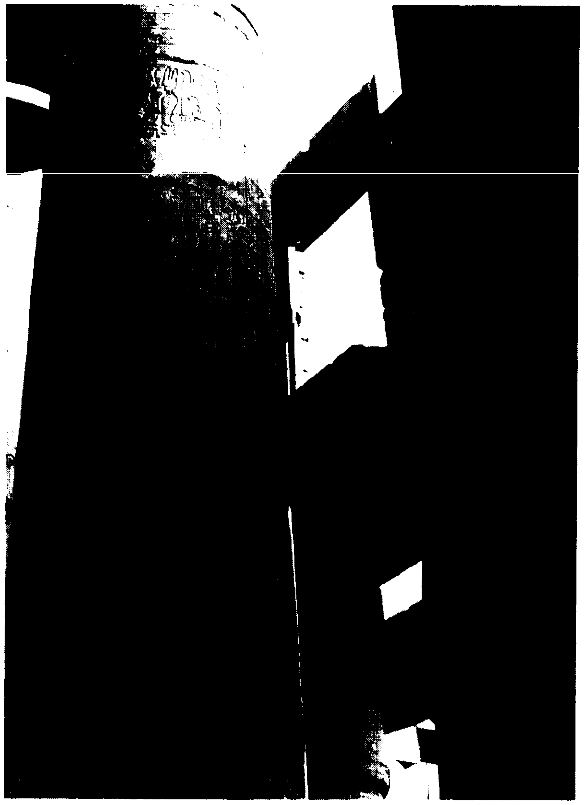
[8] Although the following discussion emphasizes the potential role of renewable energy in buildings, no distinction should be made in practice between the contributions of renewable energy and energy efficiency. Buildings should be designed on an integrated basis, considering all the potential efficiency and renewable energy benefits, and combining them in the most cost-effective and highest architectural- and amenity-value form possible.

[9] Only new construction is examined here. Renewable energy retrofits of existing buildings are also possible, but are often not as cost-effective as designing and building renewable technologies into new construction. Some retrofits, such as cooling load avoidance and ventilation air preheat, may be cost-effective in some cases.

[10] Note that industrial buildings (i.e., where manufacturing takes place) also offer significant opportunities for using RETs to supply space heating and cooling, lighting, and other energy needs. Many of the RETs used in commercial buildings can be adapted to these industrial building applications. Industrial buildings, however, are not explicitly included in the discussion here nor in the summary statistics because the Energy Information Administration separates residential and commercial buildings from industrial energy uses.

[11] *Clerestories* are windows located at the top of high walls and designed to cast light deep into interior spaces.

MARSHA FENN OTA STAFF



Clerestory at the temple of Karnak, Egypt

winter, carefully sized overhangs for shading in the summer, heavy masonry (thermal mass)[12] construction to moderate day-night temperature swings, and clerestories to cast light deep into the building. At the same time, they developed a remarkable body of law to protect citizens' rights to access the sun yet not block their neighbors' access.[13] In Iran, Wind towers, the shape of the roof, evaporative cooling, and carefully placed plantings were used to control overheating.[14] Many early Renaissance cathedrals have carefully designed clerestories to provide sufficient light to define the interior without letting in so much light as to cause glare or overheating.[15]

These same elements—siting, landscaping, proper placement and design of windows, overhangs, clerestories, thermal mass, and others—are characteristic of solar architecture today (see figure 3-2), and can be adapted to a wide variety of architectural styles. With modern materials and design tools, these solar architectural techniques have become much more effective.

The processes of solar heating, ventilation, thermal storage, evaporation, and radiative cooling occur naturally in buildings. The way we design and position our buildings, size and orient their windows, and landscape the property all impact these energy flows. Thus, the question is not whether renewable energy can influence fossil energy consumption in our homes and offices-it already does. The question is whether energy flows are allowed to cause problems such as overheating and glare or are employed instead to deliver useful services. Achieving this goal requires careful tradeoffs between a variety of design parameters. Thoughtful, balanced design can provide substantial financial, energy, and aesthetic benefits; poor design or overreaching to reduce conventional energy use can increase costs and decrease building comfort and performance.

Historically, buildings were designed for the local climate and natural daylighting. Many were, however, uncomfortable and poorly lit due to insufficient design knowledge, lack of insulation, and low-quality windows. Then, plentiful and inexpensive supplies of fossil fuels and electricity provided architects a degree of freedom they had never before known (and habitants a degree of comfort never before experienced), Building designs gradually changed to reflect abstract visions rather than the reality of the local climate. Energy use for heating, cooling, and lighting buildings increased accordingly. The first oil crisis of 1973 re-

[12] Thermal mass means the heat storage capability of a material multiplied by its mass (weight). A wood frame wall has a low heat storage capacity, whereas a solid masonry wall has a high heat storage capacity.

[13] DiiUl~Favro, "Roman Solar Legislation." *Passive Solar Journal, vol.* 2, No. 2, 1983, pp. 90-98.

[14] Mehdi N, Bahadori, "Passive Cooling Systems in Iranian Architecture,'" *Scientific American*, vol. *238,* 1978, pp. 144-154.

[15] Richard G. Stein, *Architecture* [/tit/ *Energy* (Garden City, NY: Anchor Press, 1978).

BOX 3-2: Energy Use in Building

Energy use in buidings has changed substantially in both form and function during the past several decades Primary[1] energy use in residential and commercial buildings totaled 29 exajoules in 1990 (figure 1-11 in chapter 1) Of this, about one-half went to space heating and cooling, one-fifth to lightlng, and one-tenth to water heating (figure 3-3) These proportions change significantly with the type of building, its use, and its occupants Total buiding energy use in the United States has Increased (figure 3-4)—there are more people, more households, and more offices-while energy use per unit area (commercial) or per person (residential)[2] has roughly stabilized over the past decade due to a variety of efficiency Improvements The sources of energy have changed dramatically Use of fuel 011 has dropped since the 1973011 embargo, and natural gas has largely made up the difference (figure 3-4) At the same time, new loads have appeared Electron/c office equipment has sharply Increased plug loads[3] in commercial buildings[4] and programs such as the "Energy Star Computer" have been launched in response Utility demand-side management programs are gaining momentum as they grapple with peak loads due to air conditioning during summer heat waves, as well as try to reduce overall consumption Building energy use will continue to change due to technological advances, population growth, economic growth, demographic changes, and many other factors, perhaps including global warming

[1] This breakdown assigns generation transmission and distribution losses Incurred by the electricity sector proportionately to the end use that actually consumed the electricity

[2] Residential energy use dropped about 20 percent between 1972 and 1982 and has since roughly stabilized

[3] These are loads on wall outlets due to plugging in computers, printers, photocopiers, fax machines and so forth These loads are distinct from lighting loads which are wired into place when the building is constructed

[4] L Norford et al Electricity Use in Information Technologies " *Annual Review of Energy,* vol 15, 1990 pp 423-453

versed that trend and generated a wave of interest in again using renewable energy to heat, cool, and light buildings: that reversal lasted little longer than high oil prices.

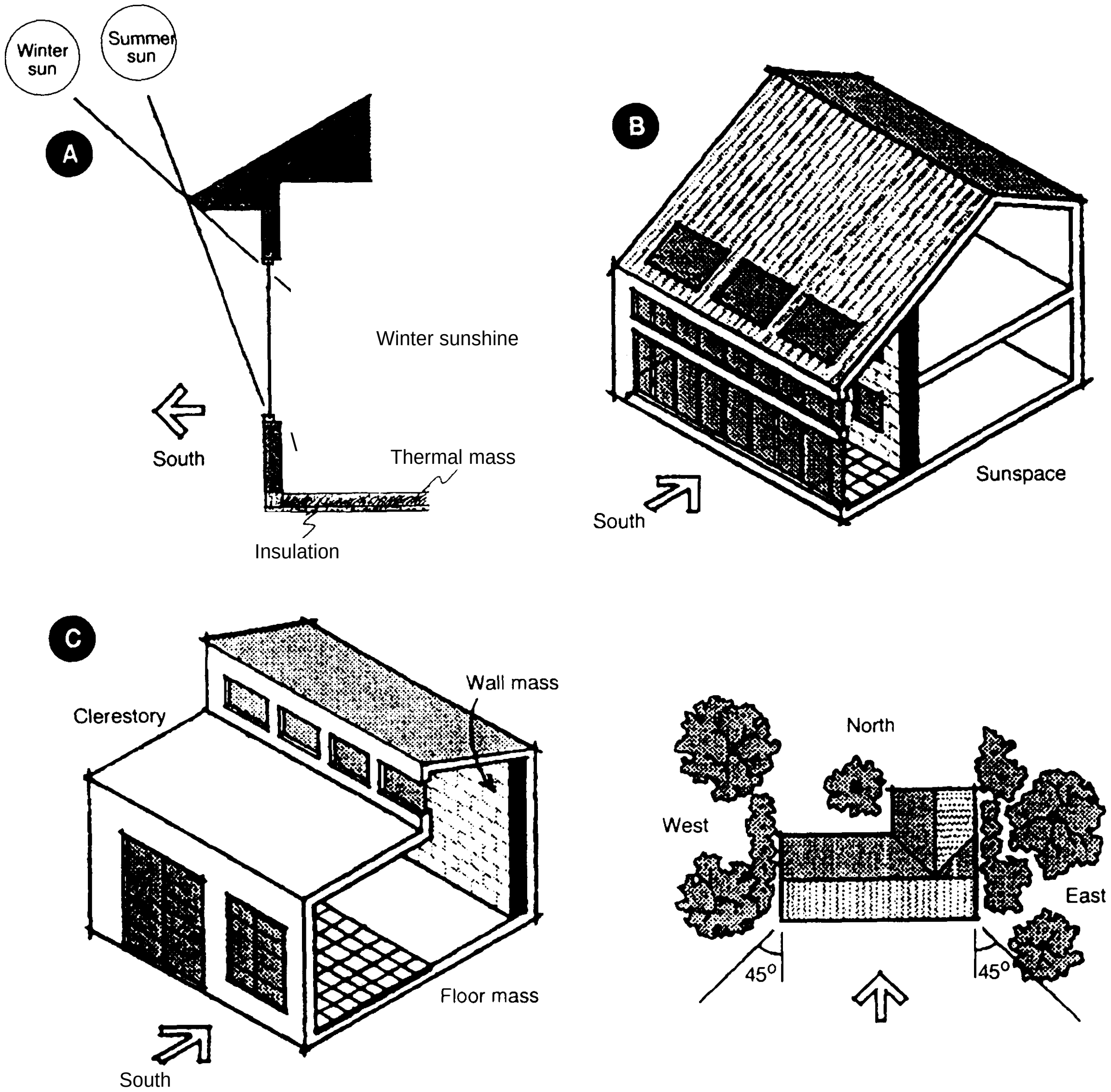
RENEWABLE ENERGY TECHNOLOGIES

The total energy performance of a building is a complex process, dominated by the continuous interaction among the building's internal sensible and latent[16] heat gains and losses, solar inputs, thermal storage, radiant heat transfer, and air movement: the external environment; and other factors. Conventional space conditioning systems have been designed simply to overpower the natural forces both heating and cooling our buildings, resulting in considerable expenditures for equipment and fuel. The process of maintaining a comfortable environment efficiently is a more subtle and site-specific undertaking.

Renewable energy technologies for buildings take several approaches in providing energy services. Generally the most cost-effective RETs for space heating, cool ing, and lighting are passive architecture and daylighting. These strategies use the building itself—walls, windows. overhangs, thermal mass—to capture. store, and distribute renewable energy. This approach requires careful design but uses little or no additional material—hence its frequent cost-effectiveness. Active systems use discrete collectors on the roof or near the building to capture sunlight and pipe the energy where it can heat the building (or domestic hot wa-

[16] Sensible heat is what we physically feel when we touch a hot object: latent heat is the energy required to evaporate a quantity of water. As used here, latent heat refers to the large amount of moisture or humidity that can be exchanged among a building's materials, indoor air, and the outside. High levels of humidity contribute substantially to occupant discomfort and increase building cooling loads.

FIGURE 3-2: Principal Design Elements of Passive Solar Architecture



NOTE: A. Solar architecture uses windows to capture sunlight for winter heating, carefully sized overhangs for summer shading, and in some cases, thermal mass (bricks, masonry) to moderate day-night temperature swings. B. Sunspaces provide passive solar heating and bright living space. C. Clerestories contribute to lighting and winter heating. D. Trees and other landscaping can shade east and west windows from summer sun.

SOURCE: Adapted from Passive Solar Industries Council and National Renewable Energy Laboratory, *Passive Solar Design Strategies: Guidelines for Home Builders* (Washington, DC and Golden, CO: 1991).

BOX 3-3: Additional Renewable Energy Technologies

A variety of other renewable energy technologies can provide useful energy services for buildings but have not been considered in detail in the course of this assessment. These Include wood heating and geothermal heat pumps

Wood Heat

Wood heating can be cost-effective where low-cost, reliable sources of wood are used 117 well-designed and well-built wood stoves Domestic wood stoves can, however, produce relatively high levels of smoke that may lead to local air pollution Catalytic combustors have reduced this air pollution problem while generally Increasing stove efficiencies

Geothermal Heat Pumps

Most heat pumps use air as a heat source or sink. The problem with this is that when heating or cooling is needed the most, the air is at its coldest or hottest which makes the air-coupled heat pump work harder and reduces its efficiency[1] Geothermal heat pumps, however are coupled to the relatively constant ground temperature by long pipes in the ground to collect heat for heating or to cool the fluid in the pipes for air conditioning The moderate ground temperatures allow geothermal heat pumps to run more efficiently typically using about two-thirds as much electricity as standard air-coupled heat pumps and less than half as much as an electric resistance heater combined with a conventional air conditioner Burying the pipes does cost more however and simple payback times for this additional cost are typically on the order of six years.

[1] It may, in fact, be cut out at times and electric resistance heating used as backup

ter) or drive a cooling systcm. These systems are cost-effective only in particular circumstancres because of the large quantities of expensive add-on materials required. Of increasing interest systems that are integrated into the building shell itself, including ventilation air preheat and photovoltaics. By integrating these systems into the building, the amount of epensive add-on material required can be minimized and the system made more cost-effective. Othcr RETs are discussed in box 3-3.

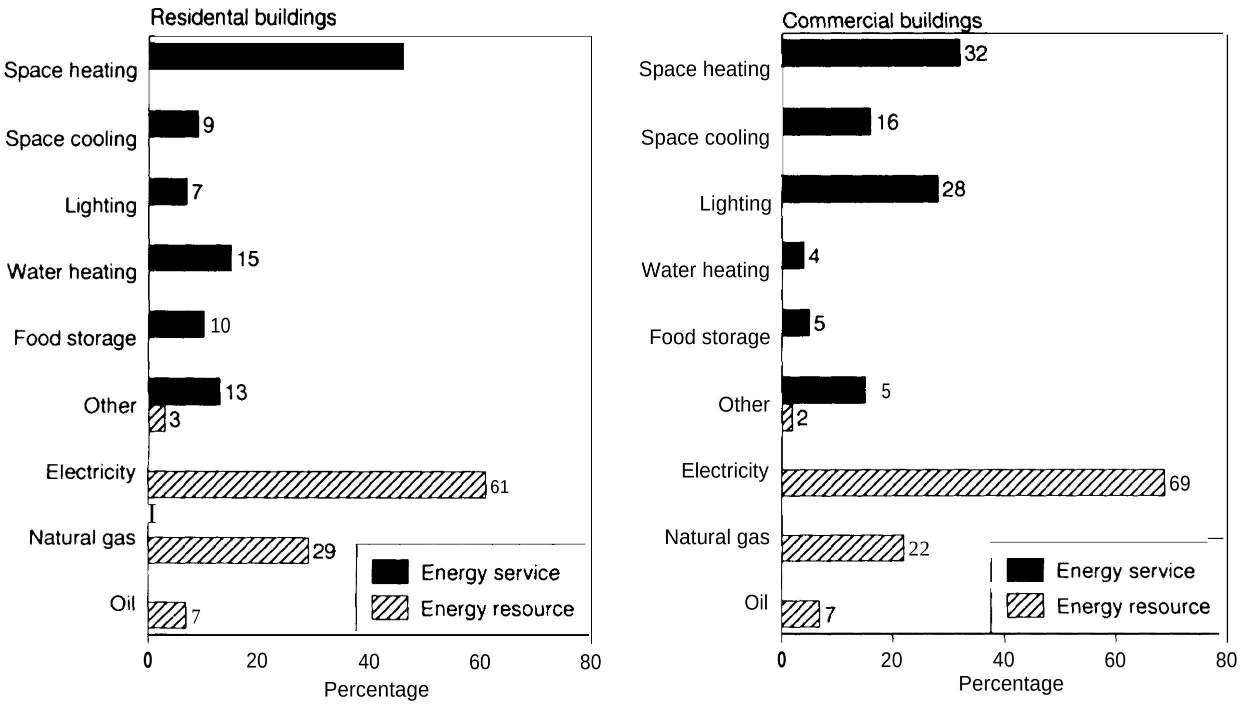
Because the environment, construction, usage, and energy demand patterns for buildings differ (see figure 3-3), renewable strategies tend to be context -dependent: a strategy designed for a building used for manufacturing may not be applicable in a comparably sized and built adjacent warehouse. Similarly, a RET strategy used for a small office building may not be applicable in a nearby residence. These energy use patterns have also changed significantly over time, particularly with increasing use of electricity (see figure 3-4).

Passive Architecture[17]

Renewable energy technologies to provide space heating, cooling, ventilation, and lighting energy services can take many forms in residential and commercial buildings. Passive heating and cooling technologies use the building itself to capture sunlight for heat and/or light and to reject heat from the building. This includes windows to let in

[17] For reviews of passive architecture, see Bruce Anderson (ed.), *Solar Building Architecture* (Cambridge, MA: MIT Press, 1990); Jeffrey Cook (ed.), *Passive Cooling* (Cambridge, MA: MIT Press, 1989); Balcomb (ed.), op. cit., footnote 5; American Solar Energy Society, "Proceedings of the National Passive Solar Conferences," various years; and references therein.

FIGURE 3-3: Energy Services and Supplies in U.S. Residential and Commercial Buildings



NOTE: Energy use by particular buildings varies greatly by the type of building, occupancy region, climate, and many other factors

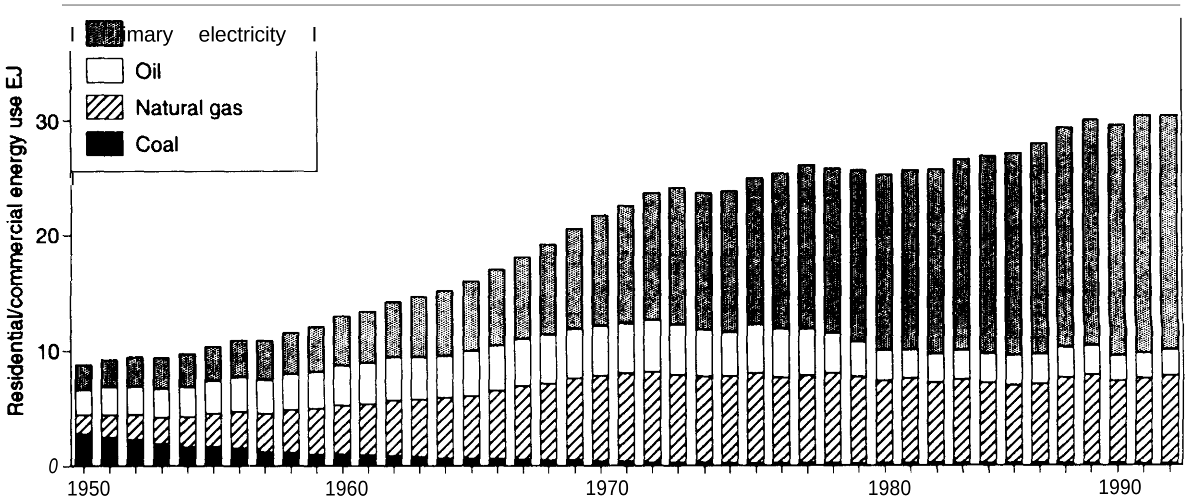
SOURCES: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1992*, DOE/EIA-0384(92) (Washington, DC: June 1993); and U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518 (Washington, DC: U.S. Government Printing Off Ice May 1992)

light for both heating and lighting; overhangs to block the summer sun and minimize cooling requirements, ventilation to reject unwanted heat or provide fresh air, and thermal mass such as bricks or concrete to store heat for use (winter) or to absorb heat for removal (summer) at some other time during the day.

Window technology and placement are critical for capturing solar energy in the winter and rejecting it in the summer; improvements in window technology over the past decade allow this to be done much more effectively than in the past (see box 3-4). Once the window captures heat, thermal mass [18] and interior air movements determine how effectively this heat is used. In recent years, passive design has emphasized "sun-tempering," which rearranges windows in the building to improve solar gain and lighting but (over the entire building) may require little additional window area and little or no additional thermal mass. This avoids the cost of adding thermal mass; it also reduces design complexity by avoiding the difficulty of properly coupling incoming sunlight to the thermal mass. Most conventional construction, in fact, has moved toward the use of lighter weight materials. Even traditional elements such as brick fireplaces are today commonly made of metal with a relatively lightweight brick veneer over it

[18] Thermal mass can moderate interior temperature swings.

FIGURE 3-4: Total Energy Use in U.S. Buildings, 1950-92, by Energy Supply Type



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(92) (Washington, DC: June 1993)

to provide the appearance of solidity; this type of construction reduces the usefulness of a fireplace as thermal mass.

As south-facing window area is increased, more sunlight is admitted into the space and the use of thermal mass gradually becomes more important to minimize overheating and moderate day-night temperature swings. Overheating and glare were frequent complaints in early passive homes, but they can now generally be avoided with proper design.

These same architectural elements can provide summer cooling. Overhangs[19] can shade south-facing windows from the summer sun, thermal mass can moderate temperature swings and can be used to absorb heat during the day for release outside at night,[20] and properly sited operable windows and open floor plans can provide effective cross ventilation. Other techniques used include shading by properly placed and selected trees or other landscaping, night cooling,[21] and others. In the dry Southwest, evaporative cooling can be effective and has long been used;[22] for the humid Southeast, desiccant moisture removal systems are being developed because moisture removal is a prime problem.[23]

A key element in cost-effectiveness for these technologies is to employ the same elements normally used to construct a building, but configure

[19] Including awnings and trellises.

[20] This will generally be accomplished with ventilation at night to circulate cooler night air.

[21] This can include ventilation with night air or radiation to the night sky—both coupled to thermal mass (including earth coupling) to remove heat absorbed by the thermal mass during the day.

[22] As the name implies, evaporative cooling uses the evaporation of water to absorb heat and cool the air. When the cooler, more humid air is discharged directly into the living space, the system is often known as a "swamp chiller." Alternatively, heat exchangers can be used, with the humidified air blown outside after it first cools off dry interior air via a heat exchanger. This prevents excessive moisture input into interior spaces.

[23] Desiccant removal systems use drying agents to absorb water from the interior air and then use solar energy to heat the agent and drive off the moisture, releasing it to the outside.

BOX 3-4: Advanced Window Technologie

Approximately 15 exajoules (EJ) of primary energy are used annually to heat and cool buidings; roughly one-quarter of this energy demand due to undesirable heat losses or gains through windows,[1] When the first 011 crisis occurred in 1973, approximately 70 percent of new windows sold in the United States were single glazed with an insulating value of R-1 [2] If an average building life of 40 years is assumed, such windows would result in the lifetime loss of more than 100 EJ worth more than $1 trillion [3] Following the first energy crisis, changes in building codes and other factors resulted by 1990 in the market shifting largely (80 percent) to double-glazed windows with an insulating value of R-2 Such windows cut energy loss in half.

Beginning in 1976, researchers at Lawrence Berkeley Laboratory began work to Improve window performance Low-emissivity (low-E) windows with special coatings to reduce heat loss were their first major focus The $2-million federal Investment leveraged some $100 million in private Investment in low-E film production technology,[4] This work produced windows with a thermal resistivity of R-3, and with low-conductivty gases, R-4, with energy savings of two-thirds and three-quarters, respectively, compared with single-glazed windows The first significant sales of low-E windows occurred in 1984 following a variety of ongoing federal supports and outreach to manufacturers; they now account for one-third of residential window sales A number of other technologies have been developed subsequently and are now in various stages of commercialization, Transparent insulation and electronically controlled coatings[5] are under development and promise substantial further Improvements in window performance,

In parallel, Lawrence Berkeley Laboratory has developed a computer design tool called Window 4.0, more than 3,000 copies have now been distributed. It is used extensively by manufacturers to design more energy-efficient windows and by Industry for the window rating and labeling system.

[1] R Bevington and A Rosenfeld, "Energy for Buildings and Homes, ' *Scientific American*, vol 263, No 3, September 1990, p 80

[2] R-1 refers 10 the resistance to heat flow, R-1 is a resistivity of 1 square foot-hour-°F/Btu

[3] This assumes that 70 percent of the windows of the total building stock are single-glazed, in fact, the fraction that was single-glazed at that time was likely to be significantly higher The dollar value is basedon the overall energy costs for buildings, the fraction of energy use lost by windows, and a 40-year building life

[4] Howard S Geller et al "The Importance of Government-Supported Research and Development in Advancing Energy Efficiency in the United States Buildings Sector" *Electricity Efficient End-Use and New Generation Technologies, and Their Planning Implications*, Thomas B Johansson et al (eds) (Lund, Sweden Lund University Press, 1989)

[5] Electrochromic windows Researchers are also examining thermochromic (responsive to temperature) and photochromic (responsive to light) coatings

them in ways that better control natural energy flows. Thus, windows on the east and west side are minimized-they tend to provide little net winter heat but significant summer overheating—and the equivalent window area is moved to the south side where it can provide winter heating. A fireplace might be positioned so that it receives direct sunlight in the winter and thus can provide some thermal mass benefits. Passive design must **be** used in conjunction with a full complement of cost-effective energy efficiency techniques, careful siting and landscaping, and other aids. These design techniques are subtle, but effective.

Passive heating, cooling, and lighting (see below) require careful and sophisticated architectural design; they are design-intensive rather than material-intensive. The development, testing, and distribution of effective computer design tools and the provision of additional supports at the design stage may therefore be important for effective and widespread use of these technologies.

In some circumstances, however, the careful "tuning" of passive design performance may also cause difficulties. For example, passive solar and daylit designs may sometimes be less amenable than conventionally heated buildings to subsequent modifications to suit the tastes of new owners. New owners of passive homes have sometimes covered interior mass floors with carpet, mass walls with wallboard, or made other changes that reduced the effectiveness of carefully tuned interior designs. Similarly, offices may raise existing or build new walls to increase worker privacy that at the same time disrupt the natural flow of solar heated air through the building or block daylight. On the other hand, unlike conventional structures, passive buildings can often remain habitable (and are less susceptible to freezing damage) during power and fuel disruptions in severe cold or hot spells. Further, passive design features do not generally wear out the way conventional heating, cooling, or lighting equipment does.

Properly designed and built, the reduction in heating and cooling loads made possible through passive solar design can allow conventional heating and cooling equipment to be downsized, in part offsetting any additional cost of RETs. Overall cost and performance results from a number of case studies of carefully monitored buildings across the United States are shown in figure 3-1. These buildings demonstrated significant energy savings, averaging roughly 50 percent energy savings for efficiency and renewable energy contributions combined, compared with conventional designs, and at relatively little increase in construction cost. The overall cost of saving energy by using these technologies is substantially lower than current or projected costs of conventional fuels, as indicated in the example supply curve of figure 3-5. These opportunities can be found throughout the United States and offer prospective owners of new residential and commercial buildings large cost and energy savings.

Daylighting[24]

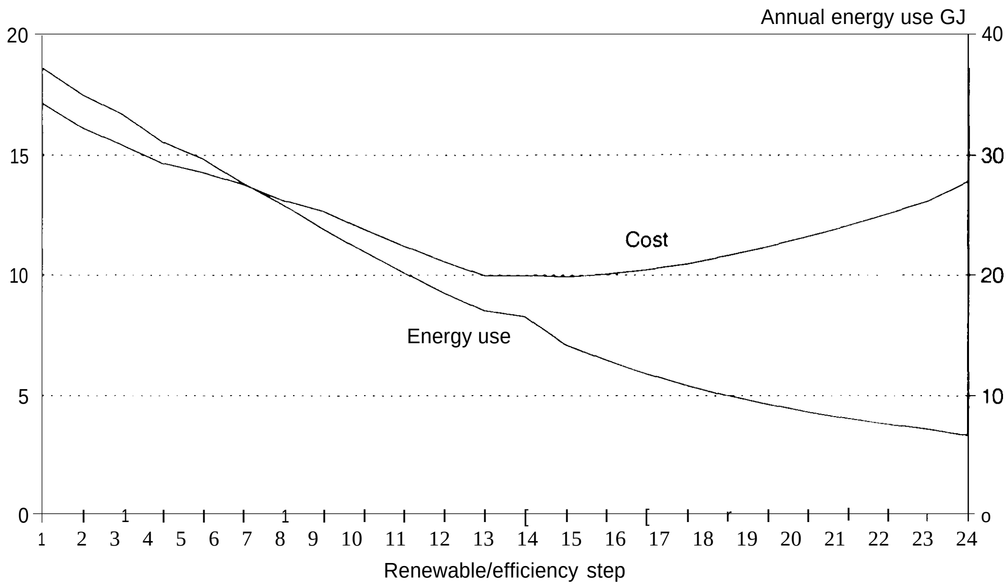
Daylighting is the process of letting light in from the outside and integrating it with interior electric lighting (o provide high-quality, glare-free, lowl-energy-use lighting for occupants. This includes adding high windows, clerestories, and skylights or roof monitors to cast light deep into the building's interior: atria to provide lighting in the core of a large building: and appropriately placed walls, screens, reflectors, and luminaires to diffuse daylight.

Both direct and diffuse sunlight can be used for daylighting. Direct sunlight is highly directional, very intense, and often variable from moment to moment (e.g., as clouds pass by). It is used for dayligh only after it has been diffused by passage through a diffusing window or fixture or after it has been reflected off an interior (nonmirror) surface. Direct sunlight may also be used for interior spaces where light must be "piped" in.[25] Diffuse sunlight is light that has been scattered by the atmosphere and comes from the entire sky. Although it is less intense than direct sunlight, it is much less directional and variable from moment to moment. Daylighting strategies often rely more

[24] See, e.g., J. Douglas Balcomb, "Daylighting," ISPRA Course on Passive Solar Technologies for Buildings in Mediterranean Climates, Kefalonia, Greece, Oct. 17-21, 1988; C. Ben[on et al., Lawrence Berkeley Laboratory, "Control System Performance in a Modern Daylighted Office Building," LB L-3061 1, October 1990; D. Arasteh et al., Lawrence Berkeley Laboratory, "Cooling Energy and Cost Savings with Daylighting in a Hot and Humid Climate," LBL- 19734, July 1985; and G. Sweitzer et al., Lawrence Berkeley Laboratory, "Effects of Low-Emissivity Glazings on Energy Use Patterns in Nonresidential Daylighted Bui ldings" LBL-2 1577, December 1986. Extensive literature on daylighting can be found m American Solar Energy Society, op. cit., footnote 17. For practical hands-on guides. see, e.g., Wayne Place and Thomas C. Howard, North Carolina Alternative Energy Corp., "Day lighting Multistory Office Building s," 1990; and Wayne Place and Thomas C. How ard, North Carolina Alternative Energy Corp., "Daylighting Classroom Buildings," 1991.

[25] If not diffused by a diffusing window, fixture, or reflector, direct sunlight tends to be used sparingly and then primarily to accent Internal design. In this context, note that simply allowing light in from large expanses of glass on modem office facades can result in glare and require high levels of artificial light as a counterbalance.

FIGURE 3-5: Representative Building Energy Supply Curve



NOTE: Estimated life-cycle cost and energy use are shown for a series (1-24) of renewable energy and energy efficiency improvements in a residential building in Albuquerque, NM, using electric resistance heating. Improvements include increases in wall, ceiling, and perimeter insulation (steps 1-5, 13); higher quality windows (steps 6-7, 14, 24); and increases in window area, placement, and associated features (8-12, 15-23). At roughly steps 12-13, life-cycle costs reach a minimum, with energy use about half the base case electric resistance heated household. The cost of saving electricity varies from around 8¢/kWh at step 2, to 4¢/kWh at step 12, to 75¢/kWh at step 24. A similar analysis for natural gas shows a supply curve that is nearly flat to steps 12-13—i.e., gas and solar heating cost the same at current low gas prices—and then becomes more expensive for solar heating after step 13. In this case, although solar heating does not have a decisive direct cost advantage over low-cost natural gas, it does reduce exposure to the risk of future gas price increase, will improve building habitability during cold spells if gas is cut off, and reduces environmental impacts.

SOURCE: Adapted from Robert W. Jones et al., "Residential Energy Standards for New Mexico," Seventeenth National Passive Solar Conference, Cocoa Beach, FL, June 13-18, 1992.

heavily on diffuse sunlight because of its higher lighting quality and stability.

Because daylight provides more visible light than heat compared with artificial lighting, it can also reduce air conditioning loads.[26] Overall, the energy savings from daylighting strategies is heavily dependent on the relationship between lighting and cooling electricity saved, or additional heating energy consumed. This relationship va-

[26] Diffuse sunlight is roughly twice as efficient as standard fluorescent bulbs and nearly six times as efficient as incandescent bulbs in terms of lighting service per unit thermal input into the building. Thus, admitting 1 watt of diffuse sunlight can allow a decrease in the fluorescent lighting load by 2 watts, and also decrease the air conditioning load by 0.5 watts (if a coefficient performance of 2 is assumed), for a net savings of 2.5 watts of electricity per watt of sunlight. This benefit is decreasing as artificial lighting becomes more efficient and lighting design reduces unnecessarily high lighting levels.

ries widely from region to region and from building to building within regions.[27]

Daylighting is of particular interest in office buildings where lighting is a very large energy demand; internal heat gains predominate so that cooling is needed over much of the year (and so daylight can reduce cooling loads); and architecture has already moved toward glass exteriors and interior atria.[28] Daylighting is also of great interest for schools. Properly designed, daylighting can provide 50 to 75 percent of the light needed during daytime hours. Daylighting must be integrated with heating and cooling design elements to achieve optimal overall performance. Windows used for day lighting can be placed to provide passive solar heating in the winter and to avoid summer solar gains. Controls to dim or turn off artificial lights are usually required to achieve the full potential savings of daylighting.[30]

Solar Water Heaters

Solar water heaters use panels or tanks exposed to the sun to warm water for domestic or service use (solar domestic hot water, SDHW)[31] or for swimming pools.[32] Early adoption was fueled by a number of forces, including emerging environmentalism, fear of high fuel prices, and government tax credits. With the expiration of the federal tax credit in 1985, the solar thermal (including the solar water heater) market experienced considerable downsizing, from 225 manufacturcrs in 1984 to 98 in 1986 and 45 today.[33] Overall, an estimated 1.8 million systems have been produced since the 1970s.[34]

Solar pool heaters are a low-temperature application, typically operating around 80°F (27°C), and thus can be quite efficient without using an insulating glass or plastic cover, or other insulation. This allows them to be very low cost with average wholesale prices in 1992 of $27/m² ($2.50/ft²).[35] Solar pool heaters are cost-effective over a fairly wide range of conditions and have developed into a significant market. Sales increased 11 percent from 1991 to 1992 and accounted for nearly 90 percent of the solar thermal collector market.[36]

SDHW is a medium-temperature application. typically operating around 120°F (50°C). These temperatures require insulating glass or plastic

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27 The relationship between cooling and heating loads depends dramatically on the length and severity of the heating and cooling seasons. The length of these seasons for a particular building depends on the assumed base case amount of heat that is generated within the building (e.g., by people, lights, and computers) and the degree to which this amount is changed by decreasing the lighting load. Thus, daylighting would save proportionately more energy in a densely packed office building or restaurant, with large internal heat gains and a long cooling season, than in a warehouse, with little internal gain and a shorter cooling season.

28 Balcomb, op. cit., footnote 24.

29 Mike Nicklas, Innovative Design; J. Douglas Balcomb, National Renewable Energy Laboratory; and Mark Kelley, Building Science Engineering, personal communication, Apr. 13, 1994.

30 In general, however daylighting is desirable where it can provide superior lighting for a large portion of the time. Otherwise, daylighting does not become the norm and people override the lighting controls too frequently. Nicklas, op. cit., footnote 29.

31 This refers to hot water used for household purposes (e. g., washing and bathing).

32 Solar water heaters can be either passive, in which the flow of water (or other fluid) is driven by natural temperature differences generated by solar heating, or active, in which the flow of water (or other fluid) is driven by an electric pump powered by the utility grid or by an adjacent photovoltaic system.

33 Downsizing actually began in 1979, but experienced its biggest jump between 1984 and 1986. U.S. Department of Energy, Energy Information Adminstration, *Solar Collector Manufacturing Activity 1992*, DOE EIA-0174(92) (Washington, DC", November 1993).

34 Sheinkoff, op. cit., footnote 6.

35 Energy Information Administration, op. cit., footnote 33.

36 Total solar thermal collector shipments in 1992 were about 7 million square feet.

covers, side and back insulation, and other techniques to reduce heat loss and improve efficiency.[37] The greater material intensity and complexity of these collectors raise wholesale prices for the collector alone into the range of $100/m2 ($1 0/ft^2).[38] Overall costs are typically in the neighborhood of $200/m^2 for all of the hardware, $ 100/m2 for installation, and up to $300/m^2 for overhead, profit, and marketing costs.[39] This gives a total installed cost in the range of $300/m^2 to $600/m^2 ($30/ft^2 to $60/ft^2).[40] Typical systems are *4* to 8 m^2 in area, depending on the climate, and deliver roughly 30 to 40 MJ/day of energy. This is equivalent to about 8 to 12 kWh of electricity with a value of $0.80 to $1.20/day at high electricity rates.[41] The simple payback may then be as low as six years in some select areas compared with electric water heating,[42] but it is not generally cost-competitive compared with natural gas systems at current prices.[43]

Large-scale production and installation of solar water heaters might allow significant price decreases through economies of scale and learning and by reducing marketing and other overheads. Although there are enough cost-effective uses of SDHW to justify large-scale manufacturing and installation, the market has been slow to develop due to a variety of market challenges.

Sola water heaters may also sometimes be made more cost-effective by considering their use in utility demand-side management (DSM) programs. Although water heating is a large energy demand (see figure 3-3), utility DSM programs must instead focus on the extent to which water heating contributes to the utility's peak electricity demand; this varies by region and time of year. As an example of it not being cost-effective, studies by Florida Power and Light found that electric water heaters only contributed an average of about 0.2 kW each to the peak load. Overall program costs and ratepayer impact concerns then made solar water heater DSM investment incentives not cost-effective (see box 3-5).

In areas with large coincident peaks between electric water heating loads and utility loads, utility incentives for SDHW systems may be cost-effective.[44] In response to this DSM opportunity, Edison Electric Institute, the American Public Power Association, and the Department of Energy established the Utility Solar Water (USH_20) Program to assist in the development and expansion of utility programs for residential and commercial solar water heating. The intent is both to reduce utility demand in regions where the SDHW option is cost-effective and to aggregate markets for SDHW so as to allow manufacturing and installation scaleup and thus help drive costs down.

As with passive systems, the cost-effectiveness of SDHW might be assisted by developing de-

[37] These include spectrally selective absorber surfaces and vacuum jackets.

38 Energy Information Administration, Op. cit., footnote 33.

[39] Henry (Greg) Peebles 111, American Energy Technologies, Inc., personal communication, May 26, 1994.

[40] In Comparison, one manufacturer estimated costs t. be typically 25 percent for the collector and related hardware, 25 percent for marketing and advertisement, 15 percent for installation, and 35 percent for overhead and profit.

[41] This ignores storage losses and the value of the electric water heater tank, and assumes a high value of 10¢/kWh for residential electricity.

[42] This assumes the higher cost of $600/m^2 for a smaller 4 m^2 system installed in a favorable climate, a high level of del ivered energy, and high electricity rates.

[43] Batch and thermosyphon water heaters are particularly cost-effective, in Some cases even when measured against natural gas.

[44] See e.g., Clifford S. Murley and Donald E. Osborn, "SMUD's Residential and Commercial Solar Domestic Hot Water Programs," paper presented at the American Solar Energy Society Solar 94 Conference, San Jose, CA, June 1994. A detailed study across the entire United States found a wide variation in coincidence between hot water demand and utility loads, ranging from 12 to 78 percent in the summer to O to 36 percent in the winter, depending on the region. See S.F. Ahmed and J. Estoque, *Solar Hot Water Manual for Electric Utilities: Domestic Hot Water Systems*, EPRI EM-4965 (Palo Alto, CA: Electric Power Research Institute, December 1986).

BOX 3-5: Consideration of Solar Water Heaters as a DSM Measure by Florida Power and Light[1]

Florida Power and Light (FPL) began prowding front-end payments of up to $400 for solar domestic water heaters (SDHW) in 1982 Installations under this program grew steadily to almost 14000 in 1985 before collapsing to less than 1,000 by 1987 when federal tax credits were withdrawn Overall FPL provided support for almost 41,000 solar water heaters between 1982 and 1990

In response to the Florida Public Service Commission, FPL developed a demand-side management plan in 1990 On reviewing the payment for domestic solar water heaters, FPL found that, in fact, there were benefits of only 75@ for every dollar spent The reason was that few people took hot showers in the late afternoon when FPL experienced its peak electricity demand, so substituting SDHW reduced the peak load little and saved FPL little Investment On the other hand during off peak times, electric water heaters consumed large amounts of power --1 ,500 kWh per year—and so contributed substantially to FPL revenues

Despite these results, FPL ultimately petitioned the Commission to continue its SDHW Incentive payment program because of FPLs concern that many of the benefits of renewable (e g , environmental benefits, fuel diversity, continued support for the embryonic solar Industry) were not captured in the cost-benefit analysis

At the same time, FPL discovered in its review of the SDHW program that swimming pool pumps had a high load during the late-afternoon peak period Subsequent analysis found that photovoltaic-powered pool pumps had a benefit-cost ratio of 1 2 (i.e., 20 percent net benefits) An Incentive program for photovoltaic-powered pool pumps is now under study.

[1] Steven R Sim Residential Solar DSM Programs at Florida Power and Light " *Solar Age* September-October 1991 pp 23-25

signs that are integrated into the building shell, reducing overall material and construction requirements. Homeowner costs may also be reduced by incorporating the costs of the system into the home mortgage—amortizing SDHW costs over 30 years and allowing interest charges to be deducted from tax payments.

Active Space Heating and Cooling[45]

Active space heating and cooling systems use discrete solar collectors—large panels glazed with glass or clear plastic---on the roof or beside the structure to capture sunlight and pipe the energy where it can heat a building or drive a cooling system.

Active space heating and cooling systems are cost-effective for only a 1 imited range of applications.[46] The primary difficulty with active systems is that large costly areas are required to collect the relatively low-energy-intensity solar resource. It is difficult to do this cost-effectively with discrete dedicated material- and labor- intensive collectors. In contrast. the cost-effectiveness of passive architecture is largely the consequence of being able to use elements of the building it-

[45] For classic descriptions of active systems, see John A. Duffie and William A. Beckman, *Solar Engineering of Thermal Processes*, 2nd Ed. (New York, NY: John Wiley & Sons, 1991); and Bruce D. Hunn et al. (eds.), *Engineering Principles and Concepts for Active Solar Systems* (Golden, CO: Solar Energy Research Institute, July 1987).

[46] U. S, Department of Energy, "Renew able Energy Technology Evolution Rationales," draft, Oct. 5, 1990; and American Solar Energy Society, *Progress in Solar Energy Technologies and Applications: An Authoritative Review* (Boulder, CO: January 1994).

self—at little or no additional material or labor cost—to perform the collection function.

Several recent efforts have focused on reducing the material intensity of active solar systems by integrating the collector into the building shell. For example, solar collectors are being developed that heat ventilation air before it enters a building.[47] These collectors form part of the building wall. Because ventilation air is a low-temperature application (roughly 65° to 70°F) and because air is pulled through the collector to the inside (minimizing heat losses), glass or plastic covers are not needed for insulation as is common for somewhat higher temperature applications (such as solar domestic hot water heaters). These factors minimize the use of additional materials. At the same time, low temperatures also mean that these systems can be relatively high inefficiency. This technology received one of the prestigious R&D 100 awards from *Research and Development* magazine for 1994. Ventilation preheat may become a more important consideration as new air quality standards for buildings are implemented,[48] and these technologies appear likely to be cost-effective in some colder climate applications.

Landscaping and Tree Planting[49]

The summer and winter temperatures of urban areas tend to be higher than rural surroundings because asphalt, concrete, and other construction materials absorb and hold large amounts of heat, and because there is little vegetation for shade or to transpire moisture and thus lower urban temperatures.[50] In some cooling-dominated climates, shading and reflective surfaces may help cool buildings.[51] For example, the National Academy of Sciences estimates that planting trees and lightening the color of roads and buildings could reduce U.S. air conditioning use by about 25 percent.[52] Likewise, absorptive surfaces and properly designed landscaping can help reduce heating requirements in other areas.

In response to this opportunity, several tree planting programs have recently been initiated or considered, including utility demand-side management programs. Little is known at this point about the overall cost-effectiveness of these efforts.[53] Balancing the potential energy and peak electric capacity savings (which require further research themselves) are outreach, planting costs, maintenance, water use, risk of loss of trees, and other factors. In addition, there are concerns about root growth into sidewalks, sewers, and foundations, among other issues. The location of trees around a house and in any urban environment must be carefully considered so as to help rather than hinder passive performance in all seasons.

47 Charles F. Kutscher and Craig B. Christensen, "Unglazed Transpired Solar Collectors," *Advances in Solar Energy*, Karl W. Boer (cd.) (Boulder, CO: American Solar Energy Society, 1992); and Charles E. Kutscher, "Unglazed Transpired Solar Collectors," *Solar Today*, August 1992, pp. 21-22.

48 In the past, ventilation air heating was generally not a separately identified load. Over the past two decades, however, residential and commercial buildings have been made substantially more airtight in order to increase efficiency; consequently, ventilation air heating is becoming a more identifiable load. With new concerns over air quality and higher ventilation rates under American Society of Heating, Refrigeration, and Air Conditioning Engineers's new standards, ventilation air heating is likely to become an important energy demand and may account for roughly 5 to 15 percent of building energy demand.

49 U.S. Environmental Protection Agency, *Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored surfacing* (Washington, DC: 1992).

50 Urban heat island effects may, however, benefit winter heating. On the other hand, trees can provide important wind shielding from winter winds and reduce building heat loss, but winter shading even by bare branches can reduce winter heat gain substantially.

51 Care must be taken, however, that light surfaces do not reflect into adjacent windows and increase glare and cooling requirements.

52 National Academy of Sciences, *Policy Implications of Greenhouse Warming* (Washington, DC: National Academy press, 1991).

53 E. Gregory McPherson, "Evaluating the Cost Effectiveness of Shade Trees for Demand-Side Management," *The Electricity Journal*, November 1993, pp. 57-65.

Much further RD&D is needed to better understand all these issues.

The potential in urban cores is less clear because of the density and scale of construction. Further research and carefully monitored demonstrations are needed to clarify this potential. Carbon sequestration and air quality benefits, as well as aesthetic benefits, are potentially also provided by suburban and urban tree planting programs. B y one estimate, a 5°F (3°C) reduction in the daily high temperature of Los Angeles by using light-colored surfaces on roads and buildings and by planting trees could reduce smog episodes by one-third .54

Integrated Design

All of these technologies—passive or active solar heating and cooling, daylighting, efficiency improvements, and others—must be considered in an integrated fashion. Adding sufficient window area to heat a poorly insulated building in the winter may require such large amounts of thermal mass to reduce day-night temperature swings that it is not cost-effective, whereas adding a small amount of window area to a well-insulated building may provide highly cost-effective heating. Thermal mass considered only for its winter heating benefits may not be cost-effective, but when considered for its summer air conditioning peak load shifting as well, it may be quite desirable.

Integrated building design is very important for achieving high performance in these systems.[55] Integrated design considers a wide range of cost and performance tradeoffs across all aspects of the building's design in order to deliver the highest quality building services—thermal comfort, lighting, clean air, aesthetics—at the lowest possible life-cycle cost. Adequate consideration of all these factors is a very design-intensive process. Consequently, the lack of capable computer design tools to aid the architect and builder in this process is an important factor that has 1imited penetration of these technologies. Improved knowledge of building physics and the widespread availability of powerful personal computers tire now opening up, for the first time. the possibility of sophisticated, integrated building design.

RD&D AND COMMERCIALIZATION

For RETs to make a substantial contribut ion to energy needs in the buildings sector a variety of RD&D and commercialization issues must be addressed. RD&D needs are examined briefly here, followed by a detailed look at several key commercialization challenges.

Research, Development, and Demonstration

Although several of these renewable energy technologies are moderately mature, further R&D is needed in areas such as monitoring systems; computer-aided design tools for integrating daylighting, passive solar heating and cooling, and other attributes in building design; more intelligent lighting controls to better integrate artificial lighting with daylighting availability; electronically adjustable and spectrally selective windows; and improved materials for active and passive solar heating elements. These and other potential areas for further RD&D are summarized in table 3-1.

past Experiences[56]

Research, development, and demonstration of RETs for buildings has been supported by federal and state policies and programs for some two dc -

54Lawrence Berkeley Laboratory, "Heat Islands and How To Cool Them," *Center for Building Science News*, spring 1994.

55J Douglas Balcomb, "Integrated Design," paper presented at the Symposium on Solar Energy and Buildings, Athens, Greece, Dec. 8-10, 1993.

56The discussion on experience is based on J, Douglas Balcomb, *Passive Renewable Energy: What's Holding Us Up ? What Should Be Done?* (Boulder, CO: National Renewable Energy Laboratory. July, 1992); and personal communications with contributor as listed in the front of this report.

TABLE 3-1: Research and Development Needs

Materials	Insulants, particularly transparent Insulants such as aerogels Electronically adjustable spectrally selective windows, Improved lighting controls for Integrating daylighting and artificial lights Improved and longer life gaskets and sealants Phase-change materials, Desiccants for cooling systems. Selective surfaces Improved catalysts for small-scale biomass combustion emissions control Air-to-air heat exchanger materials
Building physics	Passive cooling techniques, Incuding radiant cooling Perimeter daylighting systems, allowing deeper penetration of perimeter spaces Atria design for better daylighting and thermal performance Basic heat transfer and natural convection air-flow research to improve performance and comfort Moisture absorption and desorption in building materials Duct design
Whole buildings	Testing advanced concepts in buildings, Performance monitoring of solar buildings Model land-use controls to encourage proper subdivision/site design
Human comfort research	Determining what makes people comfortable or uncomfortable with respect to temperature, humidity, lighting, and other factors within a building.
Design tools	Improved residential and commercial building design tools that perform Integrated analysis, including daylighting and window design, space heating, space cooling, and utility demand-side management Development of simplified design tools for the design and construction community. Validation of design tools

SOURCE Off Ice of Technology Assessment, 1995

cades. This support has led to important developments in many aspects of passive and active solar design; a variety of efficient lighting and tippliance technologies;[57] low-emissivity window coatings[58] and other window technology improvements, including the development of design tools;[59] radiant barrier technology; ventilative and desiccant cooling; and other technologies. Not all projects were successful, of course, but the overall track record has been good.

Support has also been provided for a number of demonstrations and field monitoring. The Department of Energy (DOE) Passive Solar Commercial Buildings Program supported the design of *21*

57 Howard S. Geller et al., "The Importance of Government-Supported Research and Development in Ad\ ancing Energy Efficiency in the United States Buildings Sector," *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications*, Thomas B. Johansson et al. (eds.) (Lund, Sweden: Lund University Press, 1989).

58 By one estimate, the return on [his technology—national savings to federal investment-hus been 7,000 to l See ibid.

59 Of particular note is the Lawrence Berkeley Laboratory Window 4.0 and other window design tools.

commercial buildings throughout the United States and monitored the cost and performance of 12 of them.[60] Energy and operating expenses were cut in half with, on average, no net increase in construction costs. Overall, 1ighting energy was reduced 65 percent, cooling 65 percent, and heating 44 percent compared with standard construction (figure 3-1). Detailed surveys found occupants highly satisfied with the buildings, particularly the daylighting. Key factors contributing to success included federal use of private parties to design, construct, and use the buildings, with the federal role limited to bringing the parties together, absorbing the additional cost of designing the buildings, and monitoring building cost and performance. This program helped train numerous architects, engineers, and builders: provided demonstrable proof that the concepts worked; and helped leverage the construction of many other passive buildings.

Similarly, the Class B Residential Passive Solar Performance Monitoring Program conducted by the Solar Energy Research Institute (SERI—now known as the National Renewable Energy Laboratory) took detailed data (about 20 data points an hour) for about 60 passive houses over an extended period.[61] These data showed that the passive systems provided more than half of the net heating load of these buildings and gave insights into how they worked as well as what did not work. This program provided reliable documentation and support for these technologies and data to aid researchers in improving these designs further. Some believe this to be one of the most valuable programs of the period because it provided detailed information to designers and engineers on what worked, what did not work, and why.

Some programs were, however, less successful, particularly those that attempted to push inappropriate or immature technology into the market. For example, a number of active solar cooling systems using different technologies were designed and built as demonstrations. A few were technically successful, but many never operated and none were ever close to being cost-effective or developing a self-sustaining market. The development of cooling systems is important for much of the United States, as well as much of the developing world. Before such technology pushes are attempted, however, realistic technologies must be chosen and the research and development (R&D) must be focused on ultimately providing commercially viable products.

RD&D Funding

Overall federal funding for such RD&D programs is listed in table 1-4 and has been in the range of $2 million to $5 million per year in recent years. In comparison, annual private and public expenditures for energy to heat, cool, light, and provide other energy services for residential and commercial buildings are roughly $180 billion annually.[62] If a 10-percent overall energy savings could be realized in the longer term by using RETs in buildings---one-half to two-thirds the potential—$18 billion would be saved annually, without even considering growth in the stock of buildings or increases in energy prices. This amount is roughly 4,000 to 10,000 times recent federal expenditures

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[60] Burt Hill Kosar Rittelmann Associates and Min Kantrowitz Associates, *Commercial Bul/ding Design: Integrating Climate, Comfort, and Cost* (New York, NY: Van Nostrand Reinhold Co., 1987); and U.S. Department of Energy, *Project Summaries: Passive Solar Commercial Buildings Program* (Washington, DC 1982).

[61] Solar Energy Research Institute, *Passive Solar Homes: 20 Case Studies*, SERI/SP-27 I -2473 (Golden, CO: December 1984); and Solar Energy Research Institute, *Passive Solar Manufactured Buildings: Design, Construction, and Class B Results*, SERI/SP-27 1-2059 (Golden, CO: December 1984).

[62] Energy Information Administration, op. cit. footnote l

on RD&D in these technologies. A 10-percent savings in the buildings sector corresponds roughly to reducing total U.S. primary energy use by about 3.5 percent.[63]

In comparison, coal currently supplies about 23 percent of total U.S. energy and 54 percent of U.S. electricity. Fully implemented, the clean coal program would reduce U.S. energy use by about 4.3 percent,[64] as well as substantially reducing emissions of sulfur and nitrogen oxides (SO_x and NO_x).[65] (RETs in buildings would have a substantially smaller direct impact on emissions of SO_x and NO_x.)

While annual appropriations for RETs in buildings have been $2 million to $5 million in recent years, those for the clean coal program have typically been in the $400 million to $500 million range, roughly 100 times greater. Although these calculations are crude and the programs are not directly comparable in many respects, these estimates do give an order-of-magnitude comparison of the relative benefits and costs of these programs. A much more detailed analysis of the relative long-term value of these and other programs would be useful.

Commercialization Overview

A variety of market challenges limits the commercialization of RETs in the buildings sector. These challenges must be addressed if a significant share of cost-effective applications of RETs in buildings are to be developed.[66] Such actions are particularly important in the buildings sector because of several factors: the large amount of energy consumed and the corresponding environmental impacts of fossil energy use; the very long lifetime of buildings and the inherent difficulty and cost of modifying them after construction; and important interconnections with other sectors, particularly electricity.

There is a large literature for the buildings sector discussing the extent to which various challenges to commercialization and/or observed consumer behavior actually represent market distortions and barriers.[67] For example, studies of energy efficiency investments consistently find implicit discount rates of 20 to 800 percent, compared with market rates of 10 percent real and less.[68] Some believe that this discrepancy indicates substantial market distortions and barriers;

[63] In solar buildings, there may be small additional emissions for the production of additional glass, cement, and so forth. A total life-cycle estimate of emissions is needed, but is not done here.

[64] It would raise electricity-generation efficiencies from the current 35 percent to roughly 45 percent. Since electricity accounts for about 85 percent of coal use and is 23 percent of total national energy use, the improvement in efficiency corresponds to national energy savings of 4.3 percent when fully implemented at today's rate, without considering future changes in the mix or number of generating plants.

[65] Emissions reductions of 90 percent are a research goal.

[66] Although cost-effectiveness as discussed here is based only on market prices for energy, it may be useful to include environmental and other externalities in this cost-effectiveness criterion to the extent possible. These issues are not addressed in the discussion here for the buildings sector but are discussed for electricity in chapter 6.

[67] Most of this literature focuses on energy efficiency and related investments. See, e.g., Alan H. Sanstad et al., *On the Economic Analysis Of Problems in Energy Efficiency: Market Barriers, Market Failures, and Policy Implications, LBL-32652* (Berkeley, CA: Lawrence Berkeley Laboratory, Energy Analysis Program, January 1993); J.A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *Bell Journal of Economics*, vol. 10, 1979, pp. 33-54; H. Ruderman et al., "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *The Energy Journal*, vol. 8, No. 1, 1987. pp. 101-124; Harry Chemoff, "Individual Purchase Criteria for Energy-Related Durables: The Misuse of Life Cycle Cost," *The Energy Journal, vol. 4, No. 4,* October 1983, pp. 81-86; Fereidoon P. Sioshansi, "The Myths and Facts of Energy Efficiency," *Energy Policy*, April 1991, pp. 231-243; and Kevin A. Hassett and Gilbert E. Metcalf, "Energy Conservation Investment: Do Consumers Discount the Future Correctly?" *Energy Policy, vol. 21,* June 1993, pp. 710-716. The references In these papers, particularly that@ Sanstad et al., provide a very extensive guide to the literature.

[68] Hausman, op. cit., footnote 67; and Ruderman et al., op. cit., footnOte 67.

others believe that this represents legitimate consumer sensitivity to the risk and uncertainties of investing in energy-efficient equipment.[69] Regardless of the cause of these investment patterns, there appears to be a need to find mechanisms that reduce the gap between what is cost-effective from the societal perspective and what is currently invested in by the individual. The focus here is on the practical ways in which various factors may limit the commercialization of RETs in the buildings sector, rather than a theoretic] discussion of what does or does not constitute a market distortion.

Market challenges to the use of RETs in buildings occur at every step of design, construction, sale. ownership, and energy costing.

Design

Passive solar buildings are general] y more design-intensive than conventional buildings. Low margins on design fees and short time frames for completing designs, the frequent lack of training, and the lack of capable design tools and other supports tend to deter architects from pursuing such design-intensive options. There may also be little or no reward to the architect for pursuing an energy-conscious design.

Decisions on purchasing RETs require comparisons across many attributes, such as first cost, performance, appearance, and convenience. These attributes often overshadow energy considerations. For example, the builder may realize a higher profit margin or quicker sale by adding an extra bathroom or jacuzzi rather than by investing in additional insulation or adding passive solar design features to reduce life-cycle costs and improve overall societal costs and benefits. These considerations strongly influence design and particularly the time that is devoted to different aspects of design.

Renewable energy technologies may also change the amenity value of a building. Some may object, for example, to the appearance of a (non integrated) solar water heater on a rooftop. others may appreciate the warmth and light of a sun-tempered living room. In other cases. passive solar design may not--or may be (misperceived to not—fit in with the local architecture and thus be less desirable to some potential buyers. For example, brick colonial houses may be able to incorporate modest levels of passive solar techniques, but extensive use would be difficult without changing appearances. Builders consequently may hesitate to introduce passive solar features.[70] However, some analysts believe that effective passive solar designs exist for almost any architectural style, including brick colonials.[7]

Strategies to address the design challenge of passive solar include developing design tools and guidelines, providing design assistance and Supporting information exchange, supporting the education and training of architects and engineers in these technologies, and establishing design competitions and awards.[72]

Design Tools and Guidelines

The development of capable and user-friendly computer design tools would address to varying degrees all of the design challenges noted above, particularly the lack of time or resources to develop design-intensive passive solar architecture or adapt it to various architectural styles. This poten-

[69] Hassett and Metcalf. op. cit., footnote 67.

[70] Ron Nick Jon National Association of Home Builders. personal communication. July 23, 1992.

[71] Nicklas, op. cit., footnote 29; Kelley, op. cit., footnote 29.

[72] Several of those interviewed by the Office of Technology Assessment also raised concerns about the liability of the architectural firm should anything—even unrelated to the RET—go wrong m a building it designed using RETs, as well as the more general concern that an architect cannot "experiment" on a client. A possible response would be to support the development of standard practice guidelines or standards for the use of RETs in buildings through an organization such as the American Society for Heating, Refrigeration, and Air Conditioning Engineers whose standards are widely recognized and accepted. This would reduce both the liability and the "experimentation" concerns. Further analysis of these issues is needed.

DON AITKEN

Neuffer Construction homes m Reno, Nevada, use passive design techniques to reduce energy use by 35 to 50 percent compared with conventional homes

tial is largely untapped. The buildings sector—architects, engineers, builders, equipment manufacturers—tends to be highly fragmented, with relatively few resources devoted to RD&D, developing design tools, or transferring information. Some recent work has begun to focus on this issue (see box 3-6).

Such passive solar design tools should explicitly interface with the computer-aided design (CAD) tools now widely used to design commercial buildings. This would ultimately allow a variet y of performance calculat ions and optimizations to run in the background while the building is designed on CAD. (Such tools are especially needed for the earliest design stages, when the architect is just beginning to sketch his/her vision for the building.) Similar development is needed for the residential sector. It is important, however, that design tools be validated on an ongoing basis against actual building performance.[73]

Past experience with the development of design tools has been quite positive. Useful design tools developed with federal funding and distributed to the buildings industry include the "Passive Solar Design Strategies: Guidelines for Home Building" by the National Renewable Energy Laboratory and Passive Solar Industries Council, the Solar Load Ratio Method of Los Alamos, computer programs such as DOE-2[74] and Window-4 by Lawrence Berkeley Laboratory, and the F-Chart method of the University of Wisconsin. These tools have been very useful to many designers and researchers in the buildings sector.

Design Assistance and Information Exchange

The ongoing collection of data from actual monitored field demonstrations of technologies and the conversion of those data to information usable by practitioners can potentially play a key role in supporting design work and validating various design approaches. This was shown to be an important part of past federal support of RET development for buildings, as discussed above for the DOE Passive Solar Commercial Buildings Program and the Class B Residential Passive Solar Performance Monitoring Program. Such monitoring efforts virtually ceased in 1982.

The federal government has also played a vital role in supporting valuable information exchange. For example, 18 Passive Solar Conferences have been held in the United States. The first was sponsored by the U.S. Energy Research and Development Agency (ERDA)[75] and organized by the Los Alamos National Laboratory solar group in 1976. Since then, these conferences have been organized by the American Solar Energy Society with some funding from DOE and others. Similarly, there have been international Passive and Low-Energy Architecture Conferences held annually since 1982 with some federal support. The *Passive Solar Journal* was also launched by a single $85,000

[73] For example, theoretical models often break down when critical parameters such as air infiltration rates are simply guessed or when practical construction techniques compromise performance (e.g., by creating thermal short circuits between the building interior and exterior).

74 Although admittedly user unfriendly, DOE-2 has played an important role in providing a technically oriented design audience with an important tool for understanding energy flow in buildings. Lawrence Berkeley Laboratory, with funding from the Electric Power Research Institute and DOE, is developing a user-friendly, interactive version of this energy-simulation software.

[75] ERDA was a forerunner of the Department of Energy.

BOX 3-6: Passive Solar Design Strategies: Guidelines for Home Building

The lack of high-quallty user-friendly computer tools for passive building design has been a serious constraint on more widespread use of these systems In response, researchers at the National Renewable Energy Laboratory and the Passive Solar Industries Council, in a five-year collaborate effort, have developed a computer tool, Passive Solar Design Strategies: *Gudelines for Home Building,* with support from the Department of Energy It has been distributed widely through the Pass-we Solar Industries Council To date, more than 100 versions of these guidelines have been generated for different Iocalities, and nearly 50 workshops have been held with more than 3,000 attendees The response has been good with almost 100 known passive homes constructed using these guidelines or the accompanying software called *Builder Guide* A similar program is now under development for small commercial buildings.

Further development and dissemination of these design tools could fill an Important gap in making passive designs a viable option for designers and builders

SOURCES J Douglas Balcomb National Renewable Energy Laboratory personal communications, March 1994 Helen English Passive Solar Industries Council personal communications March 1994

federal grant.[76] These efforts were a primary source of in format ion and a meet ing ground for researchers. architects, builders, financiers, and policymakers.

Education and Training

For RETs to be designed and built into buildings, architects and engineers must be trained in the technology. Education and training thus play an important role if solar buildings industry is to develop.

Past experiences have shown both the benefits and the risks of depending on federal assistance for education and training support. For example, the masters of science (MS) program at Trinity University in San Antonio is noted by some as having produced a particularly fine group of well-educated solar engineers and technologies. This program received considerable support from the DOE Solar Program in the late 1970s and early 1980s, but then folded in the mid- 1980s when funding dried up. In contrast, the School of Architecture at Arizona State Universit y has maintained an MS solar design program for more than two decades with essential y no federal support. This has greatly limited its resources, but has also protected it from arbitrary shifts in federal funding.

Design Competitions and Awards

Design competitions can potentially be used to stimulate interest in RETs for buildings, and numerous small awards can be given for better designs. Such programs could be structured so that there are many winners—perhaps half of the entrants, while the awards vary from a few thousand dollars for residential buildings to a few tens of thousands for commercial buildings. These amounts would be sufficient to cover a substantial portion of the additional design costs of including RETs in the building, while keeping overall program costs relatively low.

Past experience with such design competitions has been positive. DOE and the Department of Housing and Urban Development (HUD) collaborated in holding three rounds of passive solar design competitions in the late 1970s and early 1980s. Awards were given to the best designs, based on performance and architectural quality,

[76] Support ended, howev cr, before this publication became self-supporting; it is no longer published.

and covered the additional cost of designing a passive home and entering the competition.[77] Only a few hundred awards were given out, but the interest generated led to the construction of thousands of passive solar homes.[78] These competitions also pushed designers to develop better quantitative analysis tools for passive design and encouraged their more widespread use in the private sector. A number of construction practices now becoming standard were derived in part from these competitions and related demonstrations, including better-insulated walls and roofs, improved windows and doors, airtightening techniques, and foundation insulation.

Construction

In 1990, the residential construction industry built 1.4 million new homes, two-thirds of which were single family. This industry consists of about 100,000 firms with an average of five employees each. Small firms, however, built only 13 percent of new housing units; firms that build more than 100 units per year account for two-thirds of new housing units and may be better able to use new designs. In general, however, the industry is highly fragmented, which makes the introduction of new design and construction practices difficult.[79] This problem is compounded by the highly fragmented local codes and standards to which buildings must be constructed. As a trade industry, practices are generally learned by experience, which also contributes to the long times for change within the industry.

Some have argued that laying out a new subdivision to maximize the potential solar gain may reduce the number of homes that will fit in a tract, potentially raising prices and lowering developer revenues. Others note that lots can be laid out as desired; those most suitable for passive solar can have appropriate designs built on them, while others can place less emphasis on passive solar and more on efficiency.[80]

Construction bidding (by building contractors) is almost always done on a competitive first-cost basis rather than a life-cycle cost basis. Higher real or perceived upfront costs may then deter investment in RETs. Construction budgeting (by owners or architect/engineering firms) is usually done on a first-cost basis as well, but sometimes is based on life-cycle cost.

Strategies to address the construction challenge include supporting the construction of demonstration buildings and monitoring their performance carefully; supporting information exchange; establishing solar equipment rating and certification; encouraging utility investment; developing voluntary or mandatory building energy rating systems, codes, and standards; and giving "golden carrots" to manufacturers.

Demonstrations

Demonstration buildings and detailed performance monitoring can provide builders with visible, physical proof that a technology works. These demonstrations differ from the RD&D efforts described above in that they would not feature new or unproven technologies, but instead would serve as showcases for commercially viable technologies that builders and potential users could see and touch.

Information Exchange

Information programs can play an important role in generating interest among potential builders of

77 California Energy Commission, "Solar Gain: Winners of the Passive Solar Design Competition," February 1980; and Franklin Research Center, "The First Passive Solar Home Awards," prepared for the U.S. Department of Housing and Urban Development, January 1979.

78 J. Douglas Balcomb, National Renewable Energy Laboratory, personal communication, February 1994.

79 Office of Technology Assessment, op. CII., footnote 3.

80 Jeffrey Cook, Arizona State University; Mike Nicklas, Innovative Design; and Mary-Margaret Jenior, U.S. Department of Energy, personal communications, Apr. 3, 1994. Mark Kelley, Building Science Engineering, personal communication, Apr. 13, 1994.

passive solar buildings or other RETs in the buildings sector and educating them as to what works and what does not.

Solar Equipment Rating and Certification

Private sector equipment rating and certification systems have sprung up widely where large markets exist; establishing such systems where markets are young or small is more difficult. Such rating and certification programs can increase consumer confidence and reduce the risk of "quick-buck" operations that damage the industry's reputation; they can help standardize technology evaluations; and they can provide a means of comparing technologies. These benefits can be important to a young and struggling industry.

Several equipment rating and certification systems have been initiated with assistance from federal and state governments. A system for rating windows has been developed by the National Fenestration Rating Council and Lawrence Berkeley Laboratory. Solar water heaters are rated under the Solar Rating and Certification Corporation, an independent nonprofit corporation formed in 1980 by the Solar Energy Industries Association and the Interstate Solar Coordination Council, which represents state governments and publicly owned utilities.[81] Rating and certification could be extended to other products, particularly those used in passive applications such as daylighting systems and integrated lighting controls, and integrated mechanical systems.

Utility Investment

Utilities could potentially benefit substantially from RETs by reducing overall load, reducing peak loads, and shifting peak loads to offpeak hours. The cost-effectiveness of these DSM applications depends on the location, the particular building load, the utility load, the RET, and other factors. Utility DSM programs have grown rapidly to exploit the potential for improvements in energy efficiency. Because of internal procedures, Public Utility Commission directives, or other factors, however, many utility DSM programs may not adequately consider RETs. Factors such as the Ratepayer Impact Test may also play a role in reducing support for RET DSM programs[82] (see box 3-7). To overcome this potential shortsightedness requires specific recognition of the role of renewable as a DSM measure. This is primarily a state public utility regulatory commission issue. Potential federal roles might include supporting case studies, developing generic model DSM programs that can be adjusted by region, and providing information transfer of needed baseline data.

Building Energy Rating Systems, Codes, and Standards

Improvements in building energy performance could be achieved with building energy rating systems or with codes and standards.

Building energy rating systems could be used to provide reliable information on the expected energy costs of a particular building. This would provide potential buyers or renters with useful information for making their decision. As a first step, sellers of existing properties might be encouraged (or required) to inform potential buyers of the building's energy bills for the previous 12 months. For new construction, other methods of determining energy costs are needed. For example, Home Energy Rating Systems are at various stages of pilot demonstration and are described briefly in box 3-8.

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[81] "Solar Rating & Certification Corporation Presents OG-300-89: The Most Comprehensive Guide on Solar Water Heating Systems," *Solar Industry Journal*, fourth quarter, 1990, p. 36.

[82] For more detailed discussions of this issue, see David Moskovitz et al., *Increasing the Efficiency of Electricity Production and Use: Barriers and Strategies* (Washington, DC: American Council for an Energy Efficient Economy, November 1991); and James F. Deegan, "The TRC and RIM Tests, How They Got That Way, and When To Apply Them," *The Electricity Journal*, November 1993, pp. 41-45.

BOX 3-7: Consideration of Passive Solar Homes at Sierra Pacific Power Company[1]

[1] Donald Aitken and Paul Bony, "Passive Solar Production Housing and the Utilities," *Solar Today,* March/April 1993, pp 23-26
[2] The higher cost is due to additional features provided

Codes and standards might be used to mandate certain minimum building energy performance standards; these in turn would rely on renewable and energy-efficient technologies for implementation. The key to this is developing guidelines by region and building type that list reasonable energy budgets and goals.[83] At least 40 countries now have voluntary or mandatory standards for energy use in new buildings.[84]

Whether or not codes and standards are preferable to market mechanisms depends on many factors, including the flexibility allowed by the codes and standards as implemented, the cost-effectiveness of codes/standards or market mechanisms, and the influence of market challenges described in this section and the effectiveness of market mechanisms in overcoming them. For example, the disjuncture between owner and tenant, or the consumer's perception of risk and uncertainty,[85] may overwhelm many market mechanisms and require the use of codes and standards or other nonmarket approaches if there is to be rapid market penetration by cost-effective technologies.

Codes and standards are often problematic in practice. It maybe difficult to properly account for integrated design, the variability of building types and orientations, or a variety of other factors within the constraints of prescriptive standards. Performance standards can be difficult to enforce:

[83] A history of building codes and standards is provided in Office of Technology Assessment, Op. cit., footnote 3, pp. 107-109. These codes are now being reviewed and updated under the Energy Policy Act of 1992, sections 101, 102, 104, and elsewhere.

[84] Kathryn B. Janda and John F. Busch, "Worldwide Status of Energy Standards for Buildings," *Energy, vol.* 19, No. 1, 1994, pp. 27-44.

[85] Hassett and Metcalf, op. cit., footnote 67.

BOX 3-8: Home Energy Rating Systems and Energy-Efficient Mortgages[1]

Home Energy Rating Systems (HERS) are being developed to provide a reliable tool for predicting the energy use of residences; Energy-Efficient Mortgages (EEMs) will incorporate consideration of energy costs when underwriting mortgages. Thus, purchasers of low-energy-use homes will more easily qualify for a mortgage[2] or will qualify for a larger loan than those who purchase inefficient homes.

Efforts to develop HERS and EEMs go back to about 1980, but the programs had been relatively inactive. The current national effort began in 1990 with the National Affordable Housing Act and in 1991 with the National Energy Strategy. In 1992, the Departments of Energy and Housing and Urban Development, and 25 stakeholder groups released "A Blueprint for Action" calling for voluntary HERS and EEMs and providing a framework for HERS-EEMs programs, including criteria for qualifying for a loan, default rate data collection and use, lender indemnification, property evaluation, rating system validation, quality control, public information programs, and builder and lender training. Work to further define each of these and other issues is proceeding.

The National Energy Policy Act, the Housing and Community Development Act,[3] and the Veteran Home Loan Program Amendments,[4] all signed in 1992, accelerated the HERS-EEMs effort The Housing and Community Development Act, in particular, requires the establishment of a five-state pilot EEM program and work is proceeding

HERS and EEMs represent an Important step forward Results from pilot projects should prowde valuable Information on how to make them more effective and determine their true potential

[1] The principal source for this box is Barbara C Farhar and Jan Eckert *Energy-Efficient Mortgages and Home Energy Rating Systems A Report on the Nation's Progress* NREL/TP-461-*5478* (Golden, CO National Renewable Energy Laboratory September 1 993)

[2] By one estimate some 250 000 families might qualify for a first-tme home 'oar under EEMs who would otherwise be excluded under todays system, which does not consider energy use in loan qualification criteria See ibid

[3] U S Congress Housing and Community Development Act of 1992, Conference Report 102-1017 Oct 5 1992

[4] The Veterans Home Loan Amendments (Title 38, section 9) establishes a nationwide loan guarantee program—for loans up to $6000 in some circumstances—for energy efficiency improvements to an existing home owned and occupied by a veteran

officials charged with enforcing building codes, for example, are generally more concerned with health and safety—they will not be aware of a higher energy bill, but if a deadly fire occurs in a building they inspected, they will see and hear about it on the news and in the office. Officials are often already overcommitted, and energy codes and standards tend to be complex, potentially requiring considerable additional attention.[86] Technically, codes and standards often significantly lag best practice and are slow to incorporate technological improvements. Codes and standards may nevertheless be an important tool in ensuring a minimum level of performance.

Where codes and standards are used, state and local governments generally play the lead role; the federal government can also tighten energy-related codes and standards and work with state or

[86] In many cases, however, code enforcement depends more on the architect, engineering (A/E) firm than on inspectors. When an A/E submits a set of construction documents for a building permit, it is representing that the documents are in compliance with all applicable regulations. Building officials can check only limited aspects of any plan to verify code compliance. Therefore, if compliance with an energy standard is required, A/Es are obligated to comply, just as they are with fire safety provisions. Of course, training is still needed to provide the A/E with the knowledge needed to understand and comply with the requirement. This is not intended to minimize the importance of code review or of training code officials, but one need not rely solely on code officials to achieve compliance. Harry Gordon, Burt Hill Kosar Rittelmann Associates, personal communication, Apr. 25, 1994.

local government to improve model building codes. Providing an overall energy code and allowing substantial flexibility within it can give designers and builders more opportunities to cost-effectively and market-effectively meet the standard; however, such flexibility also increases the complexity of enforcement, compared with the use of prescriptive codes with simple checkoffs. For example, the California Energy Commission Title 24 Building Standards are noted for their allowance of passive solar design techniques to offset heavier use of insulation; however, they also require complex technical documentation. Title 24 also lags technically in some areas. For example, it has yet to incorporate low-emissivity coatings on windows.

Where codes and standards are pursued, it is also helpful to provide support for validating and adopting particular design strategies that meet the overall energy code requirement. Efficiency and renewable should be treated equally within codes and standards. If possible, however, it is generally preferable to use a carrot to improve building energy performance rather than the stick of codes and standards.

Golden Carrots

Manufacturers of RET equipment for buildings might be given cash awards in competitions to build the best-performing equipment. This has proven an effective approach in the development of efficient refrigerator designs, and would complement design competitions and awards for architects and builders.

| Sale

Individuals pursue several goals when making energy-relaed building investment decisions—for example, minimizing the time to make a decision, spending the least amount upfront, minimizing risk by obtaining the same item that worked before, or simply avoiding "hassle." Few pursue the goal of minimizing life-cycle costs, which RETs can help achieve.[87]

Individuals often lack a source of credible information needed to make sound energy-related investments. Vendors of solar systems may be viewed with suspicion because of early performance problems by some vendors in the field. Reliable information on actual field performance of various RETs is difficult to obtain, and RETs are often (misperceived as requiring discomfort or sacrifice, which limits their appeal.

Strategies to address these problems include information programs, field demonstrations, solar equipment rating and certification programs, utility encouragement of or investment in building RETs, building energy rating systems, and energy-efficient and renewable energy mortgages or other forms of financial support such as tax credits. Most of these have already been discussed briefly; the focus here is on various forms of financial supports.

RET Mortgages

RET mortgages would allow a potential home buyer to qualify for a higher loan by using expected future savings in energy costs to cover the higher mortgage payments. Several pilot programs for energy-efficient mortgages are now under development or in operation and will provide useful information to guide future efforts in this area. Energy efficiency mortgage pilot programs are described in box 3-8.

Tax Credits

Tax credits reduce the effective cost to an investor of an investment in an RET technology. There has been considerable experience with these financial supports.

Federal solar tax credits were enacted in 1978.[88] In response, markets for solar equipment

[87] Office of Technology Assessment, op. cit., footnote 3.

XX Energy Tax Act of 1978, Public Law 95.6] 8, Nov. 9, 1978. There are also a number of state tax credits, many of which continue today. State tax credits were not examined in the course of this assessment, but deserve detailed analysis to determine better what works and why.

grew rapidly. There were, however, unintended side effects. Equipment prices were often increased, and some of this solar equipment was poorly designed, poorly built, and poorly installed, which resulted in failures. The market grew so quickly with its intense, artificial fertilizing by tax credits that it had insufficient time to weed out poor products and establish reputable brands or dealers. The tax credits may also have been somewhat inequitable in that they tended to go toward individuals in higher income brackets that could afford the upfront investment. When the tax credits were withdrawn in 1985, the market crashed and numerous systems were left orphaned in the field. Some manufacturers survived, have persevered, and today market well-designed, high-performance systems.

In addition, the tax credits applied only to add-on equipment, not to passive design features—the most cost-effective approach—because it is very difficult to design tax credits so that they apply to the marginal investment in passive features. For example, when is a window a window and when is it a passive design element? This question indicates the difficulty of separately identifying what components of a passive solar design should qualify for a credit when they are intimate components of the building structure. Consequently, tax credits can be difficult to implement.

Improvements in technology may, in some cases, sidestep the problem of identifying passive solar value. For example, advances in window technology make high-performance windows energy savers, irrespective of their orientation. Tax credits might be provided for windows that perform better than a baseline standard, according to the ratings of the National Fenestration Rating Council.

Finally, the tax credits were expensive, and there has been considerable debate over their effectiveness in stimulating investment.[89] Recent work has indicated that tax credits are modestly effective in stimulating investment, but are strongly impacted by consumer perception of the risk of future energy costs versus sunk investment and other factors.[90] If targeted on specific, high-performmce but expensive technologies, tax credits may be effective in increasing sales, which in turn should reduce costs of manufacture.

Feebates

Rather than use a broad-based energy tax, a tax/rebate might be applied to new construction based on its estimated energy performance under building energy rating systems.[91] For example. buildings projected or measured[92] as requiring more energy than average might be taxed at a rate that increases with decreasing performance. These taxes would provide rebates. again on a sliding scale, for buildings expected to use less energy than average. This would avoid the equity issues inherent in a broad-based energy tax; it would also help address the problem of the sensitivity of buyers to upfront capital costs.

Although feebates have been proposed frequently in various sectors, they have not been used in the buildings sector. Pilot programs would be needed to demonstrate that building energy usc can be estimated reliably in practice and to address a host of technical. commercial, and institutional

[89] T.A. Cameron, "A Nested logit Model of Energy Conservation Activity by Owners of Existing Single Family Dwellings," *Review of Economics and Statistics*, vol. 117, 1985, pp. 205-211, J.A. Dubin and S.E. Henson, "The Distributional Effects of the Federal Energy Tax Act," *Resources and Energy*, vol. 10, 1988, pp. 191-212; and M.J. Walsh, "Energy Tax Credits and Housing Improvement," *Energy Economics*, 1989, pp. 275-2X4.

[90] Hassett and Metcalf, op. cit., footnote 67; Kevin A. Hassett and Gilbert E. Metcalf, "Energy Tax Credits and Residential Conservation Investment," January 1993.

[91] It would be necessary to ensure the accuracy of building energy rating systems through ongoing monitoring of a random sampling of buildings.

[92] Measurements might be made of building airtightness and other factors to determine overall building performance.

issues. Although intriguing in concept, feebates require much more study and demonstration.

Ownership

Roughly one-third of housing and one-quarter of commercial building floor space is leased or rented rather than owned.[93] Landlords have little incentive to invest in RETs for buildings when the tenant pays for the energy consumed. Tenants have little incentive to invest in RETs since they have little expectation of remaining long enough to recoup their investment.

When trading off first-cost and energy savings, homeowners will often not invest in RETs unless they offer very short payback periods. Reasons for this sensitivity include the following:

- *Inability to recoup their investment.* Homeowners typically move every 6 to 10 years, If the resale market does not value RET investments, the owner must recoup the investment within this short ownership period, which encourages a desire for a quick payback.
- *Perceived high risk and low resale value.* Investment in RETs is perceived as presenting some risk for which the owner must be compensated by a higher return (or equivalently a shorter payback period). In particular, a residence is generally the largest purchase a consumer ever makes, and anything that might conceivably make the dwelling less marketable or otherwise increase consumer risk may then require a compensating "risk premium" payment.
- *Large sunk investment, risk, and uncertainty,* Investments in energy savings are sunk investments, and homeowners must be appropriately compensated for tying up so much of their capital in a "risky" illiquid investment. Given the wide fluctuations in energy costs, the option of waiting to invest may be viewed as reducing their risk. Technologies are also changing rapidly; early investment poses the risk of early technological obsolescence, so there may be advantages in waiting to invest.[94]

On the other hand, building owners also face risks by being so utterly dependent on outside sources of conventional energy. As witnessed over the past two decades, energy prices can skyrocket, subjecting the owner to unexpected costs over extended periods. This may be a particular problem for low-income people or fixed-income retirees. Further, should there be a disruption in energy supplies, buildings can quickly become uninhabitable. Such risks are not commonly considered in building design, construction, or ownership.

Strategies to address these problems include building energy rating systems; RET mortgages; financial supports, possibly including tax credits; utility encouragement of and investment in RETs; codes and standards; and feebates. These have been discussed above.

Energy Costs

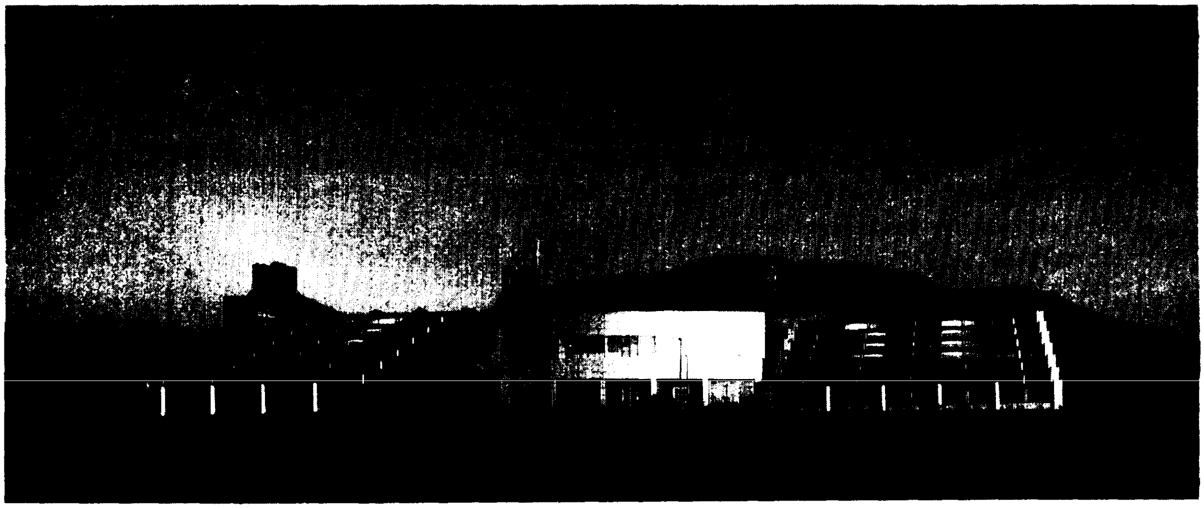
Energy costs, particularly for a business, often constitute only a small percentage of total operating costs and are much less than, for example, employee wages. Few businesses are willing to risk any disruption in energy-generated services—such as heating, cooling, or lighting—that might lower worker productivity. Although this concern is real, it may often be unfounded. Productivity studies have found that well-designed passive solar and efficient buildings can actually enhance productivity.[95]

The price of energy in the market today may not reflect the "true" societal cost of energy given the distribution of goods and services across the cur-

[93] Office of Technology Assessment, op. cit., footnote 3.

[94] Hassett and Metcalf, op. cit., footnote 67.

[95] Walter Kroner et al., *Using Advanced Office Technology To Increase Productivity* (Troy, NY: Center for Architectural Research, Rensselaer Polytechnique Institute, Troy, NY, 1992); and Joseph Romm and William Browning, "Greening the Building and the Bottom Line: Increased Productivity Through Energy Efficient Design," Asilomar Summer Study, American Council for an Energy Efficient Economy, 1994.



HEDRICH BLESSING

The Solar Energy Research Facility at the National Renewable Energy Laboratory in Golden, Colorado, uses a variety of passive and other technologies to reduce overall energy use by an estimated 30 to 40 percent compared with conventional buildings.

rent population or across generations, the risk of energy disruptions, uncertain y over future energ y costs, potential national security impacts, and environmental impacts.[96] These issues are discussed in more detail in chapter 6 in the context of the electricity sector.

Individually, designers. builders, and consumers are each responding logically within the constraints that they face; collectively, the net result is the construction of' many buildings that have much higher energy use than is necessary or cost-effective. This poses a variety of financial, risk, and environmental costs that are not now adequately incorporated in marketplace decisionmaking.

Strategies to address these problems include, in addition to those is ted above, energy and environmental externality taxes.

Energy and Environmental Taxes

The cost of energy could be raised to more accurately reflect the full costs of using it, including environmental and other external costs. For this to have any significant impact, however, it would best be combined with building energy rating systems and RET mortgages or other mechanisms. The overall impact for reasonable tax levels, however. is likely to be modest and will take a long time to occur because of the numerous market challenges noted above. In addition, a broad-based energy tax would fall more heavily on those who own or rent older and less well-built housing. Retrofitting housing can help reduce these costs and is an important policy in its own right, Retrofits, however, are not nearly as effective as incorporating RETs in new construction.

Federal Procurement

The federal government has considerable purchasing power because of its size, and this power can be used to increase the sales and distribution of RETs for buildings. In 1989. for example. the federal government spent $3.5 billion for energy used in its own buildings and another $4 billion

[96] The Price of energy may not even reflect the cost to deliver it within the existing accounting framework. Energy prices charged residences are averages and do not reflect the true cost of, for example, utility-generated power. particularly peak power. Time- of-use metering might better reflect systemwide costs of' providing power and offer additional incentives for consumer investment in RETs.

subsidizing energy use of low-income households.[97] This includes the roughly 500,000 office buildings owned or leased by the federal government, 1.4 million low-income housing units owned by the government, 9 million households for which the government subsidizes energy bills, and 422,000 military housing units. Incorporating RETs in existing or new federally owned or energy-subsidized buildings may offer an important opportunity to save taxpayer dollars where RETs can be cost-effective alternatives to conventional systems, while simultaneously providing meaningful acknowledgment of the value of these technologies.

Lessons Learned

Several other overall lessons can be noted from the history of past programs and policies. First, premature termination of many of the federal programs in building RETs in the early 1980s resulted in the loss of valuable data, the disbanding of highly productive research teams, and an abrupt halt to the momentum that had been developed. Second, although well intentioned, several of the commercialization programs did not usefully address the key market challenges discussed above; appropriate mechanisms to address these challenges remain elusive, and further experimentation is needed. Third, many of the technologies were initially oversold, promising cost and performance that could not be delivered.

An important difference now, compared with two decades ago when these efforts began, is that there is a foundation on which to build. Two decades ago, R&D was just getting under way, while commercialization of unknown technologies was being pushed at the same time. This led to many failures as well as many successes. Today, R&D and detailed field monitoring have shown what works and what does not. Commercialization efforts, therefore, have a base of proven technologies on which markets can be built, while RD&D can continue to provide new opportunities.

POLICY OPTIONS

There is already considerable experience with a variety of effective policies as well as some that are ineffective in developing and commercializing RETs for buildings. Some of this experience is discussed above, and a number of policy initiatives continue today (see box 3-l).

Current policies have been described throughout this chapter and in box 3-1. As for funding support, the total DOE fiscal year 1995 budget for solar buildings is $4.69 million up from $2 million in fiscal year 1992. This can be compared, however, to a high of $260 million (1 992 dollars) in 1978. Support will be used to develop solar water heater rating and certification procedures, improve their reliability, and demonstrate their use in utility DSM programs, and to examine a few advanced technologies, including the integration of photovoltaics into buildings—with funding of $500,000[98] in fiscal year 1995.

Almost no support is provided for high-leverage activities such as the development of design tools for passive solar buildings, and no support is provided for design competitions, which proved so successful in the late 1970s and early 1980s. Similarly, there is little or no support for RD&D in passive design, daylighting, field monitoring, or other potentially high-leverage activities discussed earlier. As a consequence, market penetration by RETs into the buildings sector is likely to continue to be slow, and numerous cost-effective opportunities for using RETs in buildings are likely to be lost.

Taking advantage of low-cost, high-leverage opportunities to greatly expand the development and use of RETs in buildings could help capture a significant portion of cost-effective applications and proportionally reduce the use of fossil fuels in

[97] U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government by Good Example?* OTA-*E-492* (Washington, DC: U.S. Government Printing Office, May 1991).

[98] This is part of the total request of $4.69 million.

buildings along with their attendant environmental impacts. Balanced against these potential benefits are, of course, some costs and risks, including increased direct federal expenditures (higher than present spending) and the risk of incurring unanticipated costs in attempting to further the use of RETs.[99] Federal expenditures would increase under this strategy but could be kept modest by targeting the highest leverage opportunities.

Policy options that might be considered as part of such a strategy are listed below. Most of these RD&D and education/information programs could be supported through DOE, with commercialization programs also supported through the Department of Housing and Urban Development and other agencies.

RD&D programs might include:

- *Collaborative research, development, demonstration, and field monitoring.* High-1 everage R&D targets for RETs in buildings could be supported at significantly higher levels in cooperation with manufacturers and builders (see table 3- 1). Collaborative field demonstrations of promising near-commercial technologies with extensive performance monitoring could also be supported. Many of the best field performance data remain those collected under the DOE Passive Solar Commercial Buildings and the Class B Residential Passive Solar Performance Monitoring Programs over a decade ago, as described earlier. Building on this previous experience could have considerable value.
- *Golden carrots.* Increased support for the development of manufactured RETs for the buildings sector should also be considered. Current funding is limited to a small solar hot water heater program and a few others.[100] Such RD&D can be conducted collaboratively between the national labs and manufacturers. It might also be done by using private sector incentives such as the "golden carrot" award won by Whirlpool for the development of the high-efficiency refrigerator. [101]
- *Commercial demonstrations for builders and users.* Demonstrations of proven RETs in buildings could be built, with federal support for the difference in cost, if any, compared with conventional buildings. In contrast to the above R&D demonstrations, these buildings would not be testing new technologies. Instead, they would provide local builders and users examples of what is possible within particular market segments. Since many of the passive solar buildings constructed to date have been for an upscale clientele, these designs might best target low- and medium-income housing. Recent examples include the award winning "Esperanza del Sol" development[102] in Dallas, Texas, featuring three-bedroom homes for $80,000 and Neuffer Construction's Homes in Nevada. [103]

Design and information programs might include:

- *Design tools.* Passive solar and other RET design tools are slowly being developed today. In-

[99] See, e.g., Linda Berry, *The Administrative Costs of Energy Conservation Programs*, ORNL/CON-294 (Oak Ridge, TN: Oak Ridge National Laboratory, November 1989).

[100] This includes some work on unglazed transpired collectors and a small effort to integrate photovoltaics into buildings.

[101] U.S. Congress, Office of Technology Assessment, *Energy Efficiency: Challenges and Opportunities for Electric Utilities*, OTA-E-561 (Washington, DC: U.S. Government Printing Office, September 1993).

[102] This development received Edison Electric Institute's first E-Seal award for environmentally superior design. With estimated overall annual energy savings of *50* percent at an additional construction cost of 0.2 percent, this design has a payback time of less than one year. See Burke Miller Thayer, "Esperanza del Sol: Sustainable, Affordable Housing," *Solar Today*, May/June 1994, pp. 21-23.

[103] Donald Aitkin and Paul Bony, "Passive Solar Production Housing and the Utilities," *Solar Today*, March/April 1993, pp. 23-26.

creased support would enable their more rapid development, and their integration into commercial CAD tools could provide a high-leverage means of encouraging the use of passive solar and daylighting strategies in commercial buildings. Similar development of design tools for the residential sector could be supported, building on work already done by the National Renewable Energy Laboratory, the Passive Solar Industries Council, Lawrence Berkeley Laboratory, and others.
- Design cornpelitions. Providing numerous but small prizes (sufficient to cover the additional cost of solar design) for the best solar designs has proven effective in the past, and could be restarted. This option complements the development of design tools and also provides a high-leverage means of encouraging the use of passive solar and daylighting designs in buildings.
- *Design assistance.* Design assistance could be provided to those who are interested in pursuing solar designs but lack sufficient technical means of doing so. This may be particularly important, for example, for small residential builders. A set of region-specific, high-performance solar designs for residences might also be developed, demonstrated (see above), and distributed as models. This strategy complements the development of design tools and the use of design competitions.
- *Education.* Support might be provided for the development of additional course materials on RETs for buildings at architecture schools and for the development of focused RET design programs such as those described above at Trinity University or Arizona State University.
- *Information programs.* Broad-based information programs might be developed to provide potential builders and users relevant information for encouraging use of RETs in buildings and for informing their decisionmaking.

Rating and standards programs might include:

- *Solar rating and certification programs.* Current solar rating and certification programs, such as those described earlier, might be expanded and strengthened to include more RETs.
- *Voluntary standards.* Support might be provided for the American Society of Heating, Refrigeration, and Air Conditioning Engineers or other professional organizations that help establish industry standards to develop guidelines and standards for best practice in solar design. This wouid give RETs in buildings higher visibility and credibility at relatively low cost.
- *Building codes and standards.* Building energy codes can help ensure that minimum energy performance standards are met; such codes have been used extensively in the United States.[104] Building codes might be further developed in support of RETs, recognizing the potential difficulties as discussed above.

Finance and commercialization programs might include:

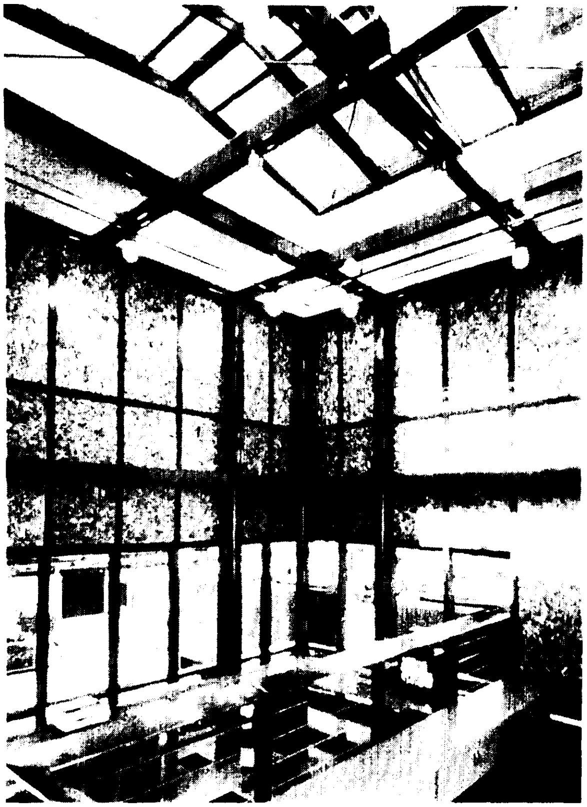
- *RET mortgages.* Energy-efficient mortgages are now under study in pilot programs (box 3-8). If the results of these efforts are positive, such programs might be expanded in their technical scope to more fully consider renewable and in their geographic scope to include a progressively larger portion of the United States.
- *Federal procurement.* All federal construction, purchase, or rental of residential, commercial, or other buildings could be based on life-cycle cost analyses (including external i ties) that consider efficiency and RET options, with mandated acquisition of the highest level of efficiency and RET technology projected to be cost-effective.
- *Utility investment,* Utility investment in RETs for buildings could be encouraged through supporting case studies to determine where, when. and to what extent RETs can provide DSM

[104] Office of Technology Assessment, op. cit., footnote 3.

benefits, including offsetting lighting, heating, and air conditioning loads. The current effort and the primary focus of the DOE Solar Buildings program is on utility DSM opportunities using solar water heaters, as described above.

Other types of policies designed to increase market competitiveness of RETs could include the following:

- Tax credits. Although tax credits were used during 1978-85 with mixed results, as described earlier, they might be combined with building energy rating systems, solar rating and certification programs, or other mechanisms to better target them toward technologies that are cost-effective over a wide range of circumstances. The design of these programs should also consider the lessons now being drawn from modern finance theory concerning the effectiveness and structure of tax credits.[105]
- *Fecbates.* Pilot projects might be considered to evaluate the potential of feebates as a means of reducing the upfront capital costs of investments in RETs in buildings.



ADVANCED PHOTOVOLTAIC SYSTEMS INC

Building-integrated PV system. The PV material in the skylight serves a multiple purpose: the skylight offsets interior artificial lighting as well as cooling to remove heat generated by artificial lights; the PV material coating the skylight generates electricity.

CROSSCUTTING ISSUES

Visions of the distributed utility (chapter 5) often project large numbers of photovoltaic (PV) cells or fuel cells in residential and commercial buildings. Integration of PVS into building structures may significantly lower PV balance-of-system costs; the use of distributed fuel cells might provide thermal benefits for space heating or hot water but would continue to use natural gas as a fuel for the near to mid-term with a transition to renewable fuels in the long term.[106] In both cases, these early markets might help ramp up production and allow further economics of scale and learning to be realized. Such economies might also cvcntually help fuel cells to penetrate transport markets.[107]

CONCLUSION

Renewable energy technologies arc available for residential and commercial buildings but are not yet widely utilized. As shown in this chapter,

[105] Hassett and Metcalf, op. cit., footnotes 67 and 90.

[106] A transition to renewable-generated hydrogen might be possible in the long term. Use of natural gas in the near to mid-term could then be part of a transition strategy to develop the distributed utility, capture cogeneration benefits, and reduce the price of fuel cells for other applications. See Joan M. Ogden and Joachim Nitsch, "Solar Hydrogen," *Renewable Energy: Sources for Fuels and Electricity*, Thomas B. Johansson et al. (eds.) (Washington, DC: Island Press, 1993).

[107] Note that the potential benefits depend on the type of fuel cell used. Chapter 4 describes a variety of potential paths for transport technologies, some of which use particular fuel cells such as the proton exchange membrane cell. The choice of technology within the buildings sector should, therefore, consider in part the potential synergisms with transport technologies.

greater utilization of these technologies could save money over the building's life cycle and reduce energy use. The indirect benefits of these technologies—particularly reduced environmental damage from fossil fuel use and reduced sensitivity to power and fuel cost increases or supply disruptions-could be considerable. There may also be a significant export market for these technologies, including spectrally selective and/or electrochromic window coatings, lighting controls, building-integrated photovoltaics, and design tools. Past experience provides a number of lessons that may be used to refine policies intended to move these technologies into the buildings sector. A number of policies may offer significant leverage to move these technologies more rapidly into the marketplace with relatively little investment.

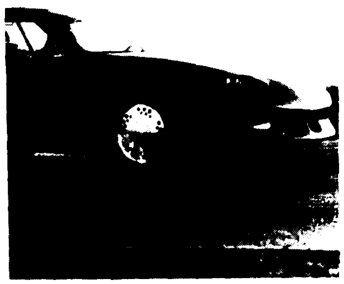
Transport 4

Renewable fuels and advanced vehicle technologies have the potential to provide a large portion of our highway transportation energy needs. These fuels and technologies could substantially reduce oil imports, urban air pollution, and the emission of greenhouse gases, while providing jobs and income to rural areas. To realize this potential, however, will require a long and dedicated research and development (R&D) effort in order to achieve cost-effective, high-performance systems.

WHAT HAS CHANGED IN TRANSPORT FUELS?

In the 1970s, the only renewable fuel considered seriously for transport in the United States was ethanol derived from corn.[1] Corn-to-ethanol production, however, is expensive. In addition, when all the energy inputs to grow com and convert it to ethanol are considered, there is—at best—a modest energy gain, with relative] y 1 ittle room for improvement compared with new technologies based on lignocellulose.

Advances in biotechnology are enabling researchers to convert cellulose to sugars that can be fermented to ethanol. These advances allow use of much cheaper feedstocks (e.g., wood, grass, and com stalks, rather than com grain) with relatively high yields. This has lowered the cost of biomass-derived ethanol[2] from



[1] In Brazil, ethanol from sugar cane was vigorously pursued.

[2] As used here, biomass-ethanol refers to ethanol produced from lignocellulose biomass feedstocks.

$4. 15/gal in 1980 to $1 .65/gal in 1993.[3] Advances in gasification and catalysis are also lowering the cost of producing methanol and hydrogen from biomass. As described in chapter 2, the production of the biomass itself has improved greatly.

Similarly, advances in energy conversion devices, particularly fuel cells, offer the prospect of high-efficiency propulsion systems that can use a variety of renewable fuels. For example, the amount of platinum catalyst necessary in the proton-exchange membrane (PEM) fuel cell has been greatly reduced. Ultimately, with other advances, this may make it possible to reduce the cost of such fuel cells with large-scale mass production to a level competitive on a vehicle life-cycle basis with internal combustion engines (ICES).

In addition, reductions in the cost and improvements in the performance of power electronics and electric motors are allowing the development of all-electric drivetrains as a substitute for today's mechanical gearbox and drivetrain. This may allow substantial increases in efficiency-both directly and indirectly through the use of regenerative braking (recovering the braking energy). Numerous other advances have occurred across many aspects of transport fuels and motive power technologies.

| Potential Roles

The U.S. transportation system plays a central role in the economy.[4] Highway transportation, however, is dependent on internal combustion engine vehicles fueled almost exclusively by petroleum. This has given rise to a number of energy supply and environmental concerns. Despite substantial improvements in U.S. transportation energy efficiency in recent decades,[5] the United States still consumes more than one-third of the world's transport energy.[6] Transportation accounts for about one-quarter of total U.S. primary energy use and nearly two-thirds of oil use. About one-half of this oil is imported, costing the United States about $45 billion per year. Domestic oil production has declined since 1970 and is expected to continue declining while demand is expected to increase. With current policies, U.S. imports of oil are likely to increase dramatically over the next several decades (see chapter 1).

The U.S. dependence on oil not only makes the economy vulnerable to the supply and price vola-

[3] 1992 $/gal. S.R. Venkateswaran, Energetics, Inc., and John Brogan, U.S. Department of Energy, personal communication, May 12, 1994. This includes approximately 35¢/gal for transport and delivery to the end user. Production costs above are approximately $3.80/gal and $ 1.30/gal, respectively. This does not include road transport fuel taxes.

[4] The availability of reliable and efficient transportation systems has historically been an important determinant of economic growth. During the past 20 years, the demand for transportation goods and services in the United States has generally matched overall economic expansion and currently accounts for about one-sixth of the gross domestic product. See S.C. Davis and S.G. String, *Transportation Energy Data Book: Edition 12*, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, 1992), table 2-19.

[5] Aggregate travel energy intensity (energy use per passenger-mile) in the United States has declined about 15 percent since 1973. This drop was principally due to the introduction of automobile fuel economy standards and higher oil prices. See L. Schipper, "Energy Efficiency and Human Activity: Lessons from the Past, Importance for the Future," paper presented at the Annual World Bank Conference on Development Economics, Washington, DC, May 3-4, 1993.

[6] 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), p. 150.

tility of the world oil market, but also exacerbates local and global environmental problems. Motor vehicles currently account for 30 to 65 percent of all urban air pollution in the United States and up to 30 percent of carbon dioxide (CO_2) emissions.[7] Urban air pollution problems have motivated the development of a substantial body of federal and state regulations. Although urban air emissions from highway vehicles are expected to drop significantly[8] in this decade through improvements in engines, fuel systems, exhaust controls, and fuel characteristics, after the year 2000, carbon monoxide (CO) emissions are projected to begin growing due to increases in the number of vehicles on the road and total vehicle-miles traveled.[9]

In addressing the environmental and energy supply problems posed by our current transportation system, a number of approaches are possible. Creating incentives for reducing vehicle-miles traveled and promoting greater reliance on mass transit have been central components of recent federal legislation.[10] For the foreseeable future, however, the strong preference of American citizens for personal transport is unlikely to change. Thus, strategies that revolve around fuels produced from domestic resources, whose production and use involve minimal emissions of greenhouse gases (mainly CO_2) and criteria air pollutants (CO, sulfur oxides, nitrogen oxides, hydrocarbons, and particulates), are likely to become increasingly important. Renewable energy resources and technologies could help meet these objectives over the long term and could make unnecessary much of the regulatory overhead now in place for conventional fossil fuels and engine systems emissions. Indeed, efficiency improvements may not be sufficient to achieve long-run, deep cuts in CO_2 emissions unless there is a switch to renewable transport fuels.

Ethanol and methanol derived from biomass; diesel oil substitutes derived from oil-producing plants; electricity generated from renewables (chapter 5); and possibly, in the much longer term, hydrogen produced directly from biomass or electrolyzed from water by renewable-generated electricity are the principal renewable energy-based fuels that might substitute for today's petroleum-based liquids. If transportation fuels were derived from renewable sources such as solar, wind, or biomass energy, emissions of CO_2 would be largely eliminated (see table 4-1). Renewable fuels could also be used in zero- or near-zero-emission vehicles.[11]

[7]About 45 to 50 urban areas still violate the ozone quality standard, with emissions from highway vehicles—primarily automobiles and light trucks—contributing 40 to 50 percent of the volatile organic compounds (VOCs) and one-third of the nitrogen oxides that are the precursors of ozone. Evaporative emissions—as opposed to tailpipe emissions—may be responsible for more than 50 percent of automobile hydrocarbon emissions. Motor vehicles are estimated to be responsible for about 65 percent of carbon monoxide (CO) emissions. U.S. Environmental Protection Agency, *National Air Pollutant Emission Trends*, 1990-1992, No. EPA-454/R-93-03 (Washington, DC: October 1993); National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution* (Washington, DC: National Academy Press, 1992); and J.G. Calvert et al., "Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions," *Science*, vol. 261, July 2, 1993, pp. 37-45.

[8]By the year 2000, compliance with the Clean Air Act Amendments of 1990 is expected to reduce CO emissions by 27 percent, nitrogen oxides by 19 percent, and volatile organic chemicals by 30 percent. See U.S. Environmental Protection Agency, op. cit., footnote 7.

[9]See U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

[10]The Clean Air Act Amendments of 1990 require the use of "transportation demand management"—especially during peak travel times—as a tool in reducing urban air pollution. The Intermodal Surface Transportation Efficiency Act of 1991 allows states to shift highway funds to transit, promotes new high-speed ground transportation systems, and generally establishes energy efficiency as a major goal of new transportation investment.

[11]Some alternative fuels such as methanol and hydrogen can be derived from both renewable (biomass) and nonrenewable sources (natural gas or coal). Although fuel-cycle emissions of CO_2 can be dramatically lowered by using renewable energy sources, vehicle tailpipe emissions of criteria air pollutants will be essentially the same for both renewable and nonrenewable derived fuels.

TABLE 4-1: Projected CO_2-Equivalent Emissions of Greenhouse Gases, Circa 2000[a]

Feedstock/fuel	Fuel-cycle CO_2-equivalent emissions (grams/km)[b]	Change in CO_2-equivalent emissions (percent)
internal combustion engine vehicles (ICEVs)		
Baseline Petroleum/reformulated gasoline[c]	290	0
Coal/methanol	460	~ 58
Coal/compressed H_2	440	+52
Corn/ethanol (E85)[d]	210 to 320	-27 to ~ 11
Corn/dedicated ethanol (EI 00)	210 to 320	-27 to +11
Natural gas/dedicated methanol (MI 00)	270	-6
Natural gas/compressed H_2[e]	220	-25
Natural gas/dedicated CNG[f]	220	-26
Biomass/compressed H_2[g]	70	-75
Solar/compressed H_2[h]	50	-82
Biomass/methanol	50	-83
Biomass/ethanol (E85)	35	-88
Biomass/dedicated ethanol (EIOO)[i]	0 to 30	-90 to 100

[a]The estimates shown here are meant to illustrate the potential reductions in greenhouse gas emissions that are possible with a shift to renewable fuels; there is considerable uncertainty in some of the values listed.

[b]This is the sum of emissions of CO_2, CH_4, N_2O, CO, NO_2, and NMOCs from the entire fuel production and use cycle (excluding the manufacture of vehicles and equipment), per kilometer of travel, relative to the total g/km emissions for a year-2000 light-duty vehicle running on reformulated gasoline. All vehicles specified have the same total energy consumption. Emissions of gases other than CO_2 have been converted to an "equivalent" amount of CO_2 by multiplying mass emissions of each gas by the following "global warming potentials": CH_4, 21; N_2O, 270; CO, 2; NO_2, 4; NMOCs, 5. The resultant CO_2 equivalents of these gases have been added to actual CO_2 emissions, to produce an aggregate measure of greenhouse gas emissions. The results shown are from unpublished runs of an updated version of the greenhouse gas emissions model documented in M.S. DeLuchi, *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,* Report No. ANL/ESD/TM-2 (Argonne, IL: Argonne National Laboratory, Center for Transportation Research, November 1991).

[c]Projected greenhouse gas emissions for a year-2000 light-duty vehicle (26 mpg) operating on reformulated gasoline.

[d]Assumes use of 85-percent ethanol mixed with 15-percent gasoline in a "flexible-fuel" vehicle that can burn any mixture of alcohol and gasoline. It also assumes that the E85 flexible-fuel vehicle is 5 percent more efficient than the comparable dedicated gasoline/ICEV. The dedicated ethanol/ICEV (E100) is assumed to be 12 percent more efficient than the gasoline/ICEV because it can be optimized to run on ethanol, whereas the flexible-fuel vehicle cannot.

[e]Hydrogen is made at the refueling site from natural gas delivered by pipeline and then compressed to 8,400 psi for delivery to vehicles. The compressor uses electricity generated from the projected national mix of power sources in the United States in the year 2000.

[f]Natural gas is compressed to 3,000 psi for delivery to vehicles with high-pressure tanks.

[g]Hydrogen is made in centralized biomass gasification plants, then compressed for pipeline transport using electricity generated at the biomass plant. At the station, hydrogen is compressed to 8,400 psi for delivery to vehicles by a compressor using the projected year-2000 U.S. mix of power sources.

[h]Hydrogen is produced from water using solar power, delivered by pipeline to the service station, and then compressed to 8,400 psi for delivery to high-pressure tanks onboard vehicles. The hydrogen compressor at the refueling station runs off electricity generated from the projected national mix of power sources in the United States in the year 2000.

[i]Assumes advanced biomass-to-ethanol conversion technology and electricity cogeneration from corn residue.

TABLE 4-1 (cont'd): Projected CO_2-Equivalent Emissions of Greenhouse Gases, Circa 2000[a]

Feedstock/fuel	Fuel-cycle CO_2-equivalent emissions (grams/km)[b]	Change in CO_2-equivalent emissions (percent)
Battery-powered electric vehicles (BPEVs)		
Average U.S. power generating mix[j]	250	-14
Solar power[k]	0	-90 to 100
Fuel cell electric vehicles (FCEVs)		
Coal/methanol	210	-27
Coal/compressed H_2	180	-37
Natural gas/methanol	120	-58
Natural gas/compressed H_2	90	-69
Biomass/compressed H_2	30	-90
Solar/compressed H_2	20	-93
Biomass/methanol	17	-94
All solar/compressed H_2[l]	0	-90 to 100

[j] BPEVs are recharged at night using the extra electricity generated specifically to meet the BPEV demand.

[k] This BPEV is recharged from 100 percent solar power.

[l] The hydrogen compressor at the station runs on solar power.

KEY: CNG = compressed natural gas; CH_4 = methane; H_2 = hydrogen; mpg = miles per gallon; NMOC = nonmethane organic compounds; N_2O = nitrous oxide; NO_2 = nitric oxide; psi = pounds per square inch.

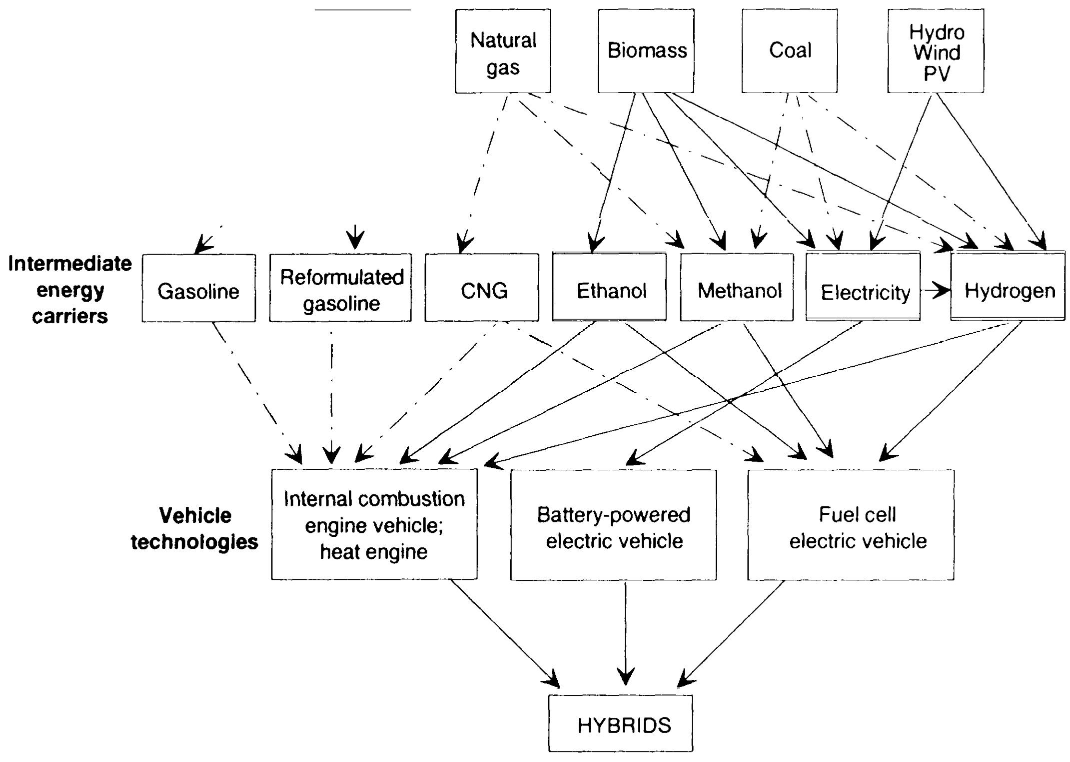
SOURCE: The estimates presented here are drawn from Joan M. Odgen et al., "A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies," report prepared for the Office of Technology Assessment, May 1994.

Biomass-derived fuels such as ethanol, methanol, or hydrogen could satisfy a significant portion of transportation energy needs if used in conjunction with high-efficiency vehicle technologies such as hybrid electric vehicles or fuel cell-powered vehicles. Some estimates for potential bioenergy production range up to perhaps 25 EJ (24 quads) by 2030.[12] Current transportation energy requirements are about 24 EJ (23 quads) annually and are projected to increaseto31 EJ (30 quads) by 2010.[13] Thus, unless coupled with very aggressive efforts to improve vehicle fuel efficiency, biomass-derived fuels will probably not be sufficient to completely displace imported oil used for transportation. Wind and especially solar resources are potentially much larger than biomass. Although wind- or solar-derived hydrogen and electricity would not be resource constrained, their higher costs will still justify attention to raising vehicle efficiency. Whether or not the potential of renewable resources can be realized, however, remains uncertain and depends on their cost and performance compared with other fuels and technologies. The larger context of transport infrastructure development and accounting for the

[12] See chapter 2. This does not include conversion losses for biomass to liquid or gaseous fuels.

[13] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook, 1994*, DOE/EIA-0383(94) (Washington, DC' January 1994).

FIGURE 4-1: Alternatives for Production and Use of Transportation Fuels



NOTE Renewable energy pathways are shown as solid lines

SOURCE Robert Williams and Henry Kelly, "Fuel Cells and the Future of the U S Automobile," n d

social costs of fossil fuel use and transport are also very important.[14]

| Principal Themes

In this chapter, a variety of alternative technology pathways are outlined that would utilize renewable fuels and advanced propulsion systems. Their relative economic, environmental, and technological performance is analyzed vis-a-vis conventional fossil-fueled systems; key research, development, and demonstration (RD&D) and commercilization issues that may impede market introduction are examined; and various policy measures that could bring these renewable technology pathways to fruition are explored.

RENEWABLE ENERGY PATHS FOR TRANSPORT

There are many possible options for automotive transportation. Some major options now under consideration are illustrated in figure 4-1, where various combinations of primary energy sources, intermediate energy carriers, and vehicle technologies are shown. Each fuel-propulsion system

[14]For a detailed discussion of the social costs of transportation, see U.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC: U.S. Government Printing Office, July 1994).

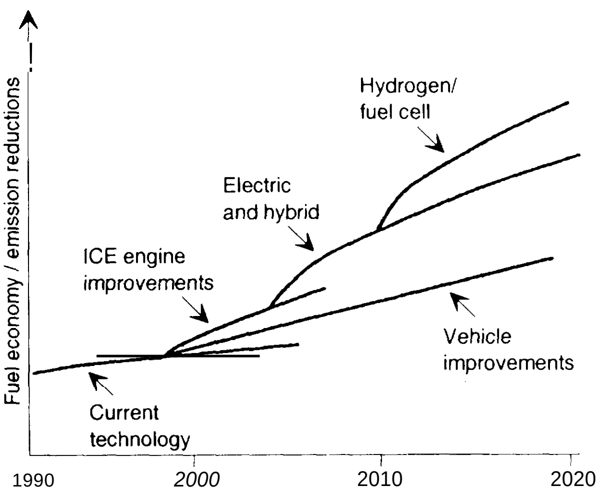
combination offers a different set of energy requirements, emission levels, and performance characteristics, as well as a different set of R&D challenges and commercial hurdles. Some technologies are relatively mature, whereas others are only now being explored. There is great uncertainty as to which of these fuel and vehicle technologies will prove most desirable; the many possible options, however, increases the likelihood that one or more will be successful.

The development and maturation of one technology can in some cases pave the way for more efficient solutions later on. For example, the use of methanol or ethanol in internal combustion engine vehicles (I CEVS) could lead to the creation of a bioenergy crop infrastructure that might later be shifted to bi s), Similarly, the creation of a natural gas distribution network for ICEVs—if properly designed and appropriate materials were used—might ultimately lay the groundwork for a hydrogen fuel infrastructure that could be used in advanced propulsion systems.[15] Thus, different fuel and vehicle technology alternatives are not necessarily mutually exclusive options but in some circumstances can serve as complementary strategies over the long term.

A variety of evolutionary paths can be outlined that lead from current technologies toward the use of renewable fuels in low-emission vehicles. One possible scenario is depicted in figure 4-2. Over the course of the next decade, for example, ICEVs operating on compressed natural gas (CNG), methanol made from natural gas, or ethanol made from corn might be introduced on a wide scale.[16] The use of natural gas or alcohols in conventional vehicles offers a relatively low-risk strategy for reducing petroleum dependence in the short term.

Depending on the particular fuel and vehicle technology, reductions in emissions of criteria pollutants could be modest (ethanol and metha-

FIGURE 4-2: Transportation Technology Pathway



NOTE: The evolution toward low-emission, high-efficiency vehicle systems could take many different directions. Pure electric vehicles or hybrid electric vehicles could emerge as important technologies. Hybrid propulsion systems combine two power sources, potential power sources include batteries, flywheels, internal combustion engines, gas turbines, fuel cells, and diesel engines. All vehicle technologies will benefit from the introduction of light-weight materials, reductions in drag and rolling resistance, and improvements in mechanical or electric drive losses. Both conventional and emerging vehicle technologies can take advantage of energy carriers such as methanol, ethanol, hydrogen, and electricity that can be derived from renewable sources.

SOURCE U S Department of Energy Off Ice of Transportation Technologies

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[15] Hydrogen can be produced by steam reforming of natural gas. If a network of natural gas service stations were developed, a decentralized hydrogen infrastructure might be created fairly quickly. Since stationary fuel cell applications are likel y to be commercially available well before transportation applications, it may be possible to tap into natural gas steam reformers at these stationary sites for refueling of hydrogen ICEVs or FCVs. Paul Miller, W. Alton Jones Foundation, personal communication, Apr. 19, 1994.

[16] Hydrogen (from natural gas or biomass) and ethanol (from cellulosic biomass) are unlikely to be widely available in the next 10 years. Hydrogen faces infrastructure limitations, and ethanol derived from cellulose is still in the development and early pilot production phase. Com-based ethanol is already in use but is unlikely to be more than a transition fuel since other sources are more promising economically.

no]) to significant (CNG) to dramatic (hydrogcn).[17] Reductions in CO_2 would similarly vary widely depending on the fuel and vehicle technology. over the long term. more substantial reductions in greenhouse gas emissions could be accomplished through the production of methanol, ethanol, or hydrogen fuels from renewable energy sources such as cellulosic biomass (see table 4-l).

If petroleum use is to be reduced significantly, propulsion systems with relatively high efficiencies arc necessary. Such efficiency requirements might be met in the mid-term by hybrid vehicles that, for example. combine a small ICE with a battery and an electric motor(s) driving the wheels. Hybrid systems may be able to provide many of the energy efficiency and emissions bencilts of pure battery-powered electric vehicles (BPEVs), while offering greater flexibility with respect to range and performance. An ICE-based hybrid could run on a variety of fuels such as hydrogen, ethanol, methanol. or reformulated gasoline. Research on hybrid systems could also speed the development of electric drivetrain technologies and advancd power control systems. Much RD&D remains, however, to determine hybrid vehicle cost and performance.

When cost-competitive, the ICE portion of the hybrid could be replaced with a fuel cell, gas turbine, or advanced diesel engine. The ICE hybrid could thus allow a significant decoupling of the various components of the vehicle system, permitting development of the fuel infrastructure that powers the ICE to be largely separated from development of the electric drivetrain. This could facil i-tate the introduction of fuel cell electric vehicles over the long term (e.g., a methanol or hydrogen infrastructure could be developed first for ICE hybrids and then used to supply energy for fuel cell-bascd hybrids).

The introduction of fuel cell vehicles operating on methanol or hydrogen from natural gas would substantially reduce both criteria pollutant and CO_2 emissions (because of the higher efficiency of FCVS).[9] Fuel cell vehicles running on hydrogen produced from biomass or renewably generated electricity, or alcohol (methanol or ethanol) produced from biomass, are potentially the cleanest and highest performance systems. A decade or more of intensive RD&D remains to bc done, however, before their technological and economic feasibility can be fully determined.

Many key fuel cell technologies arc still in the developmental phase. Although some advances have been made in the area of PEM fuel ccl] performance, much progress is required before a complete fuel cell system can be commercially packaged for an automobile. The reliability y of the essential components of a fuel cell system has not yet been demonstrated in an automotive environment or over a typical automotive duty cycle. Although fuel ccl] costs will likely drop as economics of scale are achieved in manufactur-

I 7Although alternative fuels such as methanol, ethanol, and natural gas are "inherently" less ozone-forming and less carcinogenic than gasol inc. new regulatory requirements for gasoline could very likely diminish the environmental advantage of alternat i ve fuels. See D. E. ~JU-Ace. "Alternative Fuels for Automobile\: Are They Cleaner Than Gasoline'?" Congressional Research Service Repro 92-235 S, Feb. 27, 1992; also see Alan J. Krupnick et al., Resources for the Future, "The Cost-Effectiveness and Energy Security Benefits of Methanol Vehicles." Discussi ion Paper QE90- 25, September 1990; and J. Odgen et al., "A Technical and Economic Assessment of Renewable Transportation Fuel\ and Technologies\, " report prepared for the Office of Technology Assessment, May 1994.

18The ICE would be used t. generate electricity (o power an electric motor drivetrain, and the battery would provide "peak power" to meet acceleration or hill-climbing demands. Unlike conventional ICEVs, in which the powerplant (the engine) drives the wheels directly, a hybrid or pure electric vehicle uses the powerplant (e.g., heat engine. fuel cell, or batter]) to drive electric motors that drive the wheels.

19Fuel cells are electrochemical devices that convert the chemical energy in a fuel (hydrogen is preferred) and oxidant (usually oxygen in ai r) directly Into electrical energy. Unlike batteries, the reactants are supplied continuously from an external source (e. g., a hydrogen storage tank plus air). The main exhaust product of a fuel cell is water. Over a typical urban driving cycle, fuel cell -propelled vehicles could potentially have two to three times the efficiency of ICEVs.

ing, the reductions necessary to make FCVs competitive with other vehicle options will require intensive engineering and manufacturing development in coming years.[20]

BPEVs have the potential to directly displace significant amounts of imported oil because just 4 percent of U.S. electricity is generated from oil, and most of this is for peaking power, yet virtually every trip they make would otherwise have been made by a gasoline or diesel-fueled vehicle. BPEVs could offer significant energy efficiency and environmental benefits. BPEV tailpipe emissions would be zero, while the magnitude of CO_2 and other emissions would depend on the marginal electric power generation mix of a particular region.[21] Emissions would be lower for advanced natural gas powerplants than for coal, due to their higher efficiency and the inherent cleanliness and high-energy content of natural gas. Further reductions in greenhouse gas emissions could be achieved through greater use of renewable energy sources or nuclear power by electric utilities.

At present, however, no existing battery technology would allow a pure BPEV to be fully competitive with a conventional ICEV.[22] In the near term, BPEVs are most likely to be used as secondary vehicles for commuting and short trips. In addition to vehicle performance (determined primarily by battery technology), the upfront vehicle costs and the life-cycle operating costs of BPEVs will determine the viability of this technology option. The economic, technical, and environmental characteristics of the more plausible fuel-vehicle combinations arc examined in detail in the followin: sections.

A RENEWABLE FUEL MENU[23]

A variety of transportation fuels can be produced from renewable resources. The discussion here focuses on the four most promising energy ariers that could be used in conjunction with low'-cmission vehicles: methanol, ethanol, hydrogn (H_2). and electricity. Many of the comercilizaeion issues affecting alternative transport fuels have been addressed previously in the Office of Technology Assessment (OTA) report *Replacinq Gasoline .- Alternative fue1 for Light-Duty Vehicles* particularl the difficulties inherent in dcveloping a new fuel distribution infrastructure.[24] The principal technical and economic challenges facing renewable fuels are dcscribed below.

Methanol

Methanol is a liquid fuel that can be produced from natural gas, coal. or biomass. Onc major advantage of methanol is that it would requirc fewer changes in vehicle design than some other alternative fuels, Flexible-fuel vehicles. which can operate on methanol, ethanol, gasoline, or a mixture of these fuels, arc already being produced in limitcd numbers in the United States.[25] The use of such vehicles could case the transition from gasoline. Although methanol is frequently discussed as a re-

[20] A recent study by Allison-GM estimates that the initial purchase costs of a mass-produced FCV could be comparable to a conventional ICEV. Life-cycle operating costs may also be comparable. See Allison Gas Turbine Division, "Research and Development of Proton- Exchange Membrane (PEN!) Fuel Cell S? stem for Transportation Applications: Initial Conceptual Design Report," EDR 16194. report prepared for the U. S. Department of Energy, Office of Transportation Technologies, Nov. 30, 1993.

[21] The "marginal mix" is a measure of the power generation that must come online due to BPEV charging and is above and beyond the non- BPEV electricity demand.

[22] No existing battery technology possesses the necessary energy density (for range), power density (for acceleration performance), longevity, low cost, or quick recharge characteristics that would allow BPEVs to be comparable to conventional ICEVs.

[23] The discussion in this section draws heavily from Odgen et al., op. cit., footnote 17.

[24] U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

[25] Ibid., p. 25.

BOX 4-1: Methanol Production from Biomass

Three basic thermochemical (high-temperature) processes are Involved in methanol production from biomass, The first step IS production of a "synthesis gas" via thermochemical gasifcation of biomass, using oxygen rather than air in order to eliminate dilution of the product gas with nitrogen (in air). Since oxygen plants have strong capital cost scale economies, most proposals for biomass-to-methanol facilities have Involved large plants (typically 1,500 metric tonnes/day input of dry biomass), Biomass gasiflers designed for methanol production are not available commercially. A number of pilot- and demonstration-scale units were built and operated in the late 1970s and early 1980s, but most of these efforts were halted when 011 prices fell, [1] Work on a fluidized-bed design has been revived, with the construction of a bagasse-fueled demonstration and now being planned.[2] More recently, indirectly heated gasifiers have been proposed,[3] These would produce a nitrogen-free gas without using oxygen and thus might be built economically at a smaller scale.

Second, the synthesis gas IS cleaned and its chemical composition is adjusted The specific equipment will vary depending on the gasifier used. Common to all systems is a "shift" reactor, which IS a commercially established technology, Other processing maybe required before the shift stage, however. For example, tars contained in the synthesis gas must be removed or cracked into simpler forms that WiII not deposit on and/or damage the turbine.

Third, the gas IS compressed and passed through a pressurized catalytic reactor that converts carbon monoxide and hydrogen into methanol. A variety of commercial processes can be used.

This thermochemical process is Inherently more tolerant of diversity in feedstocks than biological processes (e g., enzymatic hydrolysis used in ethanol production),

[1] A A C M Beenackers and W P M van Swaaij, "The Biomass to Synthesis Gas Pilot Plant Programme of the CEC A First Evaluation of Results, " *Energy from Biomass, Third European Community Conference* (Essex, England Elsevier Applied Science, 1985), pp 120-45, and E D Larson et al , "Biomass Gasification for Gas Turbine Power Generation, " *Electricity Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden Lund University Press, 1989), pp 697-739

[2] R J Evans at al , Battelle Pacific Northwest Laboratory, "Development of Biomass Gasification To Produce Substitute Fuels, " PNL-6518, 1988

[3] C E Wyman et al , "Ethanol and Methanol from Cellulosic Biomass, " *Renewable Energy Sources for Fuels and Electricity,* T B Johansson et al (eds) (Washington, DC Island Press, 1993), and E D Larson et al , Center for Energy and Environmental Studies, Princeton University, "ProductIon of Methanol and Hydrogen for Vehicles from Biomass, with Comparisons to Methanol and Hydrogen Product Ion from Natural Gas and Coal, " forthcoming

placement for gasoline, it can also be used to replace diesel.

Methanol is currently produced primarily from natural gas, but it can also be produced from coal and, through a similar process, from lignocellulosic biomass feedstocks.[26] Biomass-to-methanol plants can convert 50 to 60 percent of the energy content of the input biomass into methanol, and some designs have been proposed with conversion efficiencies of more than 70 percent. Box 4-1 describes the basic processes.

Two possibilities are interesting, both involving feedstocks that are produced today. One option is the use of residues produced by the forest products industry, which today is the largest organized user of biomass energy in the United States.

[26] C.E. Wyman et al., "Ethanol and Methanol from Cellulosic Biomass," *Renewable Energy: Sources for Fuels and Electricity,* T.B. Johansson et al. (eds.) (Washington, DC: Island Press, 1993).

TABLE 4-2: Estimated Baseline Retail Fuel Prices (1991 dollars), Post-2000

Transport fuel	Feedstock/electricity source	Feedstock/electricity cost	Delivered cost to consumer ($/GJ)[a]
Methanol	Biomass	$2.50/GJ	$13-15[b]
Methanol	Natural gas	$3/GJ	11-13
Methanol	Coal	$1.75/GJ	13
Ethanol	Biomass	$2.50/GJ	10-15
Ethanol	Corn	$1/bushel	14-19
Hydrogen	Biomass	$2.50/GJ	14-16
Hydrogen	Photovoltaic	6-15 ¢/kWh	25-60
Hydrogen	Wind	5-8 ¢/kWh	30-40
Hydrogen	Natural gas	$3/GJ	11
Hydrogen	Coal	$1.75/GJ	14
Hydrogen	Nuclear	5-8 ¢/kWh	26-33
CNG	Natural gas	$3/GJ	7-8
Reformulated gasoline	Crude oil	$26/barrel[c]	9
Utility residential electricity rates for recharging battery-powered electric vehicles[d]			
Offpeak power			4-6 ¢/kWh
Conventional utility			6-8 ¢/kWh
Renewable-intensive utility			4-10 ¢/kWh

[a] 1 gigajoule (GJ) = 10^9 Joules = 0.95 million BTUs = 278 kilowatt-hours; 1 gallon of gasoline = 0.13 GJ; 1 gallon of methanol = 0.065 GJ; 1 gallon of ethanol = 0.087 GJ; $1/gallon of gasoline = $7.67/GJ.

[b] Methanol, ethanol, and hydrogen fuels can be burned in ICEs with higher compression ratios and thus can operate more efficiently than gasoline engines. This should be taken into consideration when comparing alternate fuels with gasoline.

[c] Based on Department of Energy projections for fossil energy prices (post-2000) in 1991 dollars. See U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 1994*, DOE-EIA-0383(94) (Washington, DC: U.S. Government Printing Office, January 1994).

[d] Although the cost of electricity (4 to 6 ¢/kWh or $11 to $17/GJ) is relatively high compared to gasoline ($9/GJ), the actual operating electricity costs for BPEVs are likely to be substantially lower than for gasoline vehicles, due principally to the efficiency advantage of electric vehicles.

SOURCES: The estimates presented here are drawn principally from Joan M. Ogden et al., "A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies," report prepared for the Office of Technology Assessment, May 1994; and U.S. Department of Energy, Biofuels Program, 1994.

Forest residues associated with annual wood harvests for the industry contain some 1.3 EJ.[27] A second feedstock stream is municipal solid waste (MSW). This source, amounting to about 1.8 EJ per year (after recycling), is especially attractive because of its negative cost (e.g., it costs money to dispose of it). The gasification technology needed for MS W is essential y the same as that required for biomass.

Since biomass-to-methanol plants are not yet commercially available, costs are uncertain (table 4-2 gives one estimate of baseline alternative fuel production costs for the post-2000 timeframe). From scattered cost data, it is estimated that methanol from biomass could be produced for about $14/GJ, equivalent to $1 .85/gal gasoline, with commercially ready technology in a plant with a capacity of about 10 million GJ/yr (about 500 mil-

[27] Anthony F. Turhollow and Steve M. Cohen, Oak Ridge National Laboratory, "Data and Sources: Biomass Supply," draft report, Jan. 28, 1994.

lion liters/year or 130 million gal/year). Methanol derived from natural gas costs about $1l/GJ ($1 .45/gal gasoline), while production of methanol from coal costs about $ 13/GJ ($1.70/gal gasoline). Compared with reformulated gasoline (even at $26/barrel for crude oil), methanol—regardless of the primary energy source—is marginally competitive at best. As discussed below, however, methanol can potentially be used at much higher efficiency than gasoline, e.g., in FCVs, offsetting its higher cost.

Capital represents the largest fraction of the total cost of methanol produced in small plants, whereas feedstock is the dominant cost in large plants. Thus, capital cost reductions will be most important in reducing methanol costs from small plants, while increases in biomass conversion efficiency will be most important on a large scale. As a liquid fuel, methanol would carry distribution and retailing costs that are approximately the same per unit volume as gasoline. The volumetric energy density of methanol is roughly half that of gasoline, however, resulting in a reduced range for methanol-fueled vehicles (for a given storage tank volume and engine type) and higher distribution and retailing costs on an energy-equivalent basis.

The use of pure methanol could reduce air pollution, particularly urban smog. As with other alternative fuels, methanol has a number of attributes that appear superior to gasoline.28 In particular, methanol:

- *has lower volatility than gasoline, which should reduce evaporative emissions.*
- *has a lower photochemieal reactivity than gasoline.* As a consequence, emissions of unburned methanol, the primary constituent of methanol vehicle exhaust and fuel evaporative emissions, have less ozone-forming potential than an equal weight of organic emissions from gasoline-fueled vehicles.
- *has higher octane and wider flammability **lim** - its than gasoline.* This allows a methanol engine to be operated at higher (leaner) air-to-fuel ratios than similar gasoline engines, promoting higher fuel efficiency and lower CO and organic emissions.

In addition, if produced from biomass feedstocks grown on a renewable basis, methanol would provide a substantial $C0_2$ benefit over gasoline. However, any benefits are highly dependent on the feedstock. Methanol from coal, for example, would result in higher CO_2 gas emissions.[29] Methanol does have some environmental disadvantages, particularly greater emissions of formaldehyde, which could require special emission controls. The liquid fuel itself is toxic,[30] moderately corrosive, and highly flammable; thus, some modifications to the existing fuel distribution system are expected to be required.

It should also be noted that, under pressure from both state and federal regulation, gasoline is being improved to reduce its emissions and new emissions control technologies are nearing commercialization. These developments could effectively eliminate the exhaust emission advantages of alternative fuels such as methanol and ethanol. On the other hand, new formulations of gasoline must contain oxygenates such as ethanol or derivatives of either methanol (e.g., methyl tertiary-butyl ether, MTBE) or ethanol (e.g., ethyl tertiary -butyl ether, ETBE). The addition of oxygenates to gasoline can reduce CO formation but appears to offer little benefit in terms of reducing atmospheric ozone levels.

28As an additive to gasoline, however, methanol provides little or no air quality advantages except for the reduction of carbon monoxide. There are significant evaporative emissions that can affect ozone formation when alcohol fuels are blended with gasol inc. See Calvert et al., op. cit., footnote 7.

29Office of Technology Assessment, op. cit., footnote 24, p. 71.

30Methanol, however, lacks the toxics (e.g., benzene) found in gasoline and thus can reduce levels of carcinogenic emissions.

In the longer term, a potentially important advantage of methanol fuels is their possible use in fuel cell vehicles (see below). Since methanol can be derived from a variety of different sources and can be used in both conventional and advanced propulsion systems, it could play an important role in moving away from a fossil fuel-based transportation system.

Ethanol

Ethanol, like methanol, is a liquid fuel that can be used in internal combustion engines. It can be produced from biomass—about one-third of Brazil automobile fleet, for example, runs on straight ethanol produced from sugars The vehicle-related technical issues for ethanol are essentially the same as for methanol-it requires only minor modifications for use in gasoline engines, but more involved changes are required for use in diesel engines.

Generally, emissions from ethanol vehicles are expected to be similar to those from methanol vehicles, except that acetaldehyde, rather than formaldehyde, will be elevated. Ethanol, like methanol, is inherently less ozone-forming and less carcinogenic than gasoline.[32]

As previously noted, new controls on gasoline are likely to reduce or even eliminate the exhaust emission advantages of ethanol and methanol. Ethanol can be used either as an additive to gasoline or directly. As an additive, its primary environmental benefit is a reduction of CO. However, gasoline-ethanol blends that contain low percentages of ethanol (e.g., 10 percent) increase the volatility of gasoline, thus increasing the mass evaporative emissions that can react with sunlight to form ozone. By using ETBE, an ethanol derivative, instead of ethanol itself, the volatility problem can be avoided.[33] This is also true when 100-percent ethanol (E1OO) is used. E85 (85 percent ethanol, 15 percent gasoline) has evaporative emissions comparable to gasoline.

The emissions of CO_2 from the full fuel cycle for ethanol vehicles vary greatly depending on the feedstock from which ethanol is produced. With corn, the emissions have been estimated to range from modestly lower to slightly higher than those of gasoline, due to the need for fossil fuel use in the production of the corn and ethanol.[34] On the other hand, if ethanol is made from cellulosic biomass, CO_2 emissions could be reduced dramatically (table 4-1).

The overall energy balance for corn-based ethanol is only modestly positive, at best. If the byproducts of ethanol production (e.g.. CO_2 and distilled grains for cattle feed) and the energy inputs required to grow corn (e.g., fertilizers, herbicides, and machinery fuel) are incorporated into an overall energy balance, the net energy gain of corn-based ethanol is estimated to range from -2 to +34 percent (i.e., there can be a fuel-cycle-wide net energy loss of 2 percent or a net energy gain up to 34 percent) compared with fossil[35] energy inputs.[36] This energy balance does not take account

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[31] World Bank, "Alcohol Fuel\ from Sugar In Brazil," *The Urban Edge,* October 1990, p. 5.

[32] Ethanol is however, somewhat more photochemically reactive than methanol and thus can give rise to slightly higher concentrations of ozone than methanol. Gushee, op. cit., footnote 17.

[33] ETBE has a lower vapor pressure *than* MTBE, but because ethanol costs more than methanol as a feedstock, MTBE had been the ether of choice. How ever, on June 30, 1994. the Environmental Protection Agency promulgated a rule that, beginning in 1995, 15 percent of gasoline oxygenates must come from "renewable" sources, which in practice means ethanol or ETBE. In 1996, the renewable-based oxygenates would increase to 30 percent. This rule was overturned by a U.S. Court of Appeals on April 28, 1995.

[34] Some estimates show that Corn-derived ethanol can slightly reduce overall CO_2 emissions. Further research IS needed to clarify this issue.

[35] There may be some nuclear- and hydro-generated electricity inpUtS as well.

[36] John Bailey, Institute for Local Self Reliance, personal communication, June 1, 1994.

NATIONAL RENEWABLE ENERGY LABORATORY

At the National Renewable Energy Laboratory, a pilot-scale production plant converts cellulose to ethanol. **Left:** *Biomass feedstock is washed and pretreated before conversion.* **Right:** *Four 9,000-liter fermentation tanks allow scale-up of promising conversion processes*

of the corn stover (field residue).[37] The stover contains more than enough energy to operate a corn-to-ethanol plant, so the net energy fraction might improve considerably if a portion of the stover were collected and used to replace external energy sources.

Another major issue with ethanol is the cost of production. It is heavily dependent on the cost of the feedstock (corn in the United States, sugar in Brazil) and the market value of the byproducts. Among potentially renewable fuels, ethanol (primarily from corn) is the only one that is produced commercially on a largc scale in the United States. It is used principally as a 10-percent blend with gasoline in Conventional ICEVs. About 3 billion liters of ethanol arc made annually in the United States, almost all from corn. Ethanol from corn is not cost-competitive with gasoline, so federal subsidies (currently about 54¢/gal) are necessary to support continued production.

Ethanol from Lignocelluiose

The high cost of corn-based ethanol has motivated efforts to convert lower cost biomass, primarily woody and herbaceous materials. into ethanol. These feedstocks are less costly than corn because much larger quantities can be produced per land area and fewer agricultual chemical or other inputs are required. In addition, they do not directly compete with food crops.[38] They are, however, more difficult-and to date more costly-to convert into ethanol. Advances in biotechnology may change this outlook. Research by the National Re-

[37] G.O. Benson and R.B. Pearce, "Corn Perspective and Culture," *Corn: Chemistry and Technology, American Association of Cereal Chemists* (St. Paul, MN: 1987).

[38] Of course, they may compete with food crops indirectly in terms of land use, see chapter 2

newable Energy Laboratory (NREL) and others into cellulose-to-ethanol processes is promising and, if successful, could offer a cost-effective means of producing ethanol in very large quantities.[39]

Woody and herbaceous biomass, referred to generally as lignocellulosic material, consists of three chemically distinct components: cellulose (about 50 percent), hemicellulose (25 percent), and lignin (25 percent).[40] Most proposed processes involve separate processing-either acid or enzymatic hydrolysis-of these components. In the first step, pretreatment, the hemicellulose is broken down into its component sugars and separated out. The lignin is also removed. The cellulose is then converted into fermentable glucose through hydrolysis. After fermentation, the products are distilled to remove ethanol. Byproducts of the separation process, such as lignin, can be used as fuel.

Acid Hydrolysis

A number of variants on the basic process of acid hydrolysis have been proposed, each typically involving use of a different acid and/or reactor configuration.[41] One system incorporates two stages of hydrolysis using dilute sulfuric acid. In the first step, the acid breaks the feedstock down into simple sugars. The acid also degrades some of the product sugars, however, so that they cannot be fermented, thus reducing overall yield. R&D has been aimed at improving the relatively low yields (55 to 75 percent of the cellulose) through the use of other acids.[42] Low-cost recovery and reuse of the acids are necessary to keep production costs down but have yet to be commercially proven.[43]

The estimated total cost of producing ethanol by different proposed acid hydrolysis processes is high ($15 to $20/GJ or $2.00 to **$2.60/gal** gasoline).[44] The potential for cost reduction is limited because the maximum overall efficiency of converting energy in the biomass feedstock by acid hydrolysis is only about 30 percent. The sale of chemical byproducts (e.g., furfural) improves economics, but the potential market is much smaller than production by a large-scale fuel ethanol industry.[45] Byproduct electricity could also offset ethanol costs, but the amounts of exportable electricity coproduced in process configurations to date have been relatively small. This situation might change if more advanced cogeneration technologies are considered (see chapter 5).

Unless world oil prices rise considerably (to $40/barrel or more), ethanol from acid hydrolysis appears to be an unpromising technology, particu -

[39] One recent econometric study estimated that the agricultural sector could support the production of roughly 10 EJ (current national transportation energy consumption is about 22 EJ) of delivered ethanol from cellulosic biomass (not from, e.g., grain or sugarcane). Of course, this will also depend on export opportunities for agricultural commodities and other factors (see chapter 2). Randall A. Reese et al., "Herbaceous Biomass Feedstock Production: The Economic Potential and Impacts on U.S. Agriculture," *Energy Policy,* July 1993, pp. 726-734.

[40] Percentages vary for different species. Wood consists of about 50 percent cellulose and 25 percent hemicellulose. Grasses have roughly equal amounts of cellulose and hemicellulose (between 30 and 35 percent). J.D. Wright, "Ethanol from Lignocellulose: An *Overview,* ''*Energy Progress, vol.* 8, *No. 2,* 1988, pp. 71-78; and Anthony Turhollow, Oak Ridge National Laboratory, personal communication, Apr. 22, 1994.

[41] Wyman et al., op. cit., footnote 26.

[42] See J.D. Wright et al., *Evaluation of Concentrated Halogen Acid Hydrolysis Processes for Alcohol Fuel Production,* SERI/TR-232-2386 (Golden, CO: Solar Energy Research Institute, 1985).

[43] Ibid.

[44] E.D. Larson et al. "Biomass-Gasifier Steam-Injected Gas Turbine Cogeneration for the Cane Sugar Industry," *Energy from Biomass and Wastes XIV,* D.L. Klass (cd.) (Chicago, IL. Institute for Gas Technology, 1991),

[45] See P.W. Bergeron et al., "Dilute Acid Hydrolysis of Biomass for Ethanol Production, " *Energy from Biomass and Wastes XII* (Chicago, IL: Institute for Gas Technology, 1989), pp. 1277- 1296; and M.M. Bulls et al., "Conversion of Cellulosic Feedstocks (o Ethanol and Other Chemicals Using TVA's Dilute Sulfuric Acid Hydrolysis Process," *Energy from Biomass and Wastes XIV,* D.L. Klass (cd.) (Chicago, IL: Institute for Gas Technology, 1991).

larly in light of developments in enzymatic hydrolysis.

Enzymatic Hydrolysis

Enzymatic hydrolysis of cellulose has been under development for about two decades. Advances that have been made in this technique specifically, and in biotechnology more generally, suggest that economically competitive commercial systems could be developed by early in the next century.

Biological enzymes typically break down only the cellulose and do not attack the product sugars. Thus, in principle, yields close to 100 percent can be achieved from cellulose. A feedstock pretreatment step is typically required since biomass is naturally resistant to enzyme attack. The most promising option appears to be a dilute acid, in which the hemicellulose is converted to xylose sugars that are separated out, leaving a porous material of cellulose and lignin that can be attacked more readily by enzymes.[%]

A number of bacteria and yeasts have been identified and tested as catalysts of cellulose hydrolysis. Three process configurations have received the most attention from researchers:

- In the separate hydrolysis and fermentation (SHF) of cellulose, three distinct operations are used to produce enzymes, hydrolyze cellulose, and ferment the glucose.
- A promising modification of the SHF process involves simultaneous saccharification and fermentation (SSF) in a single-reaction vessel, permitting higher product yield and improved economics.[47] Projected total biomass energy conversion efficiency to ethanol with improved xylose fermentation is about 64 percent.[48] The projected costs for ethanol produced by this method range from $10 to $15/GJ ($1 .30 to $2.00/gal gasoline) (roughly similar to the cost for biomass-derived methanol) delivered to the consumer.[49] Research lowered the cost of biomass-derived ethanol from $4. 15/gal in 1980 to $1.65/gal in 1993, including the cost of delivery.[50]
- Single-reactor direct microbial conversion (DMC) combines enzyme production, cellulose hydrolysis, and glucose fermentation in a single process. In limited efforts to date, however, DMC ethanol yields have been lower than those from the SHF or SSF processes, and a number of undesired byproducts have resulted.

A potential complication for ethanol production is that the enzymes currently used in the most promising conversion process---ezymatic hydrolysis—may require relatively homogeneous feedstocks to achieve projected performance.[51] Although researchers have been able to convert wastepaper and agricultural and forest product wastes into ethanol using enzymatic hydrolysis.[52] it may prove easier and less expensive to harvest and process a monoculture. From an ecological perspective, however, the ability to draw on biomass polycultures would be preferable in the longer term (chapter 2). If polyculture feedstocks are pursued, they may require the development of improved enzymes and processing technologies.

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46 J.D. Wright, “Ethanol from Biomass by Enzymatic Hydrolysis,” *Chemical Engineering Progress,* August 1988, pp. 62-74.

47 J.D. Wright et al., *Simultaneous Saccharification and Fermentation of Lignocellulose: Process Evaluation* (Golden, CO: Solar Energy Research Institute, 1988).

48 Wyman et al., op. cit., footnote 26.

49 Ogden et al., op. cit., footnote 17.

50 1992 $/gallon. Venkateswaran and Brogan, op. cit., footnote 3.

51 Research on enzymatic hydrolysis at NREL is now broadening its focus to include research on common farm species that may be intermixed with the primary species grown.

52 Robert H. Walker, Director, Planning and Evaluations, Alternative Feedstock Development Department, Amoco Corp., personal communication, May 1994.

| Hydrogen

Interest in hydrogen as an alternative fuel for transport has grown rapidly in recent years. Hydrogen is an extremely clean fuel that can be burned in ICES or electrochemically converted to generate electricity in fuel cells. Hydrogen can be produced from natural gas or coal: however, a more environmentally appealing idea from the perspective of CO_2 and other emissions is the production of hydrogen from biomass via gasification or from the electrolysis of water by using electricity generated from renewable energy.

Fuel-cycle emissions of CO_2 and other greenhouse gases can be reduced significantly or perhaps eliminated, depending on the source of energy used to produce hydrogen. Fuel cell vehicles that use hydrogen have essentially no tailpipe emissions apart from water vapor. The tailpipe emissions from hydrogen ICEVs are much lower than those from a comparable gasoline-powered vehicle. Emissions of CO, hydrocarbons (HCs), and particulate are essentially eliminated (traces of these gases may be emitted from combustion of lubricating oils in the engine). The only pollutants of concern are nitrogen oxides (NOx), which are formed, as in all ICES, from nitrogen taken from the air during combustion. Hydrogen vehicles probably will be able to meet any NO_x standard that a gasoline vehicle can meet. In principle, an ultralean hydrogen engine could produce very little NO_x, and some recent work by Daimler-Benz has demonstrated near-zero emissions of NO_x in hydrogen-powered test vehicles.

Environmental benefits can also be achieved by blending hydrogen with other fuels. Dual fuel operation with hydrogen and gasoline or diesel fuel can substantial] y reduce emissions of all regulated pollutants. The addition of relatively small amounts of hydrogen—as little as 5 to 10 percent by mass--can reduce CO, HC, and NO, emissions.[53] By adding 5 percent hydrogen to natural gas (the blend is called "hythane"), NOx emissions from ICEVs can also be substantially reduced.[54]

The principal barriers to widespread hydrogen use include difficult storage requirements, high production costs, and lack of a distribution infrastructure.

Hydrogen Storage

Hydrogen has a very low energy density. Typical volumetric energy densities for hydrogen are 5 to 15 percent that of gasoline when stored in pressurized tanks or metal hydrides.[55] Therefore, a hydrogen-fueled vehicle requires either large on-vehicle, high-pressure storage tanks.[56] cryogenic storage,[57] or storage in another medium.[58] Factors at play in the development of hydrogen storage systems include energy densities in terms of weight and volume. safety during refueling and

53 Ogden et al., op. cit., footnote 17.

54 Congressional Research Service, "Hydrogen as a Fuel." Mar. 22, 1993.

55 *Hydrides* are special materials that absorb and hold large quantities of hydrogen. When heated, they release hydrogen gas.

56 The size of high-pressure tanks may be reduced somewhat with the introduction of advanced lightweight materials. Carbon-fiber-wrapped, aluminum-lined tanks allow storage at 8,000 psi, high enough for energy densities competitive with other storage methods. Carbon fiber is currently quite expensive at $50 per pound but is expected to drop in cost. The crashworthiness of such tanks, however, has not been fully determined.

57 Storage of liquefied hydrogen would provide high energy densities. However, insulated, crashworthy tanks would have to be developed, as well as a special infrastructure for handling liquid hydrogen. Also, hydrogen liquefaction is an energy-intensive process.

58 As an example, hydrogen can be stored in the form of powdered iron. Steam from a fuel cell, for example, could be used to oxidize powdered iron in a tank onboard the vehicle, releasing hydrogen to be used as fuel. When the entire tank of iron has turned to rust, it is exchanged for fresh iron, and oxidized material could be reduced back to iron at a central facility. This is a potentially inexpensive and compact storage approach. H-Power Corporation of New Jersey is developing this technology.

in case of accidents,[59] and cost of materials and construction. Hydrogen storage requirements could be eased if vehicle propulsion systems with high efficiencies were developed. For example, by one estimate, a hybrid electric vehicle that uses a small ICE fueled by hydrogen to generate electricity could reduce hydrogen storage requirements by 50 to 65 percent compared with a pure ICEV.[60] The high efficiencies of fuel cell-based vehicles would further ease hydrogen storage problems (see discussion below). In the near term, onboard hydrogen pressure tanks could build on the experience of compressed natural gas vehicles.

Costs of Hydrogen Fuelel

As shown in table 4-2, the cost of hydrogen produced from renewable sources varies considerably. On a large scale (for plants producing 50 million standard cubic feet of hydrogen per day), biomass hydrogen could cost perhaps $8 to $1 l/GJ to produce (assuming biomass costs of $2 to $4/GJ), with delivered costs of about $14/GJ (or $1.85/gal gasoline equivalent), making it the least expensive method of renewable hydrogen production.[62] Renewable electrolytic hydrogen—hydrogen produced from, e.g., wind- or photovoltaic-generated electricity-could cost anywhere from two to four times as much as hydrogen from biomass ($20 to $60/GJ), depending on advances in photovoltaic, wind, or other renewable technologies (see chapter 5). Because of their modular nature, however, electrolytic hydrogen systems could be employed at a much smaller scale than biomass gasifiers. On small production scales—which one would expect at the beginning of a transition to hydrogen or if environmental constraints limited the size of any one production area—the cost advantage of hydrogen from biomass compared to photovoltaic- or wind-powered electrolysis would likely be reduced.

On a large scale, hydrogen from steam reforming of natural gas could cost $5 to $10/GJ (with natural gas prices of $2 to $6/GJ) or 65@ to $1.30/gal gasoline equivalent. On a smaller scale (0.5 million standard cubic feet/day or 200 GJ/day), hydrogen from steam reforming could cost about $11 to $17/GJ ($1 .45 to $2.25/gal gasoline equivalent). Coal gasification plants would also exhibit strong scale economies. For large plant sizes, hydrogen from coal could cost about $10 to $14/GJ (for coal costing $1.50/GJ) or $1.30 to $1.85/gal gasoline equivalent. For a given plant size, the cost to generate hydrogen from biomass via gasification would probably be somewhat lower than the cost from coal because biomass can be gasified more quickly and at lower temperatures than coal, allowing the plant to be smaller and less capital intensive for a given output.

Developing a Hydrogen Infrastructure

One of the key issues for development of hydrogen as a transportation fuel is that no large-scale hydrogen delivery system exists. This is unlike the situation for gasoline, electricity, or natural gas, where widespread distribution systems are already in place. Moreover, developing an infrastructure would be more difficult for hydrogen (which must be transported as a compressed gas, as a cryogenic liquid, or by pipeline) than for liquid fuels, such as methanol or ethanol, which can

[59] Many questions have also been raised about the safety of hydrogen. Although these concerns should not be dismissed, the dangers of hydrogen use have probably been overstated. With regard to flammability, hydrogen is not much different from other fuels such as gasoline and methanol. Although hydrogen would leak through mechanical fittings at a higher rate than other fuels, it disperses much more quickly and thus is less likely to form a flammable mixture. See Joan Ogden and Robert Williams, *Solar Hydrogen.. Moving Beyond Fossil Fuels* (Washington, DC: World Resources Institute, October 1989).

[60] Glenn Rambach, Lawrence Livermore National Laboratory, personal communication, Jan. 26, 1994.

[61] Cost data in this section are drawn from Ogden et a]., Op. cit., footnote 17.

[62] A delivered cost of $ 10/GJ for hydrogen has a gasoline equivalent price of $ 1.30/gal. Some recent work indicates that hydrogen might be produced from municipal solid waste for $6 to $8/GJ or 78@ to $ 1.04/gal gasoline. J. Ray Smith, Lawrence Livermore National Laboratory, personal communication, Apr. 25, 1994.

be transported and delivered to the consumer by using systcms similar to that for gasolinc.

The components of a hydrogen energy infrastructure have already been dc~'eloped. Technologies for storing. compressing. and transporting hydrogen are well known and are used in the chemical industry. The present hydrogen distribution system in the United States consists of a few hundred miles of industrial pipeline plus fleets of trucks delivering liquid hydrogen or compressed hydrigrn gas. Although about 1 EJ of hydrogen is produced in the United States per year, most of this is produced and used onsite for petroleum refining and methanol or ammonia production. Merchant hydrogen (hydrogen that is distributed) amounts to only about 0.5 percent of the total hydrogen produced and used.

Ultimate] y, the large-scale use of rewable hydrogen as a fuel would require the development of much larger hydrogen transmission and distribution systems. In the near term, hydrogen is likely to be produced from natural gas, which is presently the least expensive source. There are several ways in which the existing natural gas infrastructure could be used to bring hydrogen to consumers. First, it is possible to produce hydrogen from steam reforming of natural gas. even on a relatively small scale. Hydrogen for fleet vehicles might be produced onsite by using small-scale reformers. Alternatively, hydrogen might bc blended at concentrations up to 15 to 20 percent by volumc into the existing natural gas system and rcmoved at the point of use. At greater than 15 to 20 percent concentrations of hydrogen, changes in the distribution and retailing systems would be required because of the differing physical characteristics of hydrogen compared with natural gas.[63]

Another option for onsite hydrogen production is eletrolysis. Here. the electricity distribution system could bc used to bring offpeak power to elcctrolyzer equipment. Alternatively, standalone photovoltaic (PV) hydrogen systems could be used if the costs of PV-generated electricity decline sufficiently (chapter 5). In the longer term, as the demand for hydrogen fuel increased, central hydrogen production plants might be built. with a gaseous pipeline distribution system similar to that for natural gas.

Electricity

Electricity may be one of the principal energy carriers for future transportation systems. Electricity has the important advantages of having an available supply infrastructure (except for home charging stations) that is adequate now-if recharging takes place at night—to fuel several million vehicles and of generating no vehicular air emissions.[64] The latter attribute is particularly attractive to regions with severe ozone problems. Also, with the exception of some electricity imports from Canada,[65] the electricity needed to run a fleet of BPEVs would be produced domestically.

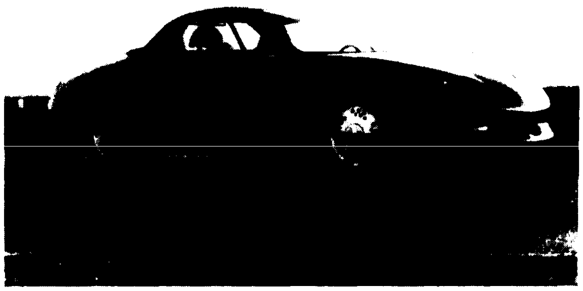
Despite virtuallly zero vehicular emissions, electric vehiclcs will have air pollution impacts because of the emissions associated with electricity production. These impacts will vary from region to region, since the power generation fuel mix varies greatly across the country. California and the northeastern United States. the two regions with the most serious pollution problems and therefore the most attractive regions for electric vehicle use. have different fuel r-nixes. California's power is generated mostly from natu -

[63] If higher percentages of hydrogen were to be used in pipelines, steps would have to be taken to prevent "embrittlement" problems. When hydrogen diffuses into pipe metal, the pipes can become brittle and crack. Embrittlement can be avoided by choosing proper pipe materials, but at a cost. Congressional Research Service, op. cit., footnote 54.

[64] Over the short term, existing baseload capacity of electric utilities should be adequate to meet the demand arising from new BPEVs. If electric vehicles capture a significant share of the automobile market, however, electric utilities will be faced with significant load management challenges. See "Charging Up for Electric Vehicles," *EPRI Journal*, vol. 18, No. 4, June 1993.

[65] Some natural gas and oil imports may also be used to generate electricity

GENERAL MOTORS CORP



General Motor's prototype two-seat electric vehicle (EV), the Impact, combines high performance (0 to 60 mph in 8 seconds) with high EV range (over 100 miles on the Federal Urban Driving Cycle).

ral gas, nuclear, and hydropower, whereas the Northeast depends more on coal. In comparison to coal-generated electric power, electricity generated from natural gas powerplants can reduce emissions of $C0_2$, sulfur oxides, and nitrogen oxides.

Although the cost of electricity ($17/GJ at 6¢/kWh) appears high relative to gasoline ($9/GJ or $1.18/gal), the actual fuel costs for BPEVs are likely to be substantially lower than for gasoline vehicles. This savings is due principally to the efficiency advantage of electric vehicles. For example, a typical BPEV might consume about 0.25 kWh/mile. At 6¢/kWh, the operating fuel cost of the BPEV is then 1.5¢mile.[66] In practice, electric utilities are expected to offer low, offpeak electricity rates (3¢ to 4¢/kWh) to consumers for nighttime recharging of BPEVs. Thus, a typical BPEV could have operating fuel costs of less than 1 ~/mile. In comparison, the operating fuel cost for the two-seater Honda Civic del Sol is 3.7¢/mile.[67] The initial purchase cost of BPEVs, however, may be considerably higher than conventional vehicles (but may be offset by lower maintenance costs and longer lifetimes for electric vehicles; see discussion below).

With BPEVs running on renewable electricity, it would be possible to produce and use energy with very low emissions of criteria air pollutants and $C0_2$. Electricity can be produced from a variety of renewable sources such as biomass, wind energy, solar energy, and hydropower. As discussed in chapter 5, the cost of producing electricity in a "renewables-intensive utility" in the post-2010 timeframe may be comparable to that for a conventional utility (4¢ to 6¢/kWh). The primary technical issues involved in a transition toward renewable electricity-based transportation are the development of renewable electricity-generating technologies, their integration into a utility grid, and the development of BPEVs (see discussion below) and their recharging systems.

Where and when recharging takes place would influence the delivered cost of electricity for transportation. It is likely that many electric vehicles will be recharged at home during offpeak (nighttime) hours. In this case, the type of generating system used to meet offpeak demand will determine the cost and types of emissions.

Another option for electric vehicle recharging is stand-alone solar PV charging that would operate while a car was parked, for example, at work or at a commuter station. In this case, some battery storage may be needed at the PV charging station for use on cloudy days, which would add to the cost of PV electricity. The cost of electricity from stand-alone PV recharging stations would likely be higher than the cost of residential electricity from a renewables-intensive utility. Stand-alone systems might be used in settings where non-grid-connected daytime recharging is desirable or home charging is not feasible.

[66] The California Air Resources Board projects that in the year 2000, a typical electric vehicle will consume about 0.24 kWh/mile. The General Motors Impact electric vehicle uses about 0.2 kWh/mile. See California Air Resources Board, "Emission Benefits of Electric Vehicles Relative (o ULEVS," draft, February 1994.

[67] This is based on 34 miles/gal (city) and a price of $ 1.25/gal for gasoline. Venkateswaran and Brogan, Op. cit., footnote 3.

Some Nonrenewable Competitors

In the near term, fuels that are derived from nonrenewable sources could also offer environmental benefits. Internal combustion engine vehicles that use reformulated gasoline or compressed natural gas are likely to be formidable competitors with renewable-based ethanol, methanol, hydrogen, or electricity y. This is primarily because reformulated gasoline and CNG will likely be substantially lower in cost than renewable fuels for the near to mid-term.

Reformulated Gasoline

Reformulated gasoline is gasoline that has been modified to have lower emissions of hydrocarbons (to reduce ozone formation), benzene, heavy metals, and other pollutants. By law, reformulated gasoline must have a 2-percent oxygen content to ensure compliance with regional CO standards. It has the advantage of not requiring engine modification or a separate fuel infrastructure. Thus, reformulated gasoline can reduce the emissions of cars already on the road.

Reformulated gasoline was first proposed as an alternative fuel in the United States in 1989 in response to the growing pressure for cleaner burning fuels, particularly the proposal by President Bush to require the sale of alternative fuel vehicles in the nine most polluted U.S. cities.[68] Subsequently, the major oil and automobile companies in the United States initiated a jointly funded multimillion dollar study to analyze the emission impacts of various reformulated blends (later expanded to include methanol and CNG) from current and future motor vehicles. Results released to date suggest that gasoline reformulation could provide modest to fairly significant emission benefits (for criteria air pollutants only; there would be virtually no reduction in greenhouse gases) at a cost of around 15¢/gal more than conventional gasoline.[69]

Natural Gas

CNG can be burned in internal combustion engines with minor modifications and in diesel engines with more substantial modifications. Natural gas is a cleaner fuel than gasoline, with lower emissions of most pollutants. A dedicated CNG vehicle could have an energy efficiency about 10 percent greater than a gasoline vehicle because of its higher octane number. Natural gas ICEVs have a much shorter driving range or reduced trunk space than gasoline-fueled vehicles, however, because CNG's volumetric energy density is much lower than gasoline (about one-quarter the energy density of gasoline when compressed to the standard pressure of 3,500 psi).

The use of liquefied natural gas (LNG) could in theory overcome this range limitation. LNG is natural gas that has been liquefied by cooling it to -161 "C. The advantage of LNG over CNG is its energy density—a given volume of LNG provides about three times the vehicle range between refueling as the same volume of CNG. At least in the near term, the practical difficulties of maintaining these low temperatures, along with the high cost of containers capable of storing LNG, make LNG less promising as a fuel for light-duty vehicles. Fleet operators of heavy-duty vehicles are, however, showing increased interest in LNG.

Another major drawback of CNG as a transport fuel is the difficulty of transporting. storing, and delivering it. Because the refueling and storage systems would be similar, however, CNG vehicles might provide a bridge toward the eventual use of hydrogen, a fuel that ultimately could be derived

[68] Considerable interest in alternative fuels had already been expressed by the state of California and industry had begun responding to this interest with the development of reformulated gasoline.

[69] Some analyses indicate that if reformulated fuels were used in conjunction with electrically heated catalysts and advanced engine control technologies, CO and NO_x might be reduced by as much as 50 percent. The emissions benefits would be much more modest without these vehicle modifications. See the series of technical reports produced by the Auto/Oil Air Qua] ity improvement Research Program and published by the Coordinating Research Council, Atlanta, Georgia, from 1989 to 1993.

completely from renewable sources. At present, no analysis has been undertaken to evaluate the costs and benefits of such a transition from natural gas to hydrogen.

One current incentive for switching from gasoline to natural gas is lower fuel cost, but this incentive is likely to diminish as demand for natural gas grows. The present retail price of CNG from domestic sources is about $7/GJ (in gasoline equivalent terms, about 91¢/gal without taxes or roughly comparable to gasoline when taxes are included). CNG vehicles also may have slightly lower maintenance costs than liquid fuel vehicles. The use of CNG in gasoline vehicles requires the installation of gas cylinders, high-pressure piping, and appropriate fittings to the engine. To take full advantage of CNG, the compression ratio should also be raised to about 12 to 1.[70] An automobile designed for CNG would cost about $800 to $1,000 more than a comparable gasoline-fueled vehicle, due in large part to the expensive high-pressure fuel storage equipment. This higher upfront cost is compensated partially by lower back-end costs: the storage systems probably will have a high salvage value, and the use of natural gas may increase the life of the engine and hence the resale value of the vehicle.

Natural gas will reduce HC emissions that contribute to urban smog, although it may increase NO_x emissions somewhat.[71] If natural gas vehicles gain greater market penetration, they should contribute less to greenhouse gases than vehicles using petroleum- or coal-based transport fuels (see table 4-1). Although natural gas presents some special handling problems, it is neither toxic nor corrosive, unlike methanol and gasoline.

EMERGING VEHICLE TECHNOLOGIES

Several technological options for improving vehicle energy efficiency and emissions are now being explored, including advanced ICEV designs and the use of new fuels in ICEVs, battery-powered electric vehicles, fuel cell electric vehicles, and hybrid vehicles (various combinations of the above).

Each of these propulsion system options could potentially play a role in bringing about a transition from the present fossil fuel transportation system to one that depends primarily on renewable energy resources.

Advanced ICEV Designs

At present, the vast majority of light-duty vehicles on the road use gasoline-powered internal combustion engines. In recent decades, federally mandated fuel efficiency and clean air requirements have resulted in significant refinements of conventional internal combustion systems.[72] Several additional advances are likely to be introduced in coming years, including improved vehicle design and alternative fuels such as reformulated gasoline, compressed natural gas, and perhaps ethanol or methanol.

Many vehicle characteristics could be modified to improve vehicle energy efficiency :[73]

- a shift to lightweight body materials such as carbon fiber or other composites;

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[70] R. Moreno, Jr., and D. Bailey, *Alternative Transport Fuels from Natural Gas,* World Bank Technical Paper No. 98, Industry and Energy Series (Washington, DC: World Bank, 1989), p. 7.

[71] CNG vehicles can emit less carbon monoxide (perhaps 30 to 50 percent less) than gasoline or methanol vehicles, because CNG mixes better with air than do liquid fuels, and it does not have to be enriched (as much) for engine startup. The magnitude of CO reduction (and, perhaps, whether there is any reduction at all) will be determined by NO_x control: if the engine has to be run slightly rich to control NO_x, there will be little or no reduction in CO; if it can be run slightly lean, there will be a reduction.

[72] Since 1978, fuel economy specifications have been dictated principally by federal Corporate Average Fuel Economy (CAFE) requirements. CAFE standards have been met by decreasing vehicle drag and weight, reducing engine size, and introducing fuel injection and other energy-efficient technologies.

[73] This material is drawn from and discussed in Office of Technology Assessment, Op. cit., footnote 14.

- a reduction in the vehicle aerodynamic drag coefficient;
- high-pressure, low-rolling-resistance tires;
- an advanced super-efficient engine with four or more valves per cylinder, adjustable valve lift and timing, and other low-friction or lean-burn measures; an advanced two-stroke engine; or advanced diesel;
- extensive use of aluminum and other lightweight materials in the vehicle suspension and other components (e.g., brake rotors and calipers, sway bars, wheels);
- advanced transmissions (e.g., a five- or six-speed automatic); and
- automatic engine turnoff at stops.

General Motors' new Ultralite prototype demonstrates both the potential and some of the 1imitations associated with a radical redesign of today's automobile. The Ultralite weighs 1,400 pounds (630 kg) despite being comparable in interior volume to a 3,000-pound (1,360-kg) Chevrolet Corsica; is powered by a 1.5-liter, three-cylinder, two-stroke engine that weighs 173 pounds (78 kg) yet generates 111 horsepower at 5,000 revolutions per minute (rpm); has a drag coefficient of only 0.19; and rolls on high-pressure, low-resistance tires that need no spare because they are self-sealing. Although its fuel economy at 50 mph (80 km per hour) is 100 mpg (42 km/liter), the Ultralite's Environmental Protection Agency (EPA) fuel economy rating is only 56 mpg (24 km/liter), or about 48 mpg (20 km/liter) when adjusted for on-road conditions.[74] Given the sports-car-like performance characteristics of the vehicle (zero to 60 mph in 7.8 seconds), this fuel efficiency is quite exceptional. Regardless, vehicle size and performance generally require tradeoffs with efficiency.

Vehicle energy efficiency might also be constrained by existing or new emissions and safety requirements. The need to meet certain emissions levels could affect engine performance specifications, while safety standards affect a number of design parameters including choice of materials.[75] If tractive loads (e.g., vehicle mass, aerodynamic drag, tire rolling resistance) can be safely reduced. however, engine power requirements will decline, potentially leading to a corresponding decrease in engine emissions. In this sense, there is a technical synergy between energy efficiency and emissions objectives.

To meet the new emissions standards of the amended Clean Air Act (see table 4-3), vehicles in the year 2000 will likely require onboard refueling controls, improved fuel metering and ignition, a larger or additional catalytic converter with electric heating to reduce cold-start emissions, and a larger evaporative-emissions canister. If the stricter "'Tier 2" standards are imposed by EPA, the cost of vehicle modifications may range from $200 (California Air Resources Board estimate) to $600 (Sierra Research Institute estimate) up to $1,000 (estimate of automobile manufacturers) per vehicle.[76]

To meet the ultra-low emissions vehicle (ULEV) standards established by the California Air Resources Board, gasoline vehicles may have to use dual oxygen sensors, adaptive transient control, sequential fuel injection. improved fuel preparation, improved washcoats on catalytic converters, more catalyst material (mainly palladium), double-wall exhaust pipes, air injection, and either electrically heated catalysts or close-coupled catalysts. These additions and modifications could increase vehicle cost beyond what would be required to meet federal standards.[77]

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[74] General Motors Co., brochure, n.d.

[75] The safety implications of vehicles that use advanced lightweight materials have not yet been fully explored.

[76] The cost of meeting federal Tier I standards could range from $150 to $275 per vehicle. See Sierra Research, Inc. and Charles River Associates, "The Cost-Effectiveness of Further Regulating Mobile Source Emissions." Report No. SR94-02-04. Feb. 28, 1994.

[77] The California Air Resources Board estimates that the cost of meeting ULEV requirements would be about $200 per vehicle (above and beyond the cost of meeting federal Tier I requirements). Sierra Research estimates that the cost could exceed $1.300. Ibid.

TABLE 4-3: Emissions Standards for Light-Duty Motor Vehicles (grams/mile)

	Emissions standard					
Pollutant	Federal 1993 standard	Federal CAAA, Tier 1 1994 MY	Federal CAAA, Tier 2 (if needed)	CARB TLEV 1994 MY	CARB LEV 1997 MY	CARB ULEV 1997 MY
HC	0.41	0.25	0.125	0.125	0.075	0.040
CO	3.40	3.40	1.70	3.40	3.40	1.70
NO_x	1.00	0.40	0.20	0.40	0.20	0.20

KEY: CAAA = Clean Air Act Amendments of 1990; CARB = California Air Resources Board; HC = hydrocarbons (California regulates nonmethane organic gases, not hydrocarbons); LEV = low-emissions vehicle; MY = model year; TLEV = transitional low-emissions vehicle; ULEV = ultra-low emissions vehicle.

SOURCES: S.C. Davis and S.G. Strang, *Transportation Energy Data Book: Edition 13*, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1993); and Sierra Research, Inc. and Charles River Associates, *The Cost-Effectiveness of Further Regulating Mobile Source Emissions*, Report No SR94-02-04 (Sacramento CA February 1994)

The effectiveness of proposed emissions control equipment for gasoline ICEVs is still not well known. It is not clear how far gasoline ICEV technology can be pushed to reduce emissions. In lowering emissions to meet future standards, however, ICEVs will likely become somewhat more complex and costly.

Alternative Fuels in ICEVs: A Comparative Analysis

Conventional and advanced ICEV designs can take advantage of a number of different alternative fuels, such as reformulated gasoline, compressed natural gas, ethanol, methanol, and hydrogen. Ethanol, methanol, and natural gas vehicles are commercially available today, although in limited quantities. Demonstration hydrogen ICEVs have been built by Daimler-Benz, BMW, and Mazda and have been tested in small fleets.

Although it is difficult to project costs for technologies and fuels that have not reached large-scale production, it is nonetheless instructive to estimate these costs. The findings of one such analysis are presented here. This analysis compares the operating costs of different alternative fuels that are used in ICEVs.[78]

The reference gasoline vehicle is a year-2000 version of the 1990 Ford Taurus (26 mpg). The other vehicles are "built" hypothetically from this baseline vehicle. The travel range of these ICEVs varies from a high of about 600 km (370 miles) for the gasoline vehicle to 320 km (200 miles) for the compressed hydrogen gas vehicle. The volumetric energy density of methanol is roughly half that of gasoline but can be partially compensated by a larger fuel storage volume and the greater fuel economy (through higher compression ratio) achievable with methanol. The net result is a 20-percent lower range (485 km, 300 miles) for the methanol vehicle relative to gasoline. The range for the ethanol vehicle (565 km, 350 miles) is greater than for methanol because ethanol has an energy density about 25 percent greater than methanol. The CNG range is assumed to be less than that of the methanol vehicle because CNG at 3,000 psi has roughly half the energy density of methanol.

[78] The reader should not view this analysis as an attempt at a definitive cost projection, but rather as a scenario analysis—an "if-then" statement. The analysis was performed by and detailed in Odgen et al., op. cit., footnote 17.

TABLE 4-4: Analysis of Baseline Cost Results for ICEV Systems (1991 dollars)[a]

Item	Gasoline	MeOH	EtOH	CNG	Liquid H_2	Hydride H_2	Compressed H_2
Fuel retail price, excluding taxes (*$/gal gasoline equivalent*)[b]	1 18	185	152	0.96	363	1.54	1 79
Full retail price of vehicle including taxes ($)[c]	18,000	17900	17,900	19,500	20,200	24,200	24550
Levelized annual maintenance cost ($/year)	396	392	392	370	392	392	392
Total life-cycle cost[d] (¢/km)	21	223	214	205	263	244	246
Break-even gasoline price ($/gal)[e]	n.a.	204	1 64	1 26	369	291	297

[a]The cost estimates for the gasoline ICEV are detailed in M A DeLuchi *Hydrogen Fuel Cell Vehicles* UC D- ITS-RR-92- 14 (Davis CA Institute of Transportation Stales University of Cal forn a al Davis September 1992) The cost estimates for the alternative-fuel ICEVs are based primarily or data summarized in D A Sperling and M A De Luchi *Alternative Transportation Fuels and Air Pollution*, report to the OECD Environment Directorate (Paris France Organization for Economic Cooperation and Development March 1991)

[b]Dollars per gasollne-equivalent gallon is calculated as the price of the fuel to the motorist (dollars per million Btu), *excluding* federal state and local taxes (31 ¢ gal in the United States) multiplied by O 125 million Btu gal of gasoline Note that this gasoline equivalence is defined in terms of energy delivered 10 the vehicle and hence does not account for the efficiency with which the vehicle uses that energy The estimate of the cost of gasoline assumes a world 011 price (post 2000 timeframe) of $2640, per barrel and reformulated gasoline of 15¢/gal more than conventional gasoline

[c]Including sales tax dealer costs and shipping costs

[d]Includes federal state and local taxes of O 78¢ km fOr all vehicles

[e]The retail price of gasoline (including federal and state taxes in the United States) at which the life-cycle consumer cost perkilometer of the alternative fuel vehicle would equal that of the gasoline vehicle

KEY EtOH ethanol MeOH methanol n a not applicable

SOURCE Joan M Odgen et al A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies " report prepared for the Off Ice of Technology Assessment May 1994

The lifetimes for all vehicles are assumed to bc the same, except for the CNG vehicle. A CNG vehicle's lifetime is assumed to be slightly longer than that of a gasoline vehicle because some evidence suggests that CNG might cause less engine wear than gasoline.[79] The weights of liquid-fueled vchicles (gasolinc. methanol, ethanol, and liquid H_2) are all comparable—about 1,400 kg (3,000 pounds). The gas-fueled vehicles (CNG and compressed H^2) arc somewhat heavier because of the weight of compressed gas cylinders. The drag coefficients arc assumed to be the same for all vehicles except the hydrogen-fueled system. The very low energy storage density of the latter demands a more streamlined design in order to achieve a reasonably acceptable driving range, Because their engines would have higher compression ratios, the fuel efficiencies of the methanol, ethanol, CNG, and hydrogen vehicles would be higher than that of the gasoline vehicle (about 7 percent higher for CNG and 15 percent higher for methanol, ethanol, and hydrogen).

Table 4-4 shows the projected retail vehicle price, fuel price, and total life-cycle costs per kilometer for the ICEV-fuel combinations considered here. The retail fuel prices correspond to those shown in table 4-2. The ethanol, methanol. and hydrogen fuel costs assume production from bio-

[79]The relationship between engine lifetime and vehicle lifetime, however, is complex.

mass, although it is unlikely that large quantities of fuel from biomass will be available before2010 under current policy. The full retail prices of all liquid-fueled ICEVs are comparable. The CNG vehicle cost is about $1,500 higher. The hydrogen ICEV (compressed gas or hydride storage) is about $6,000 higher. The hydrogen and CNG vehicles are more costly principally because of the relatively expensive storage equipment involved.

Ownership and operating costs can be combined and expressed as a total cost per kilometer over the life of a vehicle by amortizing the initial cost at an appropriate interest rate, adjusting for salvage values and vehicle life, and adding periodic costs such as maintenance, fuel, insurance, and registration. Table 4-4 projects this total levelized life-cycle cost per kilometer of travel for each fuel category. (Externality costs, such as the costs of emissions, are not included in this analysis.) The baseline gasoline vehicle costs 21 ¢/km. Among ICEVs, the CNG vehicle has a slightly lower cost, whereas ethanol and methanol have slightly higher costs. The hydrogen ICEV would be the most expensive, at 17 to 25 percent higher than the gasoline ICEV.

In addition, table 4-4 provides life-cycle costs in terms of the break-even gasoline price. This is the retail price of gasoline (including taxes) at which the life-cycle cost per kilometer for the gasoline ICEV would be the same as that for the alternative vehicle under consideration. The break-even price ranges from $1 .30/gal ($9.86/GJ) for the CNG vehicle to about $2/gal ($15/GJ) for the methanol vehicle and nearly $3/gal ($23/GJ) for the compressed H_2 vehicle.

Again, many of the important cost parameters are very uncertain, particularly the costs of delivered fuel from biomass (or fossil fuels), some fuel storage technologies (e.g., hydrogen storage), and some vehicle technologies. A sensitivity analysis of the basic assumptions use'd in these calculations indicates that if one of several important cost parameters is overly optimistic, the life-cycle cost and break-even gasoline price could increase substantially.[80]

Battery-Powered Electric Vehicles

Interest in electric vehicles has surged and ebbed several times during this century. In the past few years, there has been increasing awareness of the potential for advanced BPEVs to provide substantial air quality and petroleum conservation benefits. A cost-effective, high-performance battery-powered electric vehicle, recharged quickly by solar or biomass-derived power, would be an attractive transportation option.

At present, however, no existing battery technology would allow a pure BPEV to be competitive with petroleum-based vehicles. The energy densities of all battery systems available even in prototype form today are on the order of 100 times lower than those of gasoline.[81] This means that a given amount of gasoline contains enough energy to propel a car much further than the same weight or volume of batteries. The greater effi-

[80] Odgen et al., op. cit., footnote 17.

[81] The energy density of gasoline is 340 times greater than that of a lead-acid battery system per unit of weight and 120 times greater per unit of volume (energy density for gasoline= 12,000 Wh/kg; and for lead-acid batteries 35 Wh/kg). For an electric vehicle (EV) powered by lead-acid batteries to have a 300-mile (480 km) range (assuming the EV uses 0.24 kWh/mile), more than 4,500 pounds (2,000 kg) of lead-acid batteries would be required. If the projected energy densities of some advanced batteries can actually be achieved, however, this weight figure could be reduced by a factor of three or four (e.g., lithium polymer battery). It should also be noted that specific energy (watt-hours per kilogram) (ends to have an inverse relationship to specific power (power density determines top speed and acceleration). Thus, it is not now possible to maximize a battery's energy and its power simultaneously, a limitation that may require an EV (o have two power sources to achieve acceptable range and acceleration (e.g., either two batteries or a battery and an ultracapacitor). See "The Great Battery Barrier," *IEEE Spectrum*, November 1992, pp. 97-101.

ciency of an electric drivetrain compared with an ICE drivetrain compensates only partially for this energy density disparity[82] (see figure 4-3).

Batteries are also expensive, and thus battery characteristics are the principal determinants of both the initial and the life-cycle operating costs (total cost per mile) of BPEVs. These costs maybe offset somewhat by the relatively high efficiency of electric drivetrains. In addition, some analyses of BPEVs assume that the use of an electric drivetrain will result in lower maintenance costs and longer vehicle life.[83] If true, BPEV life-cycle costs would decrease further, perhaps allowing them to become economically competitive with ICEVs.[84] There is, however, much uncertainty regarding these assumptions. For example, because of battery life limitations, particularly in frequently cycled systems, electric vehicle maintenance and battery replacement costs may turn out to be higher than currently assumed.

Mass production may bring down battery costs, but many of the more advanced batteries under development incorporate expensive materials, as well as sophisticated engineering techniques in their construction. Lead-acid batteries for the experimental electric vehicle that General Motors expects to produce are likely to cost at least $2,000 and last for 15,000 miles (24,000 km), probably less that two years.[85] This would mean spending more than $12,000 on batteries over a 100,000-mile (160,000-km) vehicle life. The nickel-iron battery packs for the Chrysler electric minivan (the TEVan) cost more than $6,000 but are projected to last up to 75,000 miles (120.000 km).[86] The nickel-metal hydride battery under development by Ovonic Battery is projected to cost $5,000, with a life of more than 100.000 miles (160,000 km).[87]

The principal R&D challenge for BPEVs is to develop a battery that has high energy density for range, high power density for acceleration performance, reasonable longevity, and low cost[88] and is quickly rechargeable,[89] safe, and readily recy -

82 Other advances such as regenerative braking (electric motors on the wheels are used to recover braking energy) will further improve electric drivetrain efficiency. It should be pointed out, though, that the actual in-use efficiency of electric drivetrains has some areas of uncertainty. Thus far, there has been little real-world testing. The greatest uncertainty is battery cycle efficiency, which could vary anywhere from 60 to 90 percent. "Smart" charging could help ensure high battery efficiencies. See "'Batteries Charged Quickly, Electric Truck Sets Record," *New York Times*, Feb. 16, 1994, p. D2.

83 See, e.g., M. Delucchi, Institute of Transportation Studies, University of California-Davis, "Hydrogen Fuel-Cell Vehicles." Sept. 1, 1992.

84 Because of the energy density limitations of current battery technology, however, BPEVs would probably not be competitive in terms of range; they could have acceleration characteristics comparable to ICEVs.

85 A recently announced improved lead-acid battery design could greatly extend battery life. Electrosource, Inc. has developed a lead-acid battery that uses a "woven lead mesh" instead of heavy lead plates. A lead wire grid is wrapped around a fiberglass core. This construction apparently enables the battery to withstand more charge-d if charge cycles. Electrosource believes that the battery might be able to last about 80,000 miles (130,000 km), but this has not been demonstrated. The battery is currently being tested by Argonne National Laboratory. See "Producing the Near-Term EV Battery," *EPRI Journal*, April/May 1994, pp. 6-13.

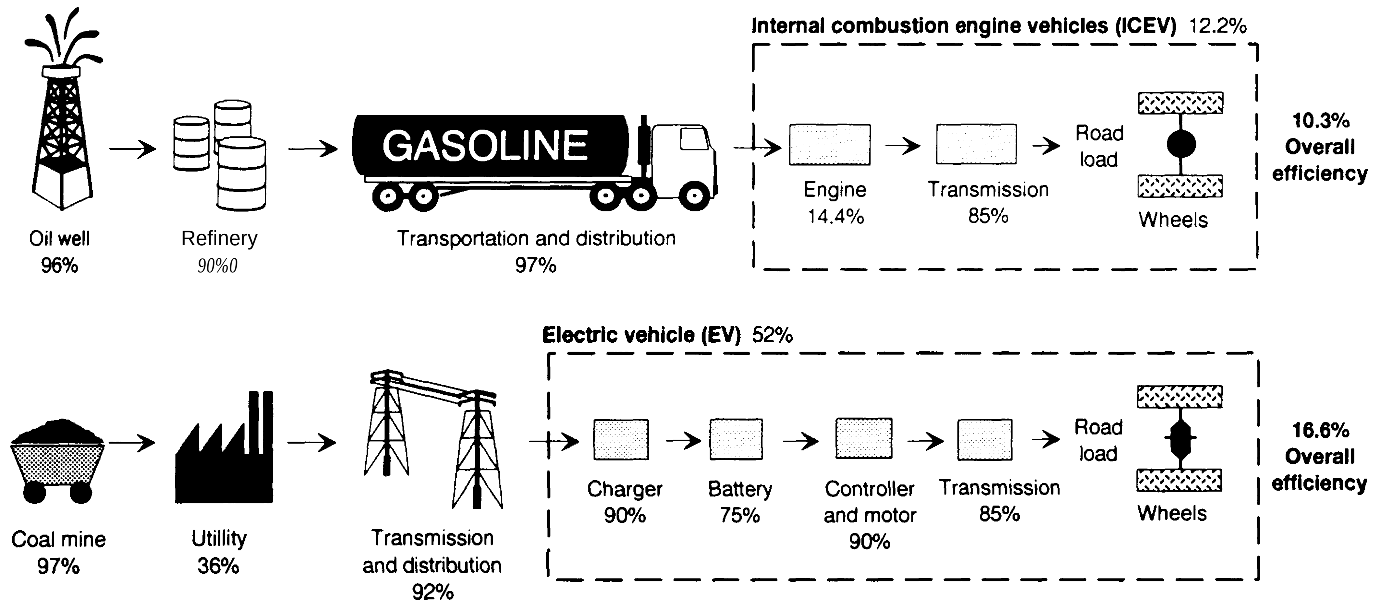
86 Chrysler Corp., brochure, May 1992.

87 The potentially long operating life of the nickel-metal hydride battery has not yet been demonstrated. Venkateswaran and Brogan, op. cit., footnote 3.

88 The mid-term cost goal of the Department of Energy-U.S. Advanced Battery Consortium R&D program is $150/kWh. This implies a cost of $6,000 for a 40-kWh battery pack for a typical electric vehicle. Achievement of these cost goals can be validated only in pilot production, which is still several years away. Ibid.

89 A "quick" recharge system (e.g., 15 minutes) could be quite costly because of the requirement for a high energy input in a short Period of time. One recently announced quick recharge system requires about 440 volts and 160 amperes. which is currently not available to homes or marry businesses. Such a recharge requirement raises a number of peak capacity and infrastructure issues. See Roberta Nichols, "The United States Advanced Battery Consortium: Making Longer Life Batteries Affordable." in *Proceedings of the International Conference on the Urban Electric Vehicle* (Stockholm, Sweden: Organization for Economic Cooperation and Development, May 1992), pp. 347-354.

FIGURE 4-3: Drivetrain Efficiencies



NOTE: An electric drivetrain can be three to four times as efficient as a mechanical ICE drivetrain (e.g., 52 percent for electric vehicles (EVs) versus 12 percent for ICEVs). This efficiency differential drops substantially when the overall fuel chain efficiency for ICEVs and EVs is taken into consideration (16.6 percent for coal-powered EVs versus 10.3 percent for gasoline-powered ICEVs). The fuel chain efficiency for EVs could be much higher if new power generation technologies are deployed. Advanced coal plants might achieve efficiencies close to 50 percent, while efficiencies of 60 percent are possible for advanced natural gas plants. With an advanced natural gas plant the overall fuel chain efficiency for EVs could rise to 27 percent.

SOURCE: John Brogan and S. Venkateswaran, "Diverse Choices for Hybrid and Electric Motor Vehicles," in *Proceedings of the International Conference on Urban EVs* (Stockholm, Sweden: Organization for Economic Cooperation and Development, May 1992).

TABLE 4-5: Technical Objectives of the U.S. Advanced Battery Consortium[a]

	Mid-term	Long-term
Specific energy (Wh/kg)	100[b]	>200
Energy density (Wh/liter)	135	>300
Specific power (W/kg)	150	>400
Power density (W/liter)	250	>600
Life (years)	5	10
Life (cycles to 80% discharge)	600	1,000
Cost ($/kWh)	<$150[c]	<$100
Operating temperature range (°C)	-30 to 65	-40 to 85
Recharge time (hours)	6	3

[a] Some of the battery technologies being pursued include nickel-metal hydride, lithium polymer, nickel-zinc, nickel-iron, zinc-air, lithium-iron disulfide, and sodium-sulfur.

[b] Current lead-acid batteries have a specific energy density of 35 to 45 Wh/kg.

[c] A goal of $150/kWh implies a cost of $6,000 for a 40-kWh battery pack for a typical electric vehicle. If the typical electric vehicle consumes 0.2 kWh/mile, then a 40-kWh battery pack would provide a range of 200 miles (320 km).

SOURCE U S Advanced Battery Consortium

clable. No battery yet exists that meets all these criteria. As a consequence, the federal government is leading a public-private sector consortium to address fundamental battery technology barriers. Table 4-5 lists the technical objectives of the Department of Energy -U.S. Advanced Battery Consortium.

Motors and control systems have improved greatly in recent years with advances in materials technology and power electronics,[90] so that the energy efficiencies of many electric drivetrain components are well over 90 percent. Total efficiency is much less, however, when components must be used together. Therefore an R&D program must include components and systems integration.

As discussed earlier, electric vehicles have essent i ally no direct emissions and therefore may alleviate urban air quality problems. Widespread use of BPEVs could greatly reduce CO and hydrocarbon emissions in particular. The overall contribution to pollution depends on the nature of the electricity generation process. Electricity generated from a coal-fired powerplant will contribute significantly to local and global pollution.[91] If vehicles were powered by electricity from renewable energy sources, however. both $C0_2$ and criteria pollutant air emissions could be largely eliminated. In any case, electric vehicles may contribute less to urban air pollution since powerplants are frequently located outside urban areas.

[90] For example, advances in microelectronic have resulted in low-cos[, lightweight direct current (de) to alternating current (ac) inverters, which make it attractive to use ac (or brushless dc) rather than conventional dc motors. With the improved inverters the entire ac system is cheaper, more compact, more reliable, easier to maintain, more efficient, and more adaptable to regenerative braking than the dc systems used in virtually all BPEVs (o date, Ogden et al., op. cit., footnote 17.

[91] It should also be pointed out that upstream emissions associated with gasoline refining can be considerable. For example, emissions of VOCs associated with gasoline production are much greater than those associated with electricity production for EVs. See M.A. Delucchi, "Emissions from the Production, Storage, and Transport of Crude Oil and Gasoline," *Journal of the Air and Waste Management Association,* v*01.43, 1993,* pp. 1486- 1495: and Q. Wang et al.. "Emissions Impacts of Electric Vehicles," *Journal of the Air and Waste Management Association,* vol. 40, 1*990, pp.* 1*275-*1*284.*

Battery-powered electric vehicles may pose an environmental hazard unique among the alternative fuels. The batteries required by electric vehicles typically have short lifetimes and may present a disposal problem. The battery technologies under development also require special disposal procedures for production wastes as well as for spent batteries. Battery recycling and disposal issues have been incorporated into the program objectives of the U.S. Advanced Battery Consortium.

| Fuel Cell Vehicles

Among the many propulsion systems in existence or under development, fuel cell-powered vehicles could perhaps take the most advantage of' a well - developed renewable fuel supply. Spurred in part by the emerging market for zero-emission vehicles, and partly by recent advances in fuel cell technology, fuel ceil-powered vehicles have been the subject of growing at tent ion. Fuel cell vehicles are of particular interest because they could potentially combine the best attributes of BPEVs—zero or near-zero vehicle emissions, high efficiency, quiet operation, and long life—with the long range and fast refueling time of ICEVs.

Like batteries, fuel cells arc electrochemical devices. In a battery, the electricity-producing reactants are regenerated during recharging: in a fuel cell, the reactants are supplied continuously from an external source (e.g., a hydrogen storage tank plus air). Fuel cells convert the chemical energy in a fuel (e.g., hydrogen or a hydrogen carrier such as methanol) and oxidant (usually oxygen in air) directly into electrical energy. Since fuel cells produce electricity without combustion, higher energy efficiencies are possible, and air pollution is virtually eliminated.

The efficiency of a fuel cell (electrical output divided by fuel input) can be higher than that of heat engines. Practical efficiencies of 40 to 60 percent are possible for fuel cells, which is considerably higher than an internal combustion engine in the sizes appropriate for vehicles (the typical gasoline engine achieves peak efficiencies of about 30 percent). When integrated into vehicle systems. the efficiency differential between fuel cells and ICES will change somewhat depending on the type of vehicle technology employed.

For example, if an ICE is used in a hybrid configuration with a battery and an electric drive train, the intrinsic efficiency gap between fuel cells and engines may be reduced by about half.[92] Fuel cell vehicles could, however, have 2 to 3 times the overall energy efficiency of conventional gasoline-powered ICEVs for a typical urban driving cycle.[93] The efficiency of an ICEV over the EPA urban driving cycle ranges from 12 to 15 percent .[94] FCVs should be capable of achieving overall systems efficiencies of 30 to 40 percent.[95]

Several types of fuel cells are now under development. These include the proton-exchange

[92] See J. Ray Smith, "The Hydrogen Hybrid Opt ion," paper presented at the Workshop on Advanced Component\ for Electric and Hybrid Electric Vehicles, Gaithersburg, MD, Oct. 27-28, 1993.

[93] In contrast to an ICE, the fuel cell system has higher efficiency at the lower end of its load range. This is particularly favorable for urban driving conditions. Some estimates indicate that the per-mile energy usage of passenger fuel cell vehicles (FCVs) would be about half that of comparable conventional vehicles. Variable valve and cylinder deactivation technologies now under development by some manufacturers may reduce low power inefficiencies in conventional ICEVs and narrow this FCV advantage. For FCV performance and cost projections, see Allison Gas Turbine Division, op. cit., footnote 20.

[94] Some estimate that this 12 to 15 percent range could be pushed to more than 20 percent with the use of an optimized drivetrain, which would not be prohibitively expensive. John DeCicco, American Council for an Energy-Efiicicnt Economy, personal communication, June 16, 1994. On the highway, where an engine can operate at constant speed, a 25-percent energy efficiency can be achieved. Smith, Op. cit., footnote 92.

[95] The 30 to 40 percent figure assumes a fuel cell efficiency of 45 to 50 percent, a fuel reforming efficiency of 80 to 90 percent (for the conversion of methanol to hydrogen), and an efficiency of 80 to 90 percent for the controller and electric motor. Regenerative braking is not assumed here.

membrane cell (PEM), the phosphoric acid cell, the alkaline cell, and the solid oxide cell. Among these options, many researchers believe that PEM fuel cells are the best suited for use in highway vehicles in the mid-term. Compared with other types of fuel cells, PEM cells are relatively light and compact and have the advantages of high power density, quick startup time, low operating temperature (80° to 100°C or 176° to 212°F) and potentially greater longevity. Phosphoric acid cell technology is perhaps the most mature, but it is too bulky for light-duty vehicle use.[96] Alkaline fuel cells perform comparably to PEM cells and have lower material costs, but they have extremely long startup times (up to 2 hours) and require a CO_2-free air supply to prevent poisoning of the cell electrolyte. Solid oxide cells potentially offer the greatest power densities but operate at very high temperature (800° to 1,OOO°C or 1,500° to 1,800°F), require extremely sophisticated fabrication techniques, and are far from commercialization. Thus, most light-duty vehicle demonstration programs today are planning to use PEM fuel cells.

In a PEM fuel cell, hydrogen is delivered to the anode and oxygen (or air) to the cathode. The anode and cathode are separated by a thin polymer membrane that conducts protons (hydrogen ions) but not electrons.[97] At the cathode, hydrogen separates into hydrogen ions and electrons in the presence of a platinum catalyst.[98] The electrons move through an external circuit, driving the motor. Hydrogen ions are conducted through the membrane, where they combine with the returning electrons and oxygen to form water, which is removed from the cell. Overall, the fuel cell combines hydrogen and oxygen to produce electricity y, heat, and water.

In addition to the engineering of the cell itself, an important challenge to designers of fuel cell propulsion systems is the means of storing the hydrogen fuel. As discussed earlier, hydrogen could be stored directly onboard the vehicle in high--pressure tanks, released in reaction with sponge iron, or produced onboard via reforming of a hydrogen carrier such as methanol, ethanol, or methane. Although onboard reforming adds complexity and weight to a fuel cell propulsion system, it probably represents the most viable fueling option since it allows the greatest vehicle range.

Methanol is perhaps the easiest to reform onboard the vehicle, because relatively modest temperatures are needed (300°C (570° F) or less) .99 Reforming of ethanol requires temperatures around 500°C (900°F) and some analysts suggest that will be a major disadvantage. It is not clear, however, whether an ethanol-fueled system would be prohibitively more complex than a methanol-fueled system.[100] Because the energy density of ethanol is about 25 percent higher than that of methanol (allowing greater vehicle range) and because ethanol is less corrosive and toxic, the

[96] The phosphoric acid fuel cell is considered a near-term option for heavy-duty vehicles. A phosphoric acid cell is currently being used in the Department of Energy's fuel cell bus demonstration program.

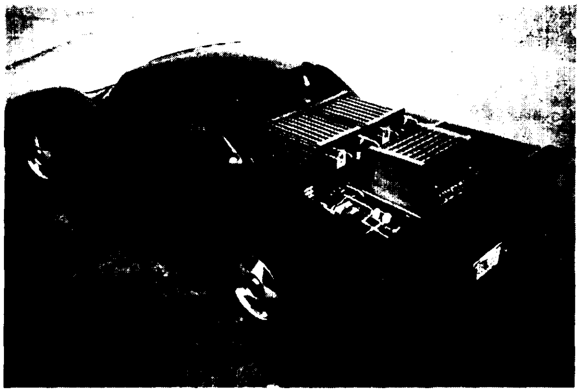
[97] A sing le membrane-electrode sandwich is about four-hundredths of an inch thick. A fuel cell stack is assembled by placing one membrane-electrode sandwich on top of another.

[98] Because the platinum catalyst is poisoned by CO, hydrogen for PEM fuel cells must contain no more than a few parts per million of CO. This imposes stringent cleanup standards on hydrogen produced via natural gas reforming.

[99] Researchers are also investigating the direct use of methanol in fuel cells (i.e., introduction of methanol fuel directly to the fuel cell anode). This would eliminate the need for an onboard reformer and could substantially reduce system complexity and cost. The technical challenges facing direct methanol fuel cells appear, however, to be significantly greater than those for hydrogen fuel cells. Michael Krumpelt, Argonne National Laboratory, personal communication, January 1994.

[100] Both methanol and ethanol are reformed at temperatures well above the operating temperature of the PEM cell. In either case. the reformate must be cooled and treated to remove CO. Thus the higher temperature of the ethanol reformer may not add much to the complexity and cost of the system. Romesh Kumar, Electrochemical Technology Program, Argonne National Laboratory, personal communication, Jan. 31, 1994.

ENERGY PARTNERS, INC



Energy Partners of West Palm Beach, Florida, is developing a prototype PEM fuel cell vehicle dubbed the "Green Car" The prototype is fueled by compressed hydrogen

reforming of ethanol for fuel cell vehicles is currently the subject of an R&D program funded by the Department of Energy (DOE). Methane reforming requires temperatures around 800°C (1,500°F). In the future, if solid oxide fuel cells are developed for transportation. methane or ethanol could be readily used because of the high operating temperature of the cells (800° to 1,000°C or 1,500° to 1,800° F).

A number of experimental PEM fuel cell vehicles are now under development.[101] The fuel cell vehicle is an electric drive vehicle that uses a fuel cell system in place of (or, in some designs, in parallel with) a rechargeable storage battery (see figure 4-4). The fuel cell system consists of a fuel cell stack, which produces the electricity; an air compressor to provide pressurized air to the fuel cell; a cooling system to maintain the proper operating temperature; and a water management system to keep the PEM membrane saturated and remove water as it is created at the cathode. If the fuel is stored as methanol or ethanol, a reformer is needed on the vehicle to convert the fuel to hydrogen.

In theory, all the power demands in an FCV can be provided by a fuel cell alone. The most practical implementation of fuel cells in vehicles, however, might involve designing a fuel cell to meet the "baseload" power requirement and using a peak power device to meet demands for quick acceleration. The peak power device could be a storage battery, an ultracapacitor,[102] or a flywheel.[103] Such a design approach could be quite important since methanol reformers cannot follow rapid load changes (unlike a fuel processor, batteries or ultracapacitors can more readily follow the load profile). Such a storage device could provide initial power during the fuel cell system warmup and also allow energy to be recovered from regenerative braking. Since most vehicles spend the vast majority of the drive cycle at low load where the fuel cell alone would be adequate, the peak power device could have a low storage capacity coupled with a high power density.

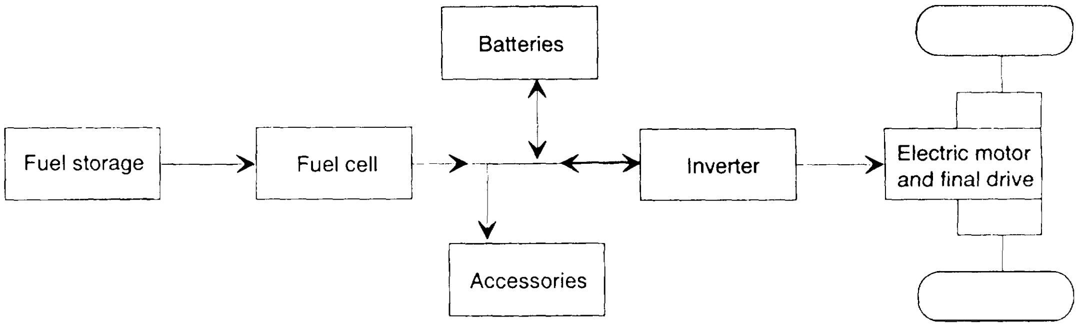
The overall environmental impact of a fuel cell vehicle will depend on the means of production and delivery of the hydrogen or hydrogen carrier

[101] DOE is now operating a demonstration fuel cell bus with onboard methanol reforming. DOE is also involved in a joint project with General Motors and other industrial partners to demonstrate a PEM fuel cell automobile (with onboard methanol reforming) by the turn of the century. Daimler-Benz recently unveiled a prototype PEM fuel cell van using high-pressure hydrogen storage. Energy Partners in Florida has recently unveiled its prototype "Green Car," a hydrogen-powered PEM fuel cell automobile. Mazda and Seimens are also developing PEM fuel cell vehicles. However, commercial production of these prototypes is still many years away.

[102] Capacitors store electric charge on metal surfaces separated by thin layers of insulator. Recent developments in materials technology, including the creation of aerogels—very light porous solids—allow the creation of substances with very large surface area compared with their volume, which makes them suitable for the construction of capacitors capable of storing and quickly delivering particularly large amounts of charge. Such devices are called ultracapacitors.

[103] Flywheels are in essence "electromechanical" batteries. A rapidly spinning rotor is used to store energy, which is then tapped electromagnetically. The principle of storing energy in a rotating wheel is an old one—potters use it, and many combustion motors employ a flywheel to smooth out fluctuations in their output-but new technology allows rotation speeds far greater than that possible with conventional steel-rimmed wheels. Modem flywheel rotors use advanced composite materials that are light and strong, and have very high energy densities because they spin so fast (up to 2,000 revolutions a second). See Michael Riezenman, "A Different Spin on an EV Battery," *IEEE Spectrum*, November 1992, p. 100.

FIGURE 4-4: Advanced Fuel Cell Vehicle Power Train Configuration



NOTE: In a fuel cell vehicle, fuel (e.g., methanol) is converted to dc electricity by the fuel cell. This energy is directed into the batteries or to the inverter depending on instantaneous demand. The inverter controls power flow to the electric motor(s) that propels the vehicle. This configuration allows the vehicle to be powered by the battery alone, the fuel cell alone, or a combination of both. The control strategy employed allows for intelligent load sharing between the fuel cell and the battery, depending on the driving requirements and state of charge of the batteries.

SOURCE: Allison Gas Turbine Division, "Research and Development of Proton-Exchange Membrane (PEM) Fuel Cell System for Transportation Applications: Initial Conceptual Design Report," EDR 16194, paper prepared for the Office of Transportation Technologies, U.S. Department of Energy, Nov. 30, 1993.

used. Just as BPEVs can offer significant environmental benefits if they are recharged by using renewably generated electricity, FCVs could have very low overall emissions if hydrogen or hydrogen fuel carriers were derived from renewable sources. If FCVs were to use hydrogen. methanol, or ethanol made from biomass, CO_2 emissions could be reduced by more than 90 percent compared with a gasoline ICEV (see table 4-1). It should be noted that fuel reforming does produce CO_2, but if renewably grown biomass is the fuel source, the global carbon budget would not be affected. The use of hydrogen produced from electrolysis of water using solar-generated electricity would virtually eliminate CO_2 emissions for the entire fuel cycle.

Despite their promise, large-scale commercial production of fuel cell vehicles is still many years or even decades away.[104] Many key vehicle technologies are still in the developmental phase. Although some advances have been made in the area of PEM fuel cell performance, much progress is required before a complete fuel cell system can be packaged for an automobile. The integration of different system components will be a formidable engineering undertaking. For example, if an onboard reformer is used, sophisticated thermal control equipment is required. The long-term reliability of the essential components of a fuel cell system has not yet been demonstrated in an automotive environment or over a typical automotive duty cycle.[105]

The costs of PEM fuel cell components must be reduced, in some cases, by orders of magnitude. Although fuel cell costs will likely decrease as

[104] The PEM fuel cell prototype vehicle being developed jointly by DOE and General Motors (Allison Gas Turbine) will not be completed until 1999 or 2000. Even if the protoyping effort is successful, it will take years of engineering refinement before mass production can begin.

[105] See Philip J. Haley, Chief Project Engineer, Vehicular Engines, Allison Gas Turbine Engine Division, testimony at hearings before the House Committee on Science. Space, and Technology, Subcommittee on Energy, July 20, 1993.

BOX 4-2: Fuel Cell Vehicle R&D Challenges

Many technical and economic barriers need to be overcome before the fuel cell vehicle becomes a viable competitor with other vehicle technologies. The main R&D issues facing fuel cell vehicles are:

- Development of proton-exchange membrane (PEM) fuel cells
  1. Reducing the cost and iImproving the performance of the polymer membrane without compromising its mechanical properties or making it more sensitive to impurlhes in the gas streams. At present, the cost of the membrane is the single largest contributor to the cost of the PEM fuel cell. Current costs for the membranes are about $1 ,000/kg, largely because these materials are custom manufactured in small quantities, Membrane costs need to be brought down to around $1 O/kg,
  2. Mass producing large-area fuel cell stacks with low platinum catalyst loadings, Platinum requirements have been greatly reduced (by fortyfold) in small-area laboratory fuel cells These advances need to be achieved for large-area fuel cell stacks as well
  3. Finding a simple and effective way to keep the membrane moist, while still removing product water at the cathode
  4. Developing a membrane that withstands temperatures of 150°C (300° F), This would allow methanol to be oxidized directly, thus obviating the need for a platinum catalyst.
  5. Reducing the size and energy consumption of the air compression system
  6. Reducting the weight, bulk, and cost of the fuel cell stack components and assembly
- Development of low-cost, compact, simple, and reliable fuel cell system auxiliaries.
- Development of electric drivetrains designed for long-range, high-efficiency, high-power, and rapid transient operation.
- Development of control systems for fuel cell vehicles, which can coordinate the use of fuel cell and peak power devices.
- Development of batteries or other peak power devices suitable for use in fuel cell vehicles, The characteristics required differ from those for battery-only powered electric vehicles.
- For hydrogen fuel cell vehicles, development of lightweight, low-cost, high-pressure compressed gas cylinders for onboard hydrogen storage.
- For methanol fuel cell vehicles, the development of onboard reformers with rapid response time, Methanol reformers today have long warmup times and cannot follow rapid load changes

SOURCES Joan M Odgen et al , "A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies, " report prepared for the Office of Technology Assessment, May 1994 and Michael Krumpelt, Argonne National Laboratory, personal commumcation, January 1994

economies of scale are achieved in manufacturing,[106] the reductions necessary to make FCVs competitive with other vehicle options will require intensive R&D in coming years.[107] Some of the major R&D challenges are enumerated in box 4-2. If mass production is able to bring down component costs and if major system integration challenges are met, some estimates indicate that it may be possible for FCVs to have life-cycle operating costs comparable to conventional gasoline ve-

[106] As manufacturing ramps up, many products typically follow a "learning" or "experience" curve, where costs decline 20 percent with each doubling of production. See Linda Argote and Dennis Epple, "Learning Curves in Manufacturing," Science, vol. 247, Feb. 23, 1990, pp. 920-924.

[107] A recent study estimates that a mass-produced FCV power system could cost as little as $50/kW. See Allison Gas Turbine Division, Op. cit., footnote 20.

hicles.[108] This is due principally to the high efficiencies and longer lifetimes possible with FCVs.[109] Many essential technologies, including the fuel cell itself, are still many years away from commercialization, however, and thus cannot be firmly costed. Consequently, such estimates should be treated cautiously.

Hybrid Vehicles

Given the technical difficulties confronting both battery-powered electric vehicles and fuel cell electric vehicles, researchers have been exploring the possible advantages of hybrid electric vehicles. Hybrid systems could provide many of the energy efficiency and emissions benefits of pure BPEVs, while offering greater flexibility with respect to range and performance. In the broadest sense, hybrid propulsion systems combine two power sources. The range of potential sources includes batteries, flywheels, internal combustion engines, gas turbines, fuel cells, and diesel engines.

One emerging hybrid concept is to use electric motors to drive a vehicle's wheels, with the motors powered by an electrical storage system that is recharged by a low-power internal combustion engine (the ICE drives an electric generator).[110] The combustion engine would run only when the electrical storage device needed recharging and would operate at a constant speed to maximize efficiency.[111] The electrical storage device could be a battery, ultracapacitor, or advanced flywheel, and could be used to recover energy currently lost during the braking cycle, thereby reducing total fuel consumption. Because the ICE would be small (about half the size of conventional ICE powerplants) and would run at one design speed, the hybrid could be quite clean and efficient.[112] Ultimately, the ICE powerplant could be replaced by a fuel cell or gas turbine.[113]

Initially, ICE hybrids would probably run on gasoline, but by taking advantage of a proven propulsion technology such as the ICE, hybrid systems might generate early market demand for various renewable fuels and facilitate the development of an alternative fuel infrastructure. Although conventional ICEVs powered by alternative fuels could offer near-term petroleum conservation benefits, ICE hybrids perhaps offer a transitional pathway to advanced BPEVs and FCVs.

An ICE-based hybrid could run on a variety of fuels such as hydrogen, ethanol, methanol, reformulated gasoline, or natural gas. Researchers at Lawrence Livermore National Laboratory have projected the vehicle efficiencies that might be

[108] FCVs could still have a higher initial purchase price. See Delucchi, op. cit., footnote 91.

[109] An electric drivetrain is expected to result in lower maintenance costs and extend vehicle life. Ibid.

[110] See Smith, op. cit., footnote 92; and A. Burke and D. Sperling, "Hybrid Vehicles: Always Second Best?" *Future Drive: Electric Vehicles and Sustainable Transportation* (Washington, DC: Island Press, 1994).

[111] The typical urban driving cycle, with its varying speed and load demands, greatly reduces engine conversion efficiency. Some estimate that a hybrid design that would allow the ICE to operate at a single speed and load point, might double engine efficiency in comparison with current designs. See Smith, op. cit., footnote 92; and Amory B. Lovins et al., *Supercars and Nega-km: The Coming Light-Vehicle Revolution* (Snowmass, CO: Rocky Mountain Institute, Feb. 1, 1993).

[112] Note, however, that the efficiency of ICEs does decrease, all else equal, as size decreases. Also, even with a relatively small range of 40 to 50 miles, such a hybrid could meet a large fraction of the daily driving needs of many urban drivers in the electric mode (i.e., without using the heat engine). If the ICE were sized in the 25- to 40-kW range, the hybrid could travel much longer distances (i.e., the hybrid would operate in all electric mode in the city and use the ICE for highway driving). See Burke and Sperling, op. cit., footnote 110.

[113] The use of a small gas turbine as an automotive powerplant could offer a number of benefits. Gas turbines can use a number of alternative fuels, including methanol and hydrogen, and can have low emissions of criteria air pollutants. However, automotive gas turbines are still in the development stage. Reliability and efficiency are uncertain. See U.S. Department of Energy, *Conservation and Renewable Energy Technologies for Transportation* (Washington, DC: 1990); and Robert Harmon, "Alternative Vehicle Propulsion Systems," *Mechanical Engineering*, March 1992, p. 58. An upcoming OTA study will provide a detailed review of automotive gas turbines.

TABLE 4-6: Estimates of Series Hybrid Vehicle Efficiencies[a]

Vehicle type	Overall vehicle efficiency for a typical urban driving cycle (percent)
Conventional Internal combustion engine vehicle (ICEV)	12-15
Battery-powered electric vehicle (BPEV)[b]	20
Gasoline internal combustion engine (ICE) hybrld[c]	24
Compressed natural gas ICE hybrid	28
Proton-exchange membrane fuel cell hybrid	*30-40*
Hydrogen ICE hybrld[d]	30-40

[a]The comparisons are done on abasis of equal vehicle weight, drag, and rolling resistance

[b]The BPEV is assumed to be charged by a powerplant operating at 36-percent efficiency, with a power transmission efficiency Of 92 Percent The BPEV itself has an efficiency of about 50 percent, resulting in an overall efficiency of about 20 percent

[c]The electrical storage dewce is assumed 10 be an advanced flywheel having a turnaround efficiency of 95 percent

[d]It is assumed that the compression ratio for a hydrogen ICE can be raised to about 15 (conventional ICEVs have compression ratios of about 10) This would result in an engine having 48-percent efficiency

SOURCE J Ray Smith "The Hydrogen Hybrid Optlon," paper presented at the Workshop on Advanced Components for Electric and Hybrid Electric Vehicles Gaithersburg, MD, Oct 27-28, 1993

achieved using different fuels (see table 4-6). In comparison to a conventional ICEV, they estimate that a gasoline hybrid might add an additional 10 percentage points to overall vehicle efficiency for a typical urban driving schedule (24 versus 13 percent).[114] Such a vehicle would effectively double the urban mileage that could be traveled for a given quantity of gasoline. A CNG hybrid would have slightly better efficiency (28 percent), because of the higher compression ratio possible for CNG engines. Efficiencies similar to CNG would be expected when alcohol fuels are used. Perhaps most interesting, a hydrogen ICE hybrid might achieve efficiencies comparable to a fuel cell hybrid (30 to 40 percent). Thus, the hydrogen hybrid has the potential to be the "mechanical equivalent of the fuel cell." As noted before, however, these projections are subject to considerable uncertainty in terms of the efficiency of individual components and overall integrated system efficiencies. Much further research is needed to better quantify performance and to develop working demonstration vehicles for these various options.

Although tailpipe emissions from a hydrogen ICE hybrid would not be zero as from a fuel cell vehicle with onboard hydrogen, the emissions of $C0_2$, hydrocarbons, and nitrogen oxides could be significantly lower than for conventional ICEVS.115 A hydrogen-fueled engine is potentially a near- to mid-term (10 to 15 years) technology option since prototype hydrogen ICEVs have already been developed. Because of the efficiency associated with a hybrid configuration, hydrogen storage requirements might be reduced by 50 to 65 percent compared with a hydrogen ICEV.[116] In

114There would be essentially no improvement for highway driving, because an ICEV runs basically at one speed on the highway. ICEVs can achieve highway efficiencies of about 25 percent.

115No ICE electric hybrid, however, has yet been built to compare emissions with pure BPEVS under real driving conditions.

116Rambach, op. cit., footnote 60.

addition, hydrogen fuel costs over a 300-mile (480-km) operating range would not be prohibitively expensive.[117] If the difficulties associated with creating a hydrogen infrastructure can be surmounted, development of a such a hybrid might provide an important pathway to a hydrogen-based transportation systcm.

The most plausible hybrid candidates in terms of cost and technical difficulty, however, are likely to be gasoline- or alcohol-based vehicles. It should be stressed that them are serious engineering challenges confronting hybrids. For example, a hybrid vehicle will require a complex power control system that coordinates heat engine (e.g.. an ICE or gas turbine) and electrical storage system operation. In addition, much must be learned about hybrid performance, efficiency, emissions, reliability, complexity, and cost. In 1993, DOE initiated a $ 138-million, five-year program with General Motors, and a $122-million program with Ford, to design and develop prototype hybrid vehicle systems.

POLICY ISSUES

The evolution of the U.S. transportation system toward full use of renewable energy sources in advanced vehicles could take very different directions depending on the market response and on the relative importance placed by policymakcrs on key energy and environmental issues, including urban air quality, greenhouse gas emissions, and energy security. The evolution and development of specific technologies, and of the policies that support those technologies, will be driven principally by the prospect of cost, energy security, or environmental benefits.

Although some of the propulsion technologies and alternative fuels discussed here could eventually be commercialized through the operation of normal market forces, it is not likely that such commercialization will happen in the near to mid-term, given the low prices of gasoline now available to consumers.[118] If Policymakers determine that it is necessary or desirable to introduce high-efficiency, low-emission vehicle technologies in the near to mid-term. then some level of government intervention will continue to be required.[119]

Federal policy is starting to play a major role in developing and commercializing these technologies, especially with the recent increases in federal funding for RD&D in alternative fuels and advanced vehicle technologies.

There exists abroad array of policy instruments that could affect either the supply of vehicles that use alternative fuels or the demand for them. Supply-side instruments can include increased public R&D funding and coordination, higher fuel efficiency standards, and stringent emissions regulations. Some of these options, however, do not guarantee that consumers will actually purchase vehicles that use alternative fuels. Thus, demand-side instruments might also be required. These could include lower tax rates for alternative fuels relative to gasol ine, "feebates” for energy efficien-

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117 One study estimates that a hydrogen hybrid that carried five passengers would consume about 1.5 MJ/mile (2.4 MJ/km). If the delivered cost for hydrogen ranges from $30 to $50/GJ, the fuel operating cost would range from $13 to $23 per 300 miles *(480* km). This is comparable to the operating cost of many conventional gasoline ICEVs. If advanced lightweight materials and streamlined aerodynamics were incorporated, hybrid operating costs would drop even further. Ibid.

118 The market challenges associated with a shift to high-efficiency vehicles that use alternative fuels will be substantial. Such a shift will require extensive and expensive development of a new fuel infrastructure, retooling of portions of the automobile industry, and additional financial considerations for consumers if the new vehicles have higher upfront capital costs (even if competitive on a life-cycle basis).

119 For example, if it is determined that national levels of greenhouse gas emissions need to be reduced below current targets, energy efficiency improvements will probably not be sufficient to achieve long-run, deep cuts in CO_2 emissions unless there is a switch to renewable transport fuels. Such a transition away from a petroleum-based transportation system would likely take many decades even with aggressive government intervention (see chapter 1).

BMW OF NORTH AMERICA, INC

BMW has developed a compact electric vehicle dubbed the "E1." The concept car has been designed as an all-electric vehicle, or as an electric hybrid that uses a small ICE for long-distance travel and to recharge the vehicle's batteries.

cy,[120] tax incentives for the purchase of advanced vehicles, pollution-based registration fees for automobiles,[121] exemptions from transportation control measures,[122] and government procurement of advanced vehicles that run on alternative fuels.

As illustrated in earlier sections, there are several plausible transition pathways that could result in greater reliance on renewable fuels. Both conventional and emerging vehicle technologies can take advantage of energy carriers such as methanol, ethanol, hydrogen, and electricity. Many economic and technical factors are, however, likely to make a transition to a renewable-based transportation system difficult.

In the short term, accelerated commercialization of ICEVs that use alternative fuels could create the groundwork for a renewable fuel infrastructure. Although many of these vehicles would bum fuels derived from nonrenewable sources (e.g., methanol from natural gas), in the near term, markets would be created that could encourage investment in renewable energy sources and technologies.

Several important policy measures for promoting the development of alternative fuels have already been taken at the federal and state levels. These are:[123]

- CAFE (Corporate Average Fuel Economy) credits are available to automakers who produce alternative fuel vehicles, permitting them to treat the vehicles as very-high-mileage cars that can be averaged into their fleets and allow fuel economy standards to be met more easily. These credits, however, are unlikely to provide much incentive to most automakers unless fuel economy standards are raised.
- The Clean Air Act Amendments (CAAA) of 1990 established three clean fuels programs: section 249 establishes a pilot test program in California; section 246 establishes a centrally fueled-fleet (10 or more vehicles) program in air quality nonattainment areas; and section 227 requires gradually increasing sales of urban buses that use clean fuels. Perhaps more

[120] Under a "feebate" system, car buyers would either receive a rebate or pay a fee based on the vehicle's fuel economy, with the fees paying for the rebates.

[121] As automobiles age, their emissions characteristics frequently deteriorate, while their registration fees Often are reduced. If registration fees were based on the emissions performance of cars, the environmental costs of driving older or underperforming cars could be partially accounted for. Such smog fees might range from $20 (for cars that use clean fuels) to $1,000 per year (for cars that emit large quantities of criteria pollutants). The fees could be used to offset the costs for low-income drivers. Some researchers believe that pollution fees could be an extremely cost-effective approach for lowering emissions. See Deborah Gordon, "Alternative Fuels Versus Gasoline: A Market Niche?" *Forum for Applied Research and Public Policy*, spring 1994, pp. 5-12; and Winston Barrington and Margaret Walls, Resources for the Future, "Shifting Gears: New Directions for Cars and Clean Air," No. 115, spring 1994, pp. 2-6.

[122] For example, consumers who purchase alternative fuel vehicles could be given permission to travel in high-occupancy-vehicle lanes. Such exemptions from transportation control measures, however, could increase congestion. See U.S. Congress, General Accounting Office, *Alternative-Fueled Vehicles: Potential Impact from Transportation Control Measures*, GAO/RCED-93-125 (Washington, DC: U.S. Government Printing Office, April 1993).

[123] The following points are drawn from and discussed more fully in Office of Technology Assessment, op. cit., footnote 14.

importantly, the CAAA requires that gasoline be oxygenated if a city is out of compliance with CO standards. As a consequence, by the turn of the century more than 70 percent of all gasoline sold could contain oxygen and thus ethanol, methanol, or their derivatives. [124] For the same mass (weight) of emissions, alternative fuels produce less ozone than gasoline because their exhaust emissions are less photochemically active. California is moving toward emissions standards that correct for this difference in the reactivity of emissions. Thus, gasoline-fueled vehicles would have to achieve lower (mass) emissions than vehicles fueled by ethanol, methanol, or their derivatives. The California Air Resources Board (CARB), however, believes that reformulated gasolines will satisfy CAAA's clean fuels requirements, which would limit the extent to which the act will actually promote alternative fuels. [125] The act Phase 11 emissions standards, set to begin in model year 2001 (if deemed necessary by EPA), are much more stringent (see table 4-3), so estimates that relatively low levels of alternative fuels will be promoted by the CAAA should be considered preliminary.

- The State of California's pilot test program under the CAAA, called the Low Emission Vehicle Program (LEVP), requires minimum sales of vehicles in different emissions categories, ranging down to zero emissions (e.g., 2 percent of vehicles sold in 1998 must be zero-emission vehicles). New York and Massachusetts have decided to adopt the California LEVP. As with the CAAA clean fuels requirements, CARB believes that reformulated gasoline, perhaps in conjunction with modified emission control systems, will satisfy most and perhaps all of the emission categories except the Zero-Emission-Vehicle (ZEV) requirement, which probably can be satisfied only with an electric vehicle or a fuel cell vehicle that uses onboard hydrogen as fuel. Some observers have criticized the ZEV requirement because it fails to consider total fuel-cycle emissions and thus might place promising technologies such as ICE-electric hybrid vehicles at a disadvantage. *26 The next most stringent category, for Ultra Low-Emission Vehicles, may generate alternative fuel use even if reformulated gasoline can satisfy its requirements, because of cost considerations. Current assessments of reformulated gasoline's ability to meet stringent emissions standards should. however, be treated cautiously.
- The Energy Policy Act (EPACT) of 1992 establishes a national goal of 10-percent alternative fuel use by 2000 and 30 percent by 2010. EPACT provides tax incentives for vehicle purchasers and for service station operations. Specific acquisition requirements are placed on federal fleets, with potential requirements for fleets run by state and local governments. Half of these nonpetroleum replacement fuels would have to be produced domestically. Thus, EPACT could encourage the development of methanol or ethanol from biomass sources. Recent analyses of the projected market penetration of alternative fuel vehicles suggest,

'24See footnote 33.

125D.E. Gushee, Congressional Research Service, "Alternative Transportation Fuels: Are They Reducing 011 Imports?" CRS Issue Brief, updated Mar. 8, 1993.

126Depending on the assumptions, some believe that certain proposed hybrid configurations could result in zero tailpipe emissions in the city, where they would run in a pure electric mode, and have ultralow emissions on the highway. Depending on the fuel used in the ICE, the overall fuel-cycle emissions of hybrids could well be less than BPEVs when electricity powerplant emissions are taken into consideration. This might be especially true for the case of ICE hybrids that run on hydrogen. Pure BPEVs may be much cleaner on a fuel-cycle basis than gasoline ICE hybrids. No ICE-electric hybrid has yet been built to compare emissions with all-electric vehicles under real driving conditions. See Delucchi, op. cit., footnote 91.

however, that these goals will not be achieved easily.[127] Without petroleum price increases, subsidies, or tax credits to quicken the pace of product commercialization, or increased federal support of R&D activities, EPACT goals will likely not be attained in the timeframes established. Only 3 to 4 percent of the light-duty fleet in 2010 will likely be alternative fuel vehiclcs.[128]

In addition, the EPACT goals established by Congress may not be achieved unless inconsistencies with other federal policies are addressed. For example, widespread adoption of some alternative fuels such as methanol might be discouraged bccausc they are taxed at higher rates per unit of energy than gasolinc.[129] current fuel taxation policy docs not appear to take full account of the unique characteristics of alternative fuels. Fuel taxation rates seem to bear no relation to energy conservation or environmental goals. Policy makers may wish to examine the possibility of taxing each alternative fuel at the same rate in dollars per unit energy. The rate could be equal to current gasoline taxes, reflecting the government's desire to allow the market to decide, or lower to favor alternative fuels over gasoline. Consideration could also bc given to differential taxation rates that reflect each fuel's "nonrnarket" characteristics such as environmental and energy security impacts, in so far as they can be calculated, given the many uncertai nt ics.

Even if a rapid increase in alternative fuel use occurs in coming decades, markets for renewable fuels still might not emerge. It is quite possible that methanol and hydrogen, for example, would be derived from coal before biomass. This could happen if natural gas supplies become scarce before bioenergy systems are commercidized. From an environmental perspective. such a scenario would not be desirable (production of methanol and hydrogen from coal would result in relatively higher emissions of CO_2 in particular and possibly other air pollutants). Therefore, policy makers might want to consider how biomass fuel pathways could be specifically encouraged. One strategy, for instance, would be to intensify R&D support of enzymatic hydrolysis efforts (for the production of ethanol from woody and herbaceous crops). This could serve as an interim measure to develop a crop production and fuel transport infrastructure. Eventually, with further development of biomass gasification technology, this infrastructure could be used for the production and delivery of methanol and hydrogen. Economically competitive gasification processing would permit a greater diversity of biomass feedstocks to be exploited.

Vehicles that run on ethanol or methanol from biomass feedstocks, or on hydrogen produced from biomass or renewably generated electricity, offer the possibility of extremely clean and high-performance transportation. However, considerable R&D is necessary to bring down production costs of these alternative fuels, and in the case of hydrogen, to develop adequate storage technologies. If funding for biomass conversion programs were to be significant 1 y reduced, this would 1ikely prove to be quite damaging to biofuel commercialization efforts. Because there are a number of' challenges associated with the production and use of hydrogen as a fuel, government support is probably necessary to ensure that some types of R&D are carried out.

Vehicle Technologies

In terms of vehicle technology, multiple R&D options exist, including R&D tax credits; direct financing of R&D through government labs,

[127] U.S. Department of Energy, Energy Information Administration, *Assumptions for the Annual Energy Outlook, 1993*, DOE/EIA-0527(93) (Washington, DC: January 1993).

[128] Ibid.

[129] D.E. Gushee and S. Lazzari, Congressional Research Service, "Disparate Impacts of Federal and State Highway Taxes on Alternative Motor Fuels," Mar. 12, 1993.

TABLE 4-7: DOE Funding of Advanced Batteries, Electric Vehicle Systems, and Fuel Cells ($ millions)

	FY 1993	FY 1994	FY 1995
Advanced batteries	$312	$358	$286
Fuel cells	119	193	230
Electilc vehicle systems (prlmarlly hybrid vehicles)	167	188	382
Total	$598	$73.9	$899

SOURCE: U.S. Department of Energy, *FY 1996 Congressional Budget Request*, vol. 4, DOE/CR-0030 (Washington, DC February 1995)

university research grants, or private contracts; and joint public-private partnerships. Successful development and domestic production of high-performancc vehicles could allow the large U.S. trade imbi.dance for vehicles and parts, currently at about $45 billion per year, to be reduced.[130]

Many of the vehicle technologies receiving federal R&D support offer the promise of improved energy efficiency and environmental qual - it y. As discussed earlier, the fuel cell vehicle is the technology that potentially offers the most benefits, but a number of serious cost and engineering barriers must bc surmounted before commercialization can occur. If system integration challenges can be met, ICE-hybrid vehicles could potentially offer a mid-term solution until FCV technologies are fully developed. Battery -powered electric vc-hiclcs are also an attractive option, but major breakthroughs in battery technology will probably be needed if they are to expand beyond niche markets.

Department of Energy R&D support of these technologies amounted to nearly $60 million in FY 1993.[131] Research on fuel cells, hybrids, and advanced batteries increased 25 percent in FY 1994 (see table 4-7). As part of the Partnership for a New Generation of Vehicles program,[132] total spending on fuel cell technologies for 1ight-duty vchiclcs could total more than $440 million through 2003.[133]

The strategy of pursuing several different technology options is advantageous for a variety of reasons. First, emphasizing one particular fuel-vehicl technology combination is extremely risky. There is no guarantee that any particular technology will ever satisfy the cost constraints required for large-scale cornmcrcialization. Al-

[130] U.S. Department of Commerce, International Trade Administration, *U.S. Industry Outlook 1994* (Washington, DC: U.S. Government Printing Office, January 1994), p. 35-1.

[131] In addition to DOE, the Department of Transportation (DOT) and the Advanced Research Projects Agency (ARPA) sponsored electric vehicle research. In FY 1992, DOT's appropriation was $12 million for electric vehicle R&D, while $25 million was appropriated for ARPA programs in FY 1993. In FY 1994, ARPA announced a $2.4 million program to advance the state of the art in PEM and solid oxide fuel cell technologies. ARPA funding is set up on a cost-sharing basis with the private sector.

[132] In September 1993, the White House announced the signing of an agreement between the federal government and the three domestic automakers designed to create a public-private partnership to develop a new generation of vehicles up to three times more efficient than conventional vehicles.

[133] See Mary Good, Undersecretary of Technology, U.S. Department of Commerce, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Technology, Environment, and Aviation, May 19, 1994.

though more expensive in the short term, a federal R&D portfolio that explores many different technologies increases the likelihood that a low-emission, high-efficiency vehicle technology will actually be introduced to the market. [134]

Secondly, a diverse R&D portfolio can take advantage of synergies that cut across technologies. For instance, load reduction is central to all vehicle technologies; thus, reductions in aerodynamic drag or vehicle mass could be applied to ICEVs, hybrids, FCVs, or BPEVs. Advances in hydrogen storage technology could benefit corresponding FCVs, hybrid vehicles, and ICEVs. Similarly, advances in electric drivetrain technologies can be applied not only to BPEVs, but also to fuel cell and hybrid systems. Given the existence of such complementary relationships among different technologies. a multipronged R&D effort-if properly designed-can ensure that promising fuel-vehicle pathways are not abandoned prematurely. Parallel development efforts could focus on energy storage technologies (e.g., battery storage or fuel storage), electric drive technologies, and powerplant systems such as fuel cells, gas turbines, or advanced internal combustion engines. Extensive interaction between these development teams would be needed. Key elements from these modules could then be combined in prototypes for different vehicle systems. Still, some focused R&D efforts could accelerate the introduction of particularly promising technology pathways. For example, a hydrogen hybrid demonstration program could expedite the development of hydrogen engine and storage systems and thereby create momentum for the development of a hydrogen fuel distribution system.

Should there be substantial cutbacks in government R&D programs, introduction of less mature alternative vehicle technologies, such as FCVs and some types of hybrid vehicles, could be delayed. For instance, DOE now has significant cost-sharing arrangements with industry that could be affected by cutbacks in funding. Regulatory pressures and competition from foreign countries could keep up some of the momentum that has been building in the private sector for development of these technologies, but perhaps not at the same scale that exists now. For example, it is reasonable to expect that electric vehicle R&D will continue and production will increase as California ZEV requirements take effect.

CONCLUSION

Even if economic and technical barriers can be overcome, the successful introduction of advanced automotive propulsion systems that use renewable fuels will be only a partial solution to our society's transportation problems. The issues of congestion, highway safety, and the overall efficiency of the transportation system will still need to be addressed. Settlement patterns and the role of mass transit must be considered as part of any policy strategy that seeks to modify the way in which people travel. [135] For the foreseeable future, however, the strong preference of American citizens for personal transport is unlikely to change. Thus, the evolution of vehicle technologies that utilize renewable energy sources will bean important element of the nation's effort to improve energy efficiency, reduce oil imports, and minimize disruption of the environment.

[134] This is the present strategy of the DOE Advanced Vehicle Propulsion Program. Venkateswaran and Brogan, Op. cit., footnote 3.

[135] For a detailed discussion of these issues see Office of Technology Assessment, op. cit., footnote 14.

Electricity: Technology Development 5

Renewable energy technologies (RETs) have the potential to contribute significantly to electricity supplies in a cost-effective and environmentally sound manner. More than one-third of all U.S. energy goes to producing electricity, so the market for generating technologies is huge.[1] Bioenergy, geothermal, hydropower,[2] photovoltaic (PV), solar thermal, and wind RETs are discussed in this chapter. The cost of these technologies over time, their potential environmental impacts, and the nature and degree of their respective contributions will vary with the particular RET and its relative maturity, the locally available renewable energy resources, the specific application, and the effectiveness with which a variety of market challenges are met. Other technologies, such as ocean thermal energy conversion and solar ponds, appear to have less potential and have been dropped from federal research, development, and demonstration (RD&D) efforts; they are not discussed here.

This chapter examines four themes: 1) the status and role of RETs applicable in the electricity sector, and their associated industries, 2) the integration of these RETs into remote applications and electricity grids, 3) RD&D challenges that need to be overcome in order to commercialize these technologies, and 4) technical and policy issues associated with further development of

[1] The electricity sector share of U.S. energy consumption has increased from 25 percent in 1970 to 36 percent in 1990.

[2] Hydropower, of course, has long been a major low-cost contributor to U.S. and world electricity supplies. In 1992, hydropower provided 8.5 percent of U.S. electricity. See U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, 1992, USDOE/EIA Report 0384(92) (Washington, DC: U.S. Government Printing Office, June 1993).

BOX 5-1: Fossil-Fueled Electricity: The Baseline

Fossil fuels currently power most electricity generation in the United States. Steam boilers, gas turbines, and diesel engines are the primary fossil-fueled technologies today New technologies becoming available Include fluidized bed systems for more efficiently and cleanly burning coal, gasification systems for gasifying coal as a fuel for gas turbines, various combinations of gas turbines and steam turbines in "combined cycles" so as to Improve overall system efficiency, and advanced gas turbine cycles such as the combined cycle or the intercooled steam-injected gas turbine Efficiencies of advanced cycles are expected to reach 60 percent and above within two decades. I

Costs of electricity from various fossil-fueled systems typically range from roughly 4¢ to 6¢/kWh for baseload systems and higher for load following and peaking power These costs depend strongly on the availability and price of fuel. Fossil-fueled systems have relatively low capital costs, high reliabilities, and a well-developed base of experience, this makes them formidable competitors to renewable energy technologies (RETs). Technical advances will allow fossil-fuel technologies to continue to be formidable competitors with RETs for some time to come.

[1] Douglas J Smith, "Advanced Gas Turbines Provide High Efficiency and Low Emissions *Power Engineenng,* March 1994, pp 23-27, and Paolo Chiesa et al , "Predicting the Ultimate Performance of Advanced Power Cycles Based on Very High Temperature Gas Turbine Engines, " paper presented at the American Society of Mechanical Engineers, Gas Turbine Congress, Cincinnati, OH, 1993

RETs for electricity generation. Chapter 6 complements this chapter by exploring many of the financial and institutional issues associated with RETs in electric power applications.

The cost of electricity generated by several of these RETs has dropped sharply over the past two decades with technological advances and modest commercialization efforts. For example, the cost of PV-generated electricity decreased by a factor of three and the cost of wind-generated electricity decreased by a factor of five between 1984 and 1994. Substantial field experience has been gained with several of these RETs as well. For example, some 8 GW of bioenergy, 2 GW of geothermal, 1.7 GW of wind, and 354 MW of solar thermal electricity-generating capacity were installed in the United States, and some 190 MW of PV capacity was installed globally between 1980 and 1990.

RETs such as biomass, geothermal, hydro, and wind can be cost-competitive with conventional energy technologies today (see box 5-1), depending on resource availability andlor cost. (Their use may be limited, however, by a variety of financial, tax, and institutional challenges, as described in chapter 6.) Other RETs, such as PVS and solar thermal, are generally more expensive and are currently limited to higher value applications, but have the potential to be widely competitive in the mid-term.

Electricity generation costs for several of these RETs are widely expected to continue to decline with further RD&D and as markets continue to develop and allow larger scale production and associated economies of scale and learning. This will make these technologies cost-effective in an increasingly wide range of applications even without considering their environmental benefhs. Cost, performance, and market advances for each of these technologies and their applications are discussed below.

RENEWABLE ENERGY TECHNOLOGIES AND INDUSTRIES

Renewable resources in the United States are very large, with one or more resources available almost everywhere. As discussed in chapter 1, site specificity, availability, and resource intensity need to be addressed in any particular application. The status and potential of these renewable energy resources and technologies,[3] and the industries that are developing and applying them, have changed significantly in the past two decades.

I Biomass

Biomass residues have long been burned by the forest products and other industries to generate process steam and electricity. As discussed in chapter 2, a growing awareness of the potential of dedicated bioenergy crops to improve the environment (including offsetting sulfur oxides (S OX) and greenhouse gas emissions (carbon dioxide) by fossil fuels), aid the rural economy, and reduce federal agricultural expenditures have prompted renewed interest in this resource. Biomass resources and technologies are described in box 5-2.

Roughly 8,000 MW of bioelectric[4] capacity is currently grid connected in the United States, compared with less than 200 MW in 1979. Additional bioelectric capacity is operated off-grids Steam turbines are now used. but a variety of new fuel handling and energy conversion technologies such as whole-tree burners and integrated gasification advanced gas turbine systems (including combined-cycle turbines and steam-injected gas turbines) promise to nearly double current efficiencies and substantially reduce costs (see box 5-2).

As biomass is "stored solar energy, " it can be used as needed to provide power in baseload or load following applications (see box 5-3). This makes biomass a very important complement to intermittent renewable such as wind and solar, which provide electricity only when the wind blows or the sun shines. Biomass can also be co-fired with coal, a potentially important near-term application for reducing SO_x emissions, among other benefits, and thus may stimulate the market for biomass production. Of course, the relative value of biomass for electricity generation must be compared with its use for producing liquid or gaseous fuels (see chapter 4), for pulp and paper, or for other applications.

The bioelectricity industry[6] is among the most diverse among RETs. It includes forest products companies, such as Weyerhauser, which ha ve long cogenerated electricity at pulp and paper plants, as well as nonutility generators (NUGs) such as Wheelbrator and Thermo Electron. Equipment manufacturers include those that produce conveying equipment, boilers, electrical machinery, and controls. The industry also includes a number of biomass-specific equipment manufacturers such as Morbark Industries or Hallco Manufacturing. The transition to advanced gas turbines will include manufacturers such as General Electric and Pratt & Whitney. Engineering and construction

[3] RETs have been extensively reviewed elsewhere and so are only briefly examined here. RETs not examined here include ocean energy technologies (ocean thermal energy conversion, wave energy, tidal energy), additional bioenergy technologies (e.g., anaerobic digestion to produce methane, municipal solid wastes), fuel cells (chapter 4), energy storage technologies, and new transmission and distribution technologies. For further information, see World Energy Council, *Renewable Energy Resources: Opportunities and Constraints /990 -2(?20* (London, UK: World Energy Council, 1993); Thomas B. Johansson et al. (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993); U.S. Department of Energy, Office of Conservation and Renewable Energy, "Renewable Energy Technology Evolution Rationales, ''draft, Oct. 5, 1990; California Energy Commission, *Energy Technology Status Report* (Sacramento, CA: June 1990); John Doyle et al., *Summary of New Genera(ion Technologies and Resources* (San Ramon, CA: Pacific Gas and Electric Co., 1993); and American Solar Energy Society, *Progress in Solar Energy Technologies and Applications* (Boulder, CO: January 1994).

[4] Most of this capacity is based on burning wood from the forest products industry. Roughly 2,000 MW of municipal solid waste electricity-generating capacity is also included in this estimate. Agricultural residues and landfill gas account, very roughly, for about 500 MW of capacity.

[5] American Solar Energy Society, op. cit., footnote 3, p. 36.

[6] For a more complete listing of companies active in developing bioenergy equipment and powerplants, see "The 1995 International Competitive Power Industry Directory," *Independent Energy*, December 1994; and Susan Williams and Kevin Porter, *Power Plays: Profiles of America's independent Renewable Electricity Developers* (Washington, DC: Investor Responsibility Research Center, 1989).

BOX 5-2: Biomass Energy Resources and Technologies[1]

Biofuels—primarily from forest, agricultural, or municipal solid waste residues—currently provide about 3 EJ (2.9 Quads) or 3.5 percent of U.S. primary energy (see table 2-2 in chapter 2) These resources are now increasingly committed in some areas. For example, spot market prices for biomass in northern California have sometimes reached $250 to $3.75/GJ ($2,60 to $3 90/MMBtu) —as much as twice the normal cost, prompting the hauling of wood in from as far away as Idaho,[2] Consequently, interest in growing dedicated energy crops has developed (see chapter **2),**

The physical and chemical composition of biomass feedstocks varies widely, potentially requiring some tailoring of fuel handling and/or conversion technologies to specific biofuels, The relatively low bulk densities of biomass and large required collection areas limit the amount of biomass at any given site, with implications for the choice of generation technology, system efficiencies, and economies of scale.

Technologies

To generate electricity, biomass can be cofired with coal in conventional coal plants, separately burned in steam plants, or gasified to power gas turbines, fuel cells, or internal combustion engines, among others,[3] All of these uses of biomass are analogous to their fossil-fuel counterparts,

Virtually all biomass electric plants use steam turbines, which are generally small scale (typically 10 to 30 MW, with few over 50 MW) due to the limited amounts of biomass typically available at particular sites. Thus, they usually do not incorporate certain heat recovery equipment common to larger systems, and their efficiency tends to be low—l 7 to 23 percent in California, for example,[4] At larger scale sites, efficiency is higher. For example, the 50 MW plant in Burlington, Vermont, has an efficiency of 28 percent, In comparison, modern coal plants are much larger and typically run at 35 percent efficiency,[5] Very-large-scale biomass steam plants would likely have efficiencies roughly comparable to coal, but these scales may be limited by the large collection areas required and the corresponding problems of land availability and transport cost,

Steam turbine technology is fairly mature and few advances are foreseen for biomass improvements are possible, however, in biomass handling Whole-tree burners, for example, are under development and may reduce the required handling, increase net energy efficiencies silghtly, and avoid the cost of chipping the wood before burning It This might save about one-third of the cost of harvesting and delivering the biomass to the powerplant.[6]

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[1] Bioenergy resources, technologies, and environmental impacts are discussed at greater length in Thomas B Johansson et al (eds), Renewable *Energy* Sources *for Fuels and Electricity* (Washington, DC Island Press, 1993), U S Department of Energy, "Electricity from Biomass National Biomass Power Program Five-Year Plan (FY 1994-FY 1998), " draft, April 1993, Blair G Swezey et al , *The Potential Impact of Externalities Considerations on the Market for Biomass Power Technologies,* NREL/TP-462-5789 (Golden CO National Renewable Energy Laboratory, February 1994), and Antares Group, Inc "Electricity from Biomass An Environmental Assessment and Strategy, " draft, January 1993

[2] George A Hay Ill et al *Summary of New Generation Technologies and Resources* (San Ramon, CA Pacific Gas and Electric Co , Jan 8, 1993)

[3] Biomass can also be converted to ethanol, methanol, hydrogen, or pyrolysis oils, among others or burned for Space heat in the residential/commercial sector or for process heat in Industry

[4] Jane Turnbull, Electric Power Research Institute, personal communication, August 1993 In comparison Williams and Larson estimate these efficiencies at 14 to 18 percent See Robert H Williams and Eric D Larson "Advanced Gasification-Based Biomass Power Generation, " in Johansson et al (eds), op cit , footnote 1

[5] See, e g Electric power Research Institute, *TAG TM Technical Assessment Guide Electricity Supply—1989* EPRI P-6587-L, vol 1, Rev 6 (Palo Alto, CA September 1989)

[6] Leslie Lamarre "Electricity from Whole Trees, " *EPRI Journal,* January/February 1994, pp 16-24 and Stephen A Johnston et al , *Who/e Tree Energy Design,* Report TR-101564, 2 vols (Palo Alto, CA Electric Power Research Institute December 1993

BOX 5-2 (cont'd.): Biomass Energy Resources and Technologies[1]

A potentially higher efficiency and more economic alternative to the steam turbine is to gasify the biomass and then use the gas generated to fuel a high-efficiency gas turbine system. Gasification/ gas turbine technologies are now being developed, primarily for coal. Biomass gasifies at lower temperatures and more quickly than coal, reducing relative gasification costs After the biomass is gasified, the gas products are cleaned of particulate and other contaminants before being burned in a steam-injected gas turbine, a combined cycle, or other configuration.[7] There appears to be a basic understanding of the means for adequately cleaning gases for gas turbine applications with either fluidized bed gasifiers[8] or updraft gasifiers, although there has been no commercial demonstration of, in particular, alkali removal

Relatively small (5 to 100 MW_e) biomass gasifier/gas turbine systems are expected to have much higher efficiencies and lower unit capital costs (dollars per kilowatt hour) than steam turbine systems.[9] The upper end of this range is probably near the practical upper limit on the size of a biomass Installation due to the cost of transporting large quantities of biomass long distances.

Some have also proposed to use fuel cells with biomass gasification systems in the longer term. The relatively small scale of fuel cells might allow such systems to be located on a single farm, reducing some of the transport and handling costs and benefiting farm income. '" There remain, however, significant technical, logistical, managerial, and other challenges in realizing such systems

Biomass systems are now cost-competitive in many areas where a low-cost waste feedstock is available. Higher cost dedicated energy crops used with these higher efficiency systems are projected to be cost-competitwe in the future across a wide range of conditions. The cost of biomass-generated electricity is expected to be in the range of roughly 5¢ to 7.5¢/kWh in the year 2000 with the introduction of advanced gasification-gas turbines or other high-performance systems. ' Costs Will thereafter decline modestly with Incremental improvements in crops and equipment. The Electric Power Research Institute recently estimated that biomass-generated electricity could cost as little as **4.6¢/kWh** in the near term using whole tree burners [12]

Environmental Impact

Burning or gasifying biomass in a powerplant generates much less sulfur oxides (SO_x) than coal, but—as with any combustion process—does produce nitrogen oxides (NOx), depending on the combustion chamber temperatures It also generates particulate, volatile organic compounds, and various toxics. Criteria pollutants such as carbon monoxide, NO_x, SO_x, and particulate are reasonably well understood, and emissions should meet air quality standards. [13]

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[7] Hot gas cleanup avoids cost and efficiency penaloyords, and pressurization gasification avoids energy losses associated with compressing the fuel gas after gasification It is necessary, however, to remove trace amounts of alkali vapor from the gas before It enters the gas turbine

[8] E Kurkela et al , "Removal of Particulates, Alkali, and Trace Metals from Pressurized Fluid-Bed Biomass Gasification Products—Gas Cleanup for Gas Turbine Applications," *Biomass and Wastes XV* Donald L Klass (ed) (Chicago, IL Institute of Gas Technology, 1991)

[9] This also holds true even for much larger steam systems

[10] See, e g Royal Resources Corp "Electro-Farming, " Jan 1, 1994

[11] U S Department of Energy, "Renewable Energy Technology Evolution Rationales, " draft, October 1990

[12] "NARUC Hails Low-Cost Potential of Electricity from Biomass, PV," *Solar Letter*, Jan 6, 1995, p 3

[13] Antares Group, Inc Op cit footnote 1

BOX 5-3: Utility Operat'

There are significant daily, weekly, seasonal, and annual variations in power demand that a utility must meet. The utility operates a range of different equipment so as to meet this variable demand in the most cost-effective manner possible. This equipment is conventionally divided into three categories baseload, Intermediate (or load following), and peaking. Operation of this equipment is determined In part by equipment costs and efficiencies, operating hours and part-load operation performance, fuel costs, and ramp times (i.e., the time required to warm up the equipment for operation or to cool It down between operational times). Potential equipment failure or other problems are met by reserve capacity.

Baseload. Baseload plants are used to meet the largely nonvarying round-the-clock load [1] These are typically large (hundreds of MWs), relatively high capital cost ($1,500/kW) plants that use low-cost coal or nuclear fuels, Their high capital cost[2] is in large part a consequence of being designed to use low-cost fuels, Because they are operated for much of the year, their high fixed costs can be spread over many hours of operation,

Intermediate or /oad fo//owhg. As the name implies, intermediate plants fall between baseload and peaking plants in terms of the amount of time they are operated, their capital cost, and their fuel cost, They are operated to meet much of the normal daily variation in power demand

Peaking. Peaking plants are run for short periods of time In order to meet utllIty peak loads, such as summer air conditioning peaks or winter heating peaks. As these plants are operated for short periods over the year, there are few hours of operation to spread the fixed capital costs over. Consequently, much effort is made to minimize their capital cost. Low capital cost equipment requires premium fuels such as natural gas and so fuel costs for these plants tend to be high, Utilities have Invested substantial time and effort in limiting peak loads due to the expense of generating this power.

[1] Although there will likely be some variation in output depending on the use of other generation units

[2] Note that 'high" Capital cost here is in the context of conventional powerplants RETs may have a similar or higher capital cost, but lower fuel costs

firms that develop these powerplants include Babcock & Wilcox and Foster Wheeler. By one estimate, some 40 to 50 companies were involved in or investigating developing bioenergy projects in the mid- to late 1980s; that number has decreased to perhaps 20 or fewer with recent consolidations,[7] increased competition from natural gas, tightening bioenergy supplies in some areas, and other factors.

Significant expansion of bioenergy use for electricity will require the development of dedicated feedstock supply systems, perhaps through cooperative agreements between agricultural interests and biomass powerplants (see chapter 2). The long lead time and logistics of growing such feedstocks is likely to be a more significant constraint on the development of the bioenergy industry than manufacturing the equipment and building the powerplant systems.

Research, Development, and Demonstration Needs

RD&D needs include further developing: high-productivity crop varieties (chapter 2); equipment for feedstock harvesting, transport, and handling

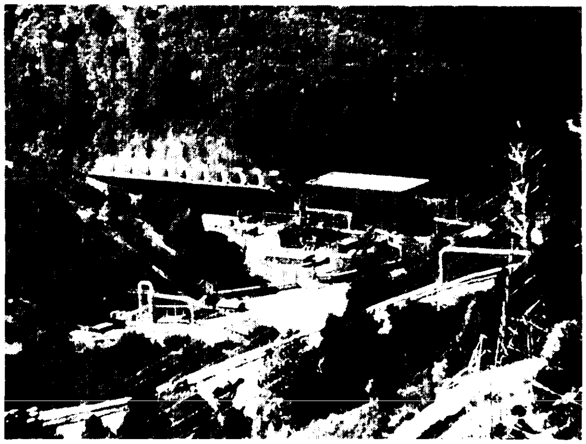
[7] Jan Hamrin and Nancy Rader, *Investing in the Future: A Regulator's Guide to Renewables* (Washington. DC: National Association of Regulatory Utility Commissioners, February 1993).

(chapter 2): feedstock drying; gasification and hot gas cleanup technologies (one of the most important and challenging needs); slagging controls; complete biomass gasification advanced gas turbine systems; whole tree burner or other minimal fuel preparation technologies; pyrolysis systems; and biomass fuel cell systems. Some of these technologies are ready for scale up and demonstration in pilot plants.

Successful development of these technologies—for example, improved crops, harvesting, transport, and biomass gasification advanced gas turbine systems-could lead to a viable industry with considerable benefits for rural communities. Further, if 50 GW of biomass electricity -generating capacity were realized by 2020,[8] savings, for example, of 1¢/kWh by these RD&D investments would correspond to $3 billion (1995 constant dollars) of annual savings in 2020.[9] Discounted to the present at a government rate of 5-percent real, the savings over the 30-year lives of these powerplants would have a present value of more than $14 billion.[10] There would be additional potential benefits to rural communities and to the environment (chapter 2). These savings are roughly 500 times the current annual federal investment in bioelectric RD&D. Although this hypothetical calculation is quite crude, it does suggest the potentially very significant leverage these RD&D investments could have.

| Geothermal

Geothermal electricity-generation systems extract heat from the ground to drive turbines. Modern day use of geothermal energy began in 1913 with a 250-kW turbine in Italy, followed in 1923 by installation of a 250-kW turbine at The Geysers, California, and other units at locations ranging from Iceland to Zaire. Geothermal resources and technologies are described in box 5-4.



GEOTHERMAL RESOURCES ASSOCIATION

Powerplant No 18 at *The Geysers geothermal field m northern Calffornla This plant consists of two 55-MW single-flash units.*

Geothermal systems are typically operated as baseload power; substantial variation in output may damage the underground resources in some cases. Geothermal systems can potentially also be operated in hybrid configurations with natural gas to improve overall output and economics of both.[11] Direct use of geothermal energy for space heating is possible as well.

Some 170 geothermal powerstations in 21 countries with 5,726 MW of electricity y generation capacity are in operation.[13] The United States has the largest installed capacity with about 2,500

[8] This much could be achieved by 2(.I 10 according to Electric Power Research Institute, *Strategies for Achieving a Sustainable, Clean, and Cost-Effective Biomass Resource* (Palo Alto, CA: 1993). This level of deployment is unlikely undercurrent conditions. See chapter 2 for details.

[9] Assuming a 70-percent capacity factor, All costs are in 1992 dollars. Of course, higher cost bioelectric systems would probably not be made use of as widely as lower cost bioelectric systems.

[10] At a market rate of 1 ()-percent real, this would have a present value of $3 billion, or 1(X) times the current annual rate of investment.

[11] Electric power Research Institute, *Natural Gas Hybrid Power Plants for Geothermal and Biomass Resources, EpRI Rp 1671-07* (Palo Alto, CA: December 1992).

[12] Johansson et al (eds.) op cit., footnote 3; and U.S. Genera] Accounting office, *Geothermal Energy*, GAO RCED-94-84 (Washington, DC. June 1994).

[13] Lynn McLarty, Dyncorp., persona] communication, June 13, 1995.

BOX 5-4: Geothermal Energy Resources and Technologies[1]

Geothermal energy IS heat energy inside the Earth—either remaming from the original formation of the Earth or generated by the decay of radioactive isotopes inside the Earth. Only in particularly active areas, such as in volcanic zones or along tectonic plates, IS geothermal energy sufficiently concentrated and near the surface that it can be used economically,

Geothermal energy comes in four forms 1) hydrothermal fluids, 2) geopressured brines, 3) hot dry rocks, and *4)* magma. Hydrothermal fluids—the only commercial geothermal resource—are hot water or steam in porous or fractured rock at depths of up to 4.5 km, and with temperatures ranging from 90°C to 360°C (190°F to 680°F), figure 5-1 maps their location,

Geopressured brines are hot, salty waters containing dissolved methane that lie at depths of 3 to 6 km trapped under sediment layers at high pressures, with temperatures of 90°C to 200°C (1900F to 390°F), Proposed systems to tap geopressured brines are generally hybrid systems, using both the geothermal heat and burning the methane to generate power. Texas and Lousiana gulf coast areas hold the only major geopressured resources identified to date (figure 5-1). Difficulties in extracting this resource include scaling (depositing minerals on equipment), its relatively low temperature (150°C or 300°F in test wells), and disposal of the brine produced, An experimental 1 -MW hybrid geopressured system at Pleasant Bayou, Texas, has demonstrated the technical feasibility of using geopressured resources for power generation, but the technology IS not yet cost-effective.

Hot dry rock (HDR) resources are regions of exceptionally hot rock, above 150°C (3000 F), that have little or no water in them Geothermal temperature gradients mapped in figure 5-1 Indicate the areas with the greatest potential for generating electricity the higher the temperature gradient, the greater the potential, Hot dry rock IS a very large potential resource, but needs further RD&D for it to become a cost-effechve and commercially viable technology,

Magma is molten rock with temperatures of roughly 700°C to 1,200°C (1 ,300°F to 2,200°F) and typically occurs at depths of 6 to 10 km Magma energy is the largest of all geothermal resources, but IS also the most difficult to extract—for example, exposing the drilling equipment to extremely hot conditions and the possible explosive release of hot pressurized gases, Cost-effective use of this resource appears unlikely for the forseeable future.

Although commonly termed a renewable resource, geothermal energy can be depleted if oversubscribed. At The Geysers in Northern California, for example, typical pressures have dropped from the initial level of 500 psi in 1960, at the start of development, to 200 psi by 19892 due to the more rapid removal of underground water and vapor resources than the rate at which they were being naturally replaced, One response in this particular case was to reinject water into the geothermal field. Whether this can bring the field back to full productity remains to be seen Extraction of heat may also decline for other reasons. For example, hot brines can leave mineral deposits (scale) on equipment or plug the pores of rocks as they are removed, impeding further flow

[1] For a more detailed discussion, see H Christopher H Armstead and Jefferson W Tester, *Heat Mining (New* York, NY E &F N Spon Publishers, 1983), M Economides and P Ungemach, *Applied Geothermics (New* York, NY John Wiley & Sons), Thomas B Johansson et al (eds), *Renewable Energy Sources for Fuel and Electricity* (Washington, DC Island Press, 1993), L Y Bronicki et al World Energy Conference, "Geothermal Energy Status, Constraints and Opportunities " draft, April 1992, U S Department of Energy, Energy Information Administration, *Geothermal Energy in the Western United States and Hawaii Resources and Projected Electricity Generation Supplies, DOE/E IA-0544* (Washington, DC September 1991)

2 John E Mock, testimony at hearings before the California Energy Conservation, Resources, and Development Commission, Sept 21, 1989

BOX 5-4 (cont'd.): Geothermal Energy Resources and Technologies

Resource exploration and development requires identifying, characterizing, and tapping the resource through well driling These technologies are similar to, but often more demanding than, those used in 011 and gas well drilling Recent development of slim-hole drilling may substantially lower costs for exploration and characterization of the resource [3]

Technologies

Technologies for utilizing geothermal resources for electricity production[4] Include direct steam, single-flash, double-flash, and binary systems The simplest technology IS the piping of hydrothermal steam directly from underground reservoirs to drive turbines According to the U S Geological Survey, high-quallty steam resources are found in the United States only at The Geysers, Yellowstone National Park,[5] and Mount Lassen [6] About 1,700 MW of capacity IS based on direct steam and IS located at The Geysers

Single-flash units are similar, except that they make use of the much larger and more widespread resource of underground hot water instead of steam When this hot water IS pumped to the surface and the deep underground pressures are reduced, it partially ' flashes" into steam in a flash-tank The steam then drives the turbine

A double-flash system uses a second flash-tank that operates at pressures Intermediate between the pressure of the first flash-tank and air pressure Double-flash systems are typically 10 to 20 percent more efflcient than single-flash systems, but at the additional capital cost of the second flash-tank and related equipment A Iittle over 600 MW of capacity in the United States IS based on single- or double-flash steam units

Binary systems pump hot water to the surface and then use a heat exchanger to transfer the heat to a working fluid This working fluid IS vaporized by the heat and then drives the turbine the cooled geothermal water IS returned underground via an injection well Binary systems can use lower temperature fluids than IS economically possible with flash technologies Binary systems also have minimal atmospheric emissions and reduced scale and corrosion of critical parts Binary plants tend to be small (5 to 10 MW) and modular, and can often be quickly built and Installed Their primary disadvantages are higher capital cost and some efficiency loss due to the heat exchanger Direct flash and binary systems are becoming relativly mature technologically About 200 MW of capacity in the United States IS based on binary systems

These technologies generally need either air or water cooling for efflcient operation, just as for coal or nuclear steam plants Water may be Iimited in some areas, using geothermal fluids for coollng—which are

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3 H J Olson Electric Power Research Institute, "Geothermal Reservoir Assessment Based on Slim Hole Drilling Volume 1 Analytical Method Volume 2 Application in Hawaii EPRI TR-103399 December 1993

4 Geothermal energy can of course be used for direct heat applications as well ranging from district heating systems to low-temperature industrial process heat

5 There is considerable concern that development of geothermal energy in the vicinity of Yellowstone National Park could damage such natural wonders as Old Faithful This has led to several legislative initiatives to limit such development See e g "Old Faithful Protect Ion Act of 1991 hearing before the Senate Committee on Energy and Natural Resources Subcommittees on Public Lands National Parks and Forests and on Mineral Resources Development and Product{on Feb 25 1992, as well as subsequent debate

6 An additional dry steam resource is reportedly located near Cove Fort UT See Susan Williams and Kevin porter Power *Plays Profiles of America's Independent Renewable Electricity Developers* (Washington DC Investor Responsibility Research Center 1989) p 203

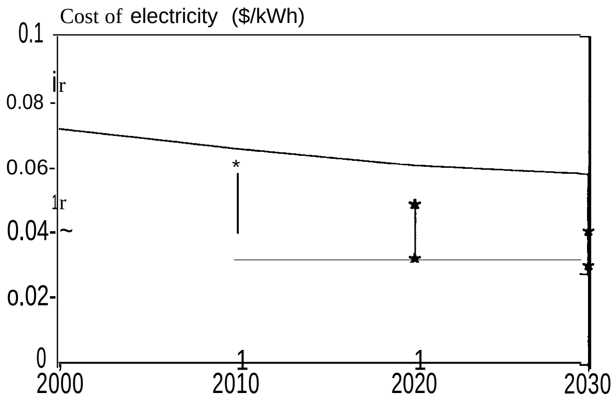
(continued)

BOX 5-4 (cont'd.): Geothermal Energy Resources and Technologies

then lost by evaporation—rather than reinfecting them into the ground may affect the geothermal resource.[7] This has been a factor in the decline of geothermal power output at The Geysers in California, Air cooling costs more and, in the summer, higher air temperatures reduce the powerplant generating capacity compared with the winter.

The cost of generating electricity from geothermal resources includes the cost of exploration for good resources, drilling wells, capital equipment, and operations and maintenance, usually including rejecting water Into the geothermal reservoir, Costs can be competitive today compared with coal where good-quallty hydrothermal resources are available.[8] Cost projections are shown in the figure; improved technologies—particularly for Identifying, characteriaing, and tapping geothermal resources—will expand the range of geothermal resources that can be tapped at these costs,

Cost Projections for Geothermal-Generated Electricity



NOTE The cost of geothermal energy is expected to be inthe range of about 4¢ to 7¢/kWh in the year 2000, declining moderately in following years, depending on the geothermal resource tapped and the technology used The shaded range encloses most of the expert estimates reviewed, with all estimates in constant 1992 dollars and, where necessary, capital cost and other estimates converted to ¢/kWh using discount rates of 10 and 15 percent (with 3 percent inflation) High and low values developed by the Department of Energy are shown as *

SOURCE Off Ice of Technology Assessment, based on U S Department of Energy, "Renewable Energy Technology Evolution Rationales, " draft, October 1990, and Science Applications International Corp., "Renewable Energy Technology Characterizations, " draft, March 1990

Environmental Impact

The environmental impact of geothermal power varies with the resource and the technology used. Direct steam and flash systems generally release gases to the atmosphere; methods have been developed to first remove pollutants such as hydrogen sulfide before these gases are released. Small quantities of brines may also be released, Binary systems generally reinject all gases and brines back into the reservoir so have few or no emissions. Overall sulfur and carbon dioxide emissions for geothermal plants are typically less than 4 percent of those by coal- or oil-fired powerplants.[9] Large quantities of cooling water may be needed in some cases, just as for fossil plants, Where geothermal resources occur in scenic areas, particular attention to siting and landscaping may be necessary if they are to be developed, Land requirements for geothermal units are generally quite small (see table 1-2 in chapter 1), but land may also be needed in some cases for disposal of waste salts from geothermal brines, There may also be some subsidence of land overlying wells.

7 Condensate from flash steam plants can be used in a cooling tower to evaporate and provide cooling for the Power cycle This typically results in 80 percent of the geothermal fluid being lost and only 20 percent being available for reinjection in the reservoir Reinjection, however, must be done carefully in order to prevent excessive cooling of the reservoir and lowering the quality of the available geothermal resource See Gerald W Braun and H K "Pete" McCluer, "Geothermal Power Generation in United States, " *Proceedings* of *the IEEE,* VOl 81, No 3, March 1993, pp 434-448, see table 1

8 Ibid

9 Ibid

MW net[14] (up from about 500 MW in 1979) spread among some 70 plants in operation with contracted power costs as low as 4.6¢/kWh. As of 1993, about 1,700 MW of this net capacity was at The Geysers, California, and 800 MW of capacity was located elsewhere in California, Nevada, and Utah. In addition, some 300 MW of capacity was under construction or announced.[15]

The geothermal industry has changed considerably over the past 10 to 15 years. Several major oil companies and their affiliates were active in geothermal development in the early 1980s due to their expertise in underground resource exploration and development—the most difficult part of geothermal energy development; all but Unocal have now ended their geothermal activities,[16] and Unocal—the largest developer—has recently sold some of its geothermal properties. Most developers now are small- to medium-size firms such as California Energy,[18] Calpine, and Ormat.

Until the mid- 1980s, private companies generally developed the geothermal field and sold the steam/hot water to public utilities, which were the primary owners and operators of geothermal plants for power generation. Most recent geothermal projects have been built, owned, and operated by nonutility generators that developed both the geothermal field and the powerplant and sell the electricity to utilities. NUGs now account for more than one-quarter of total geothermal capacity.[19] Currently, fewer than 10 firms account for most of the activity in geothermal energy. Supporting firms include well drilling and geoscience companies and equipment suppliers.[20]

Geothermal development in the United States has slowed in recent years due to low growth in the demand for new generating capacity by many utilities in areas with good geothermal resources; difficulty in funding capital-intensive and risky geothermal development; and low natural gas and other fossil fuel prices. In addition, opportunities may, in some cases, be limited by subsidies for competing technologies. For example, the U.S. Department of Energy (DOE) plans to spend $135 million to help build and operate a 100 MW coal-fired powerplant in Nevada under the Clean Coal program, reducing the need for other new capacity.[21] As a result of slower U.S. growth, geothermal companies are becoming more active in overseas markets. California Energy, for example, is developing or negotiating projects in the Philippines, Indonesia, and elsewhere.[22]

Research, Development, and Demonstration Needs

Additional technology development could be useful in a number of areas, including: improving the

14 Capacity of The Geysers has declined in recent years due to overdrawing of the underground water resources, leaving a net operating capacity of about 1,700 MW out of about 2,000 MW installed capacity.

15 Gerald W. Braun and H.K. "Pete" McCluer, "Geothermal Power Generation in the United States," Proceedings *of /he IEEE*, March 1993, pp. 434-448.

16 Some ~edium.size independent oil company affiliates, such as Freeport-McMoRan Resource Partners, continue to be involved in geothermal development.

17 For the sale of Unocal's geothermal leaseholds to Magma, see, e.g., Jeannie Mandelker, "Geothermal's Hot prospects," *Independent Energy*, November 1993, pp. 16-19.

18 California Energy Company took over Magma Power Company in December 1994 in part due to the need for greater operational resources to compete effectively in international markets. See Harriet King, "Magma Agrees to $950 Million Offer," New *York Times*, Dec. 6, 1994; and "Cal. Energy Hot for Magma But the Latter Is Resisting," *Electricity Journal*, November 1994, pp. 5-6.

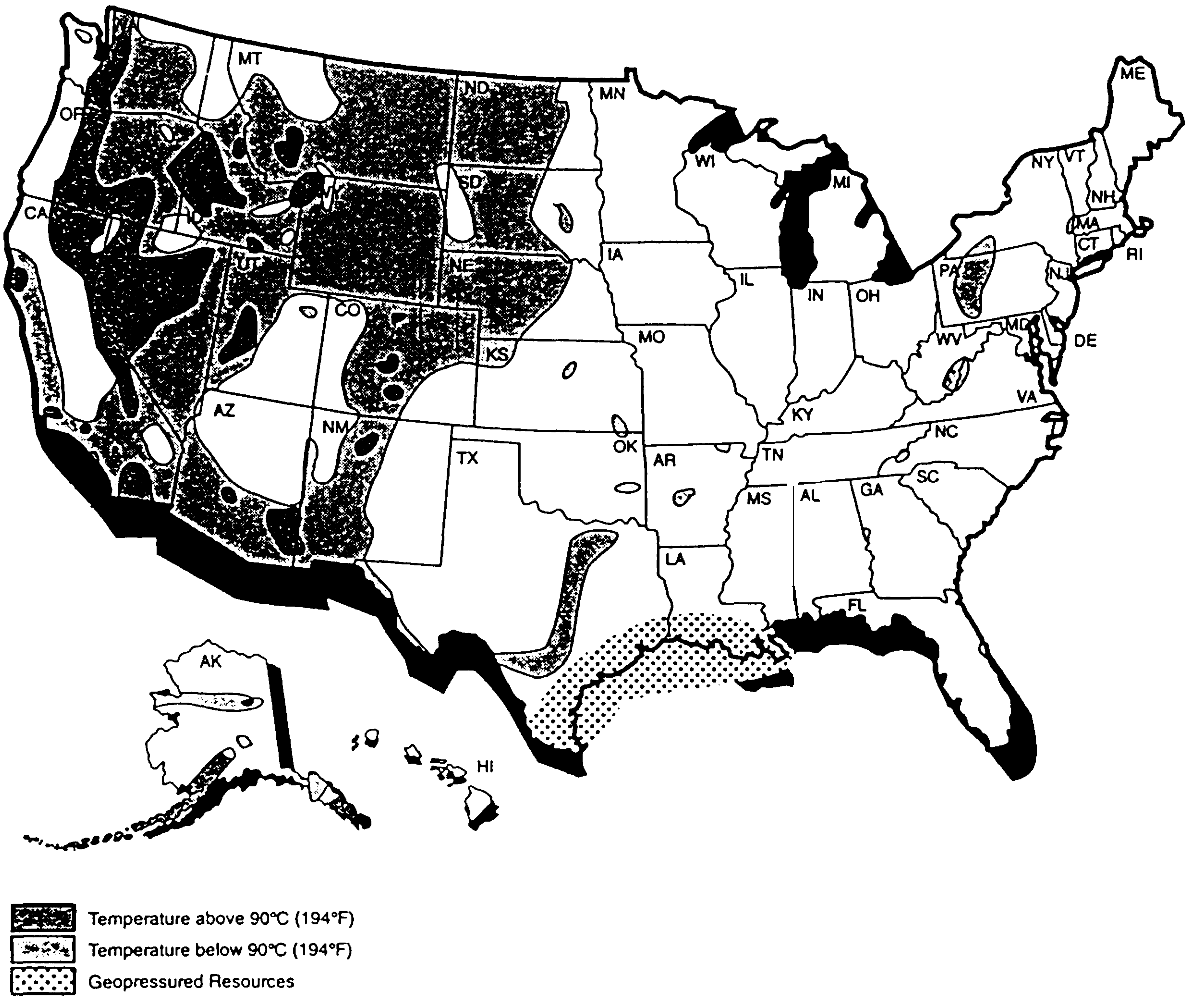
19 C) ffice of Conservation and Renewable Energy, op. cit., footnote 3.

20 Hamrin and Rader, op. cit., footnote 7.

21 U.S. General Accounting office, op. cit., footnote 12.

22 Mandelker, op. cit., footnote 17. See also footnote 18.

FIGURE 5-1A: Hydrothermal and Geopressured Geothermal Resources in the United States

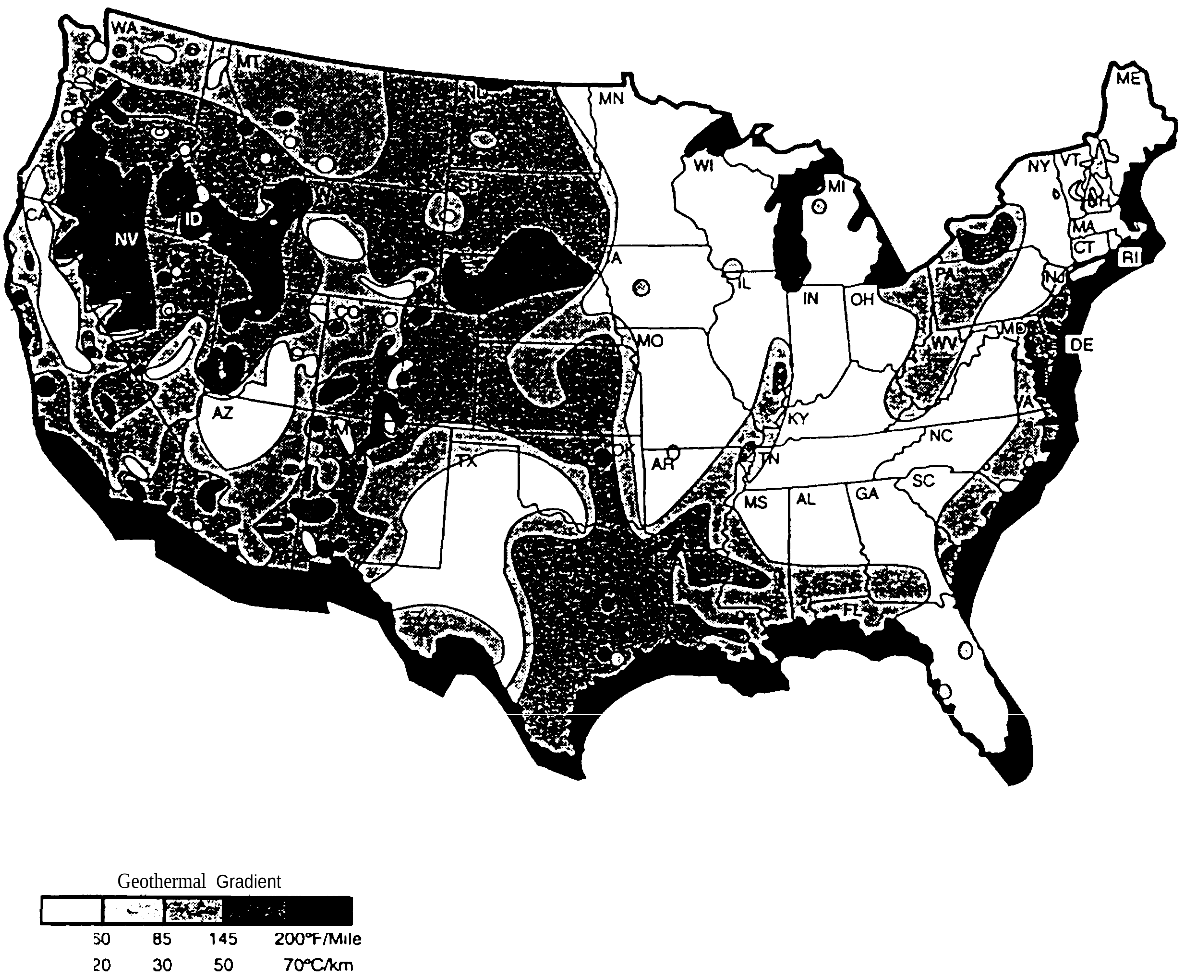


SOURCE U S Geological Survey, as cited in U S General Accounting Off Ice, *Geothermal Energy, GAO/RCED-94-84* (Washington, DC. June 1994)

ability to identify and characterize suitable geothermal fields; developing down-hole instrumentation and other equipment for geothermal characterization and real-time monitoring that can survive high temperatures and corrosive geothermal brines; improving well drilling—particularly for hard rock[23]—and related technologies; enhancing geothermal field permeability; reducing scale and corrosion of equipment by hot geothermal brines and improving materials for operating at high temperatures; improving the performance

[23] The rock overlaying geothermal resources is often harder and more abrasive, and the temperatures are higher, than that for oil and gas W'ells.

FIGURE 5-1B: Hot Dry Rock Geothermal Resources in the United States



SOURCE: U.S. Department of Energy, as cited in U.S. General Accounting Office, *Geothermal Energy*, GAO/RCED-94-84 (Washington, DC: June 1994).

of the various prime mover—single or double flash, binary, or others—technologies; and developing the capability to exploit geothermal hot dry rock and other resources.[24] Analysis of various types of hybrids, such as natural gas-geothermal hybrids, would be useful to identify opportunities where the efficiency and cost-effectiveness of both geothermal and fossil systems can both be improved simultaneously. The existing geothermal industry is too small to support a reasonable level of RD&D in these areas at this time and technologies, such as hard rock drilling for hot dry

24 See L.Y. Bronicki et al, World Energy Council, "Geothermal Energy: Status, Constraints, and Opportunities," draft, April 1992.

rock geothermal resources, are of relatively little interest to the well-capitalized oil and gas industries due to the different nature of the rock strata overlying oil and gas deposits.

Hydroelectricity

Hydroelectric generation systems use the energy in flowing water to turn a turbine. As of 1988, the United States had about 88 **GW** of hydroelectric-generating capacity—64 GW of conventional large-scale hydro, 7 GW of small-scale hydro, and 17 GW of pumped storage—with net generation of about 8.5 percent[25] of total U.S. electricity supply. Globally, hydropower currently provides about 20 percent of world electricity supplies.[26] Hydropower resources and technologies are described in box 5-5.

The primary change for hydropower in recent years has been increasing concern over its potential impacts on, for example, aquatic habitat, the land it inundates, and recreation. In turn, these factors have increased the time required and cost of meeting regulatory requirements.

In its conventional form (with dam storage), hydropower can provide base, intermediate, or peaking power. Because it can be rapidly dispatched as needed, it can serve a particularly valuable role in backing up intermittent power from sources such as solar and wind.

Before the 1930s, most hydropower was developed by industry or utilities. During and following the Depression, a large share of U.S. hydroelectric power was developed through federal support, including the Tennessee Valley Authority and the Columbia Basin Project. By 1940, some 3,100 conventional hydro sites were in operation. A variety of factors cut the number of operating projects to just over 1,400 by 1980,[27] although net capacity continued to increase, roughly tripling between 1950 to 1975.[28] The two oil crises, enactment of several tax credits,[29] and regulatory changes—particularly the passage of the Public Utility Regulatory Policies Act—spurred independent development of hydropower during the 1980s. Independents have developed many more, but smaller, sites than utilities, while utilities have developed more MWS of capacity. More recently, environmental and regulatory concerns have strongly impacted hydropower relicensing as well as new licensing.

Hydropower developers generally include individuals and small partnerships for mini-hydro projects (up to 5 MW); independent development companies such as Consolidated Hydro, Independent Hydro Developers, Synergics, and others for small-hydro projects (5 to 50 MW); and utilities for medium (50 to 100 MW) or large (>100 MW) projects.[30] There has been relatively little development of hydropower by the federal government in recent years.[31] construction follows a similar pattem, ranging from small local construction firms for small projects, to firms such as Morrison

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[25] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(90) (Washington. DC: May 1991), table 90.

[26] U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

[27] Nan Nalder, "Fixing Hydro—The Forgotten Renewable, " *Electricity Journal*, April 1992, pp. 12-21.

[28] Keith Lee Kozloff and Roger C. Dower, *A New Power Base: Renewable Energy Policies for the Nineties and Beyond* (Washington, DC: World Resources Institute, 1993).

[29] These tax credits, including an energy tax credit under the Crude Oil Windfall Profits Tax Act, an investment tax credit, and accelerated depreciation, have been phased out.

[30] The types of ownership and the size of projects indicated here are illustrative only. Ownership and project size may vary considerably from these values.

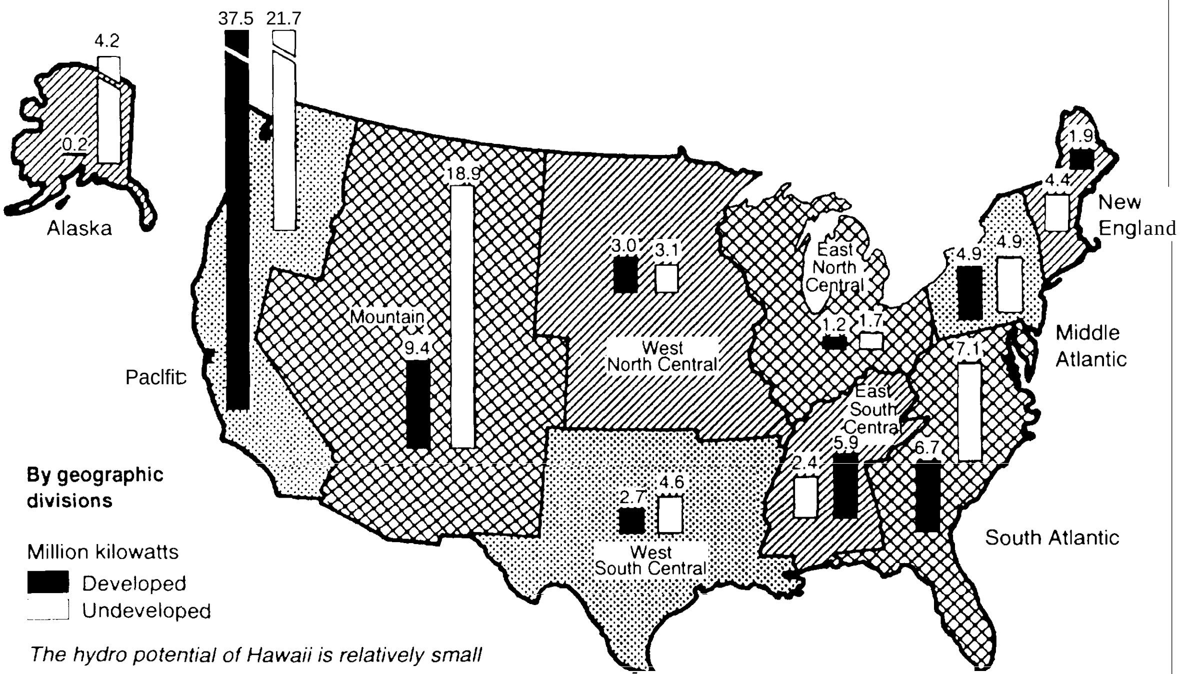
[31] Among notable exceptions were five Bureau of Reclamation hydro facilities brought online in 1993. Maria J. Barnes and Laura Smith-Noggle, ‘. Hydropower '93: The Year in Review," *Hydro Review*, vol. 12, No. 8, 1994, pp. 12-20.

BOX 5-5: Hydropower Resources and Technologies

U S hydropower resources are fairly well developed. More power, however, could potentially be obtained from existing facilities, including capturing reservoir spill,[1] upgrading equipment, and Installing equipment at dams not now used for power [2]

By one estimate, a potential of about 76 GW of conventional hydro and 19 GW of pumped storage capacity were untapped in the United States as of 1988 (see figure),[3] The U.S. Department of Energy estimates that about 22 GW of this potential could be developed economically at current prices and 19 GW more could be developed with a price premium of 2¢/kWh. As much as 13 GW of the remainder might be developed with appropriate attention to environmental and safety Issues, further development of technolo-

U.S. Conventional Hydroelectric Generation Capacity, Developed and Undeveloped



The hydro potential of Hawaii is relatively small and thus is not shown.

SOURCE Federal Energy Regulatory Commission *Hydroelectric Power Resources of fhe United States, Developed and Undeveloped FERCO0070* (Washington DC January 1992) cited in U S Department of Energy Energy Information Administration "Renewable Resources in the U S Electricity Supply DOE/EIA 0561 February 1993

[1] U S Army Corps of Engineers Institute for Water Resources "National Hydroelectric Power Resources Study Volume I " May 1983

[2] Marc Chupka and David Howarth *Renewable Electric Generation An Assessment of Air Pollution Prevention Potential,* EPA/400 *R-92 005* (Washington DC U S Environmental Protection Agency March 1992) citing the Federal Energy Regulatory Commission

3 Federal Energy Regulatory Commission Hydroelectric Power Resources of the United States " January 1988

(continued)

BOX 5-5 (cont'd.): Hydropower Resources and Technologies

gy, and the above price premium. In addition, there are an estimated 12,5 to 17.5 GW of run-of-river and other capacity, of which perhaps 10 GW could be tapped with further development of low-head technologies.[4]

Technology

Hydroelectric technologies—dams,[5] run-of-river,[6] and pumped storage[7]—are generally considered to be mature. Turbine efficiencies are typically in the 75 to 85 percent range. Nevertheless, there have been evolutionary technological developments in a variety of areas, These include better understanding of both soils and manmade materials in designing and constructing dams and related equipment, Improvements in dam constrution techniques and materials, use of devices such as inflatable weirs to raise upstream water levels, and electronic controls of turbine speed and electronic power conditioning.[8]

The capital costs for new U.S. hydropower facilities range widely around a median price of about $2,000/kW, operations and maintenance costs at large facilities typically average roughly 0.5¢/kWh, operating lifetimes are usually assumed to be 45 years, and operational capacity factors are 36 to 45 percent. Together, these parameters give costs of roughly 6¢/kWh Hydropower costs often range between 4.5¢/kWh to 7.5¢/kWh, with considerable varilation above and below this range. No significant cost reductions are forseen.[9] These costs are generally competitive with fossil-generated power.

Environmental Impact

Although hydro has long proven to be a reliable and cost-effective resource, and once constructed, does not release carbon dioxide,[10]" a number of environmental concerns have been raised. These include Inundating wildlife habitat; changing aquatic ecosystems and water quality—including temperature, dissolved oxygen and nitrogen, and sediment levels, causing high mortality among fish passing through the

[4] Solar Energy Research Institute, "The Potential of Renewable Energy, An Interlaboratory White Paper, " March 1990

[5] Most hydropower facilities use dams to raise the water level and thus Increase the potential energy, and to provide storage of water so as to smooth out seasonal fluctuations in the amount of water available for generating power

[6] Run-of-river systems do not use a dam but may use other structures reducing, but not eliminating, associated costs and environmental Impacts Lack of dam storage Increases susceptibility to seasonal fluctuations in output

[7] pumped storage systems are not a RET, but could be used to store power generated by RETs or to complement RET Power output Pumped storage systems use electricity (usually from a baseload powerplant—typically coal or nuclear powered) to pump water to an upper reservoir, this water is later dropped through a generator back to the lower reservoir to generate needed peak power Typical pumped storage systems are now 70 to 80 percent efficient over the entire cycle Limited suitable sites for pumped storage-near both cities and large electric generating plants—have led some to consider use of underground caverns for the lower reservoir See John Dowling, "Hydroelectricity," *The Energy Sourcebook A Guide to Technology, Resources, and Policy,* Ruth Howes and Anthony Fainberg (eds) (New York, NY American Institute of Physics 1991)

[8] Geoffrey P Sims, "Hydroelectric Energy, " Energy *Policy* October 1991, pp 776-786, and Eric M Wilson, "Small-Scale Hydroelectricity, " *Energy Policy,* October 1991, pp 787-791

[9] Allan R Hoffman, "DOE's Approach to Renewable Energy in the Utility Sector, " presentation at the Workshop on Generation Of Electricity from Renewable Sources, American Physical Society, Washington, DC, Nov 6-7, 1992

[10] Constructing hydro plants usually entails extensive earth moving using diesel-powered equipment and use of large amounts of concrete, both resulting in emissions of carbon dioxide In addition, the Inundation of large amounts of biomass by the dam may result in the emission of significant amounts of methane as the biomass decomposes See, e g John W M Rudd et al , "Are Hydroelectric Reservoirs Significant Sources of Greenhouse Gases?" *Amble,* VOl 22, No 4, June 1993, pp 246-248

BOX 5-5 (cont'd.): Hydropower Resources and Technologies

turbine and affecting fish migrations.[11] Large and/or rapid variations in hydropower output may also damage aquatic habitats, streambeds, or cause other problems.[12]

The history of federal, state, and court considerations in balancing the many competing interests in the hydro arena is long and complex.[13] In recent years, the Federal Energy Regulatory Commission has recently begun to revamp its hydropower licensing procedures to both better meet environmental concerns while reducing the burden on developers.[14]

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[11] This is the focus of another OTA assessment, *Technologies To Protect Fish at Darns,* forthcoming The risk of a dam failure and the potential impact on people and towns downstream is also of primary concern, but is not addressed here

[12] Because of such longstanding environmental concerns, a large body of legislation has directed attention toward the environmental impacts of hydropower development including the Water Resources Planning Act Public Law 89-80, the Wild and Scenic Rivers Act, Public Law90-542, the National Environmental Policy Act, Public Law91 -190 the Clean Water Act, Public Law92-500 and the Endangered Species Act, Public Law96-205 In 1986, the Electric Consumers Protectlon Act of 1986 directed the Federal Energy Regulatory Commission to give equal consideration to environmental concerns in its hydro licensing procedures

[13] For a discussion see, e g George C O Connor, "Will the Commission's Hydropower Program Revive in the 90s?" Energy Law *Journal,* vol 14, No 1, 1993, pp 127-151, Amy Koch, "The Battle for One-Stop Shopping, " *Independent Energy,* February 1992 pp 38-40, George Lagassa "The Exemptlon Dilemma, " *Independent Energy,* July/August 1993. pp 52-56 and Nan Nalder, Fixing Hydro—The Forgotten Renewable " *Electricity Journal,* April 1992, pp 12-21

[14] "FERC Revamps Its Procedures for Hydro, " *Electricity Journal,* October 1993, pp 15-16

Knudsen, Dillingham, Ebasco, and Stone& Webster for larger projects. Financing likewise ranges from limited partnerships or small business loans for small projects to large institutional investors in big hydro projects. Producers of hydro turbines include Voith,[32] Kvaerner (Norway), Sulzer (Switzerland), Ossberger (Germany), American Hydro, STS Hydropower, and Hydro West.

There has been little new development of hydropower in the past four to five years. An important reason for the slowdown is the substantial and increasing front-end development cost and time for permitting and licensing. The long lead times for development—perhaps three years for permitting, three years for licensing, and two to three years for construction-do not well match shortening utility planning horizons in the increasingly competitive electricity market, particularly with low natural gas prices and short lead times for gas turbine installations. As a result, many hydro power companies are concentrating on opportunities for rehabilitating and upgrading plants. [33] Contributing to this effort has been the Federal Energy Regulatory Commission's Efficiency Upgrade Program, introduced in 1991, which streamlines the approval process for such changes.[34] Some, including both independents and utility subsidiaries, are also looking overseas for new opportunities.[35]

RD&D *Needs*

Although hydro technologies are relatively mature, considerable interest is developing in systems that reduce the impact on aquatic species and habitats. This includes turbines that safely pass

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[32] Voith (Germany) purchased Allis Chalmers turbine business but continues to manufacture in York, Pennsylvania.

[33] George Lagassa, "Repowering Hydro," *Independent Energy,* October 1992, pp. 46-50.

[34] Edward Fulton, "Gaining Capacity Through FERC's Efficiency Upgrade program," *Hydro Review*, August 1994, pp. 36-42.

[35] George Lagassa, "Small Hydro Goes International," *Independent Energy,* November 1992, pp. 71-73.

fish and aerate the water. Other research and development (R&D) needs include variable speed and pitch turbine systems, improved wear-resistant materials, and better forecasting.[36]

Photovoltaics

Photovoltaics (photo for light, voltaics for battery), or solar cells, convert sunlight directly into electricity. Unlike wind turbines or solar thermal systems, PVS have no moving parts,[37] they use solid-state electronics instead. Solar resources are described in box 5-6 and applies to solar thermal as well as PV. PV technologies are described in box 5-7.

Over the past two decades, PV efficiencies and reliability have increased significantly, manufacturing capabilities have improved, and other system components have advanced. As a consequence, the cost of PV modules has decreased by nearly 10 times since the mid- 1970s. PVS are now cost-competitive in numerous market niches and their continuing drop in price is making them cost-competitive in an ever broadening range of applications. World production of PVs in 1993 was about 61 MW, more than double that in 1987.[38]

Because of the small scale and low-maintenance characteristics of many PVs,[39] they are widely used in remote applications such as communications relays or water pumping stations. Electric utilities are also beginning to consider PVs for numerous applications, and more than 60 classes of potentially cost-effective applications have been identified.[40] In grid applications, the extent to which PV power can offset other electricity-generating capacity depends on its match with the electricity load and potential complementary combinations with other generation resources such as wind.

PVs may also have a substantial role to play in building-integrated systems. This application is expected to reduce installed PV system costs by several means including:

1. The dual use of PV modules for power generation and as part of a building's roof or exterior walls will offset capital costs by displacing roofing or wall materials.
2. A separate support structure for the PV system will be unnecessary since the building itself will serve this function.
3. No additional land will be required for the PV array (this is a significant bonus in crowded urban areas and of particular interest to the Japanese).
4. Utilities may offer attractive rates for this demand-side management strategy according to its ability to reduce the need for additional central generating capacity.

The PV industry ranges from small entrepreneurial startups to subsidiaries of Fortune 500 giants. Following the oil crises, a number of large companies entered the PV industry, many of which subsequently exited due to falling fossil energy prices, long technology and market development times for PVs, and higher near-term returns from other investments. For example, Atlantic Richfield sold its Arco Solar subsidiary to Siemens (Germany) in 1989 and Mobil Oil Company[41] sold its Mobil Solar subsidiary to ASE GmbH (Germany) in July 1994. Other recent sales of U.S. PV firms to foreign companies are de-

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36 For a more complete listing of possible areas for R&D, see North American Hydroelectric Research and Development Forum, *Repowering Hydro: The Renewable Energy Technology for the 21st Century* (Kansas City, MO: HCI Publications, September 1992).

37 If mounted on a tracking collector, however, there will be moving parts associated with the collector.

38 Paul D. Maycock, *International Photovoltaic Markets, Developments and Trends Forecast* 102010 (Casanova, VA: Photovoltaic Energy Systems, Inc., 1994).

39 And, of course, they do not need fuel transported to the site.

40 E.C Kern, Jr., *Early, Cost-Effective Applications of Photovoltaics in the Electric Utility Industry*, EPRI TR-100711 (Palo Alto, CA: Electric Power Research Institute, December 1992).

41 At press time, it was not known how substantial a holding Mobil retained in its former solar subsidiary.

scribed in chapter 7. Major firms that have withdrawn from PV manufacturing also include Boeing, Exxon, General Electric, Honeywell, Kodak, Martin Marietta, and Standard Oil of Ohio.[42] This has shifted the PV industry toward smaller firms,[43] although large firms such as Amoco (through its subsidiary Solarex) continue to be active.

In the past several years, a few larger firms have again expressed interest in PVs. For example, Coors (through Golden Photon) has entered PV development and manufacturing. Amoco/Solarex and Enron, the largest U.S. natural gas company, recently proposed a venture to build a 1OO-MW PV powerplant in Nevada with a cost of electricity at 5.5¢/kWh. This very low cost, years earlier than expected, may be possible due to the relatively large scale of production in this proposal, use of government land, federal renewable energy tax break, and financing with tax-free industrial development bonds.[44] Several other large firms are carefully examining potential partners or acquisitions.

Factors driving this new-found interest include substantial technological and manufacturing advances in PVs, the recognition that there are many higher value niches where PVs are already cost-competitive, a rapidly growing international market, and the expectation that environmental technologies will be increasingly important.

Some 19 firms currently manufacture PVs in the United States,[45] but Siemens (Germany) and Solarex alone account for about 80 percent of this production (see table 7-3). PV manufacturing equipment is produced by companies such as Spire, power conditioning equipment is produced by companies such as Omnion Power Engineering, and system integrators include Photocomm.[46]

Two overall strategic perspectives are influencing the direction of the PV industy. Many have long viewed utility bulk power markets as the goal and saw large-scale manufacturing to dramatically lower costs as the key to getting there. Scaling up manufacturing to that level, however, is a substantial challenge. The Electric Power Research Institute (EPRI), for example, has demonstrated in the field the technical potential of an integrated high-concentration PV technology—winner of a 1994 R&D 100 Award-built by AMONIX, Inc., and estimates that at a production scale of 100 MW/year, the cost of electricity from this system can be lowered to 8¢/kWh. EPRI believes that volume production is a key to further cost reduction.[47]

At this scale of production, comparable or lower costs are also expected for various thin film PVs such as CIS, CdTe, and a-Si as well as certain other PV technologies. However, 100 MW/year is almost twice the current world market, which is now spread among some 14 large (>1 MW/year) producers and a host of smaller producers (see table 7-3). Further, the long lead time to develop markets seriously restricts the possibility of building, for example, a 1OO-MW production plant and forcing prices down with volume production; most producers simply do not have the capital to absorb several years of product output at these scales while they develop a sufficiently large market for their output. So far, even PV firms with deep-pocketed parents have not been willing to

42 Williams and Porter, op. cit., footnote 6.

43 Ibid.

44 Allen R. Myersen, "Solar Power, for Earthly Prices," New *York Times, Nov.* 15, 1994, p. D].

45 "Total Solar Collector Shipments Dip as Imports Soar, Exports Climb: ElA," *The Solar Letter*, vol. 4, No. 18, Aug. 19, 1994, pp. 197-200.

46 For a listing of companies involved in photovoltaic manufacturing, system integration, and related activities, see, e.g., "Membership Directory," *Solar Industry Journal, vol. 5, No.* 1, *1994,* pp. *54-76.*

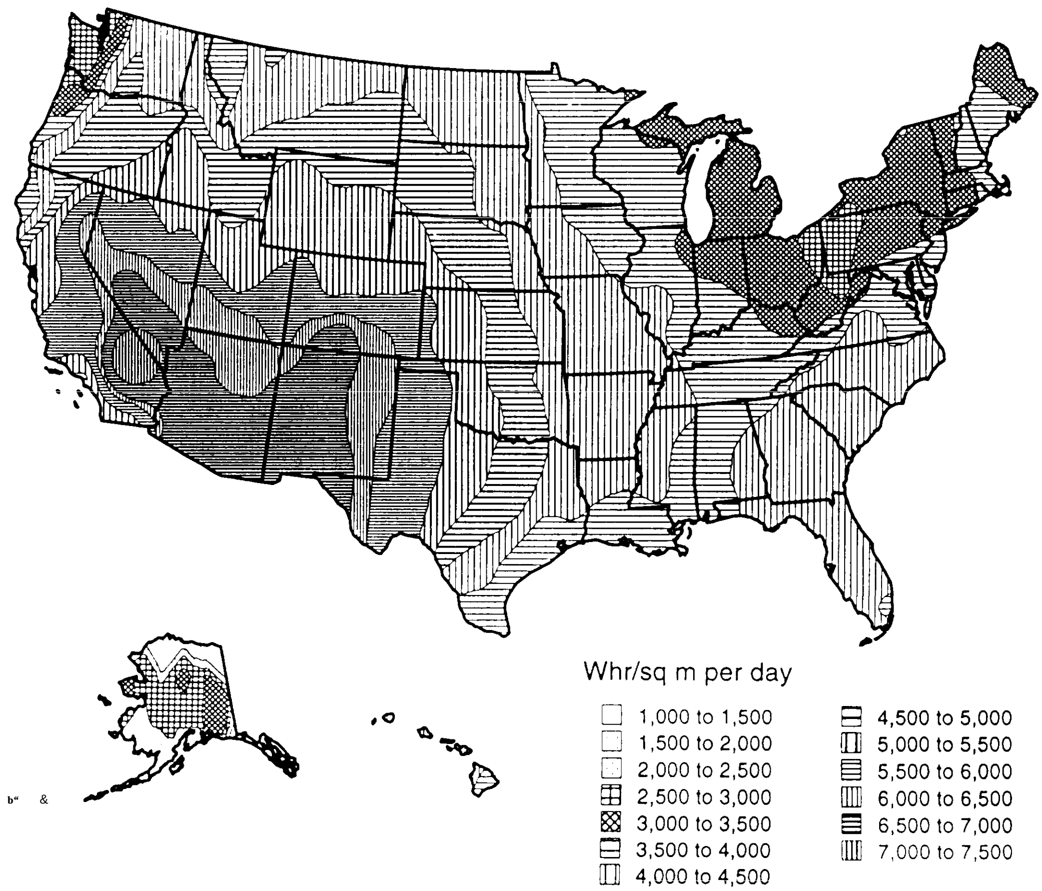
47 Electric *power Research Institute,* "Integrated *High-Concentration* Photovoltaic Technology," Technical Brief RP2948, 3256, December 1993.

BOX 5-6: Solar Resources and Collector Geometries

The solar resource varies hourly, daily, seasonally, geographically and with the local climate. Understanding this variation is important in choosing the best location and orientation for solar electric (photovoltalc or thermal) systems, for determining the optimum size of the solar system and of the associated (if any) storage system, and/or for matching the system output to the needs of the local utility, Detailed long-term records of insolation are needed for such evaluations

Sunlight at the Earth's surface has two components direct or beam radiation coming directly from the sun, and diffuse radiation that has been first scattered randomly by the atmosphere before reaching the ground. Together, these are known as the total or global radiation. In general, direct radiation IS more sensitive to atmospheric conditions than diffuse radiation heavy urban smog might reduce direct radiation by 40 percent but total radiation by only 20 percent Direct solar radiation IS shown in figure 1 and total radiation in figure 2,

Average Daily Direct (Beam) Solar Radiation, 1961-90



NOTE Direct solar radiation is the sunlight that comes directly from the sun to the receiver Values shown here are for direct sunlight on a surface always facing the sun—e g a surface that uses two axis tracking to follow the sun

SOURCE National Renewable Energy Laboratory 1993

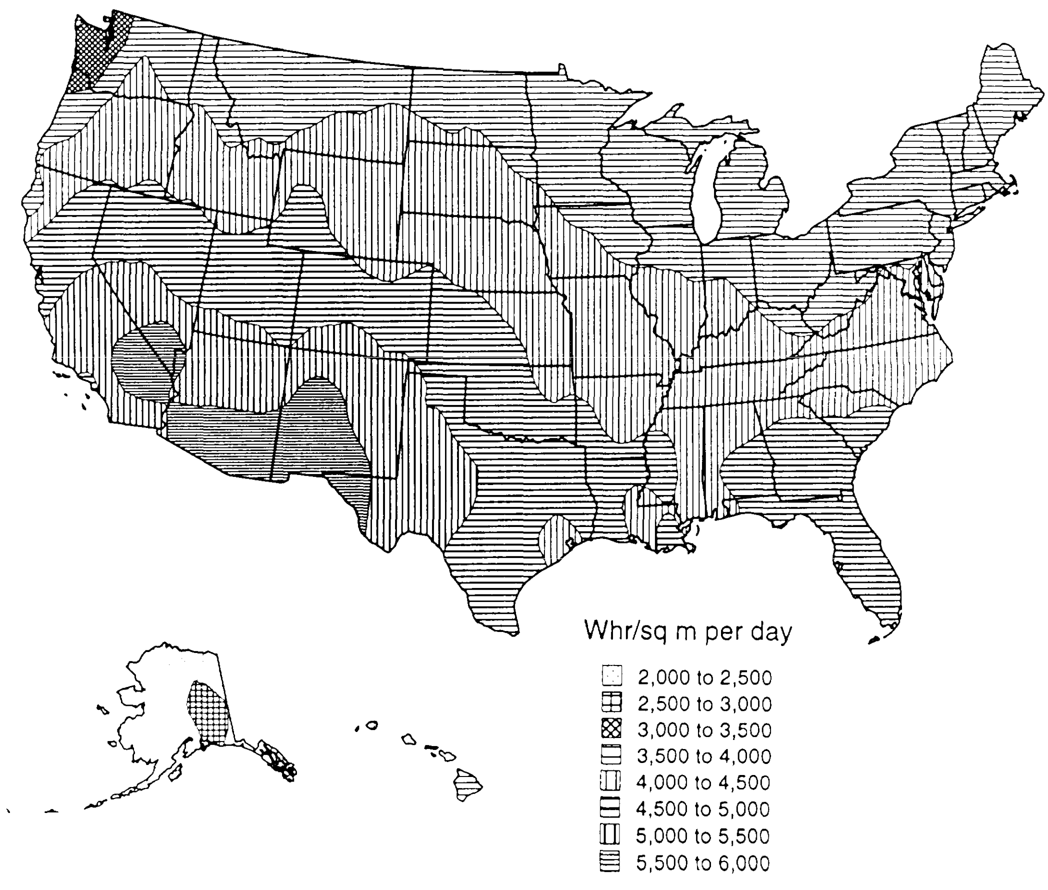
BOX 5-6 (cont'd.): Solar Resources and Collector Geometries

There are three general classes of solar collectors fixed, one-axis trackers, and two-axis trackers (figure 5-2) Fixed collectors are mounted in a fixed position and generally left there (although some may be adjusted seasonally) The amount of light Incident on the collector then changes over the day and season with the position of the sun relative to the orientation of the collector The specific orientation of the fixed collector IS adjusted to optimize the energy received-for example, to maximize winter or summer afternoon energy collection.

One-axis tracking collectors have one dlrection of movement—from east-to-west, for example—and so can roughly follow the sun's motion during the course of the day, but are not adjusted for the change in the suns position during the course of the year (or wee-versa for collectors adjusted north-south) Two-axis trackers can precisely follow the sun across the sky during the day and from one season to the next

Tracking collectors allow more direct sunlight to be captured per unit area of collector, but at a cost because of the moving parts and more complicated mounts Whether or not a tracking collector IS worthwhile depends on engineering and climatic factors, trading off the additional cost versus the value of the additional energy collected

Average Daily Total Solar Radiation, 1961-90



NOTE Total solar radiation Includes the sunlight coming directly from the sun plus that which comes from the sky Values shown here are for total solar radiation on a horizontal surface

SOURCE National Renewable Energy Laboratory, 1993

(continued)

BOX 5-6 (cont'd.): Solar Resources and Collector Geometries

Concentrating collectors must use tracking because the optics need careful orientation wtih respect to the sun. Use of concentrators, however, limits energy collection to direct radiation. Concentrators are therefore of greatest Interest in low humidity regions with relatively little scattering of direct sunlight, such as the U S Southwest. Some light is also lost by absorption in or scattering by the concentrating mirror or lens.

Although the solar resource is diffuse, the land areas required for electricity generation are similar to those for coal when mining is included (see table 1-2 in chapter 1), and are modest compared to the total U S land resource. For example, total U.S. electricity needs could be produced from less than 10 percent of the land area of Nevada. [1]

[1] John Thornton and Linda Brown, Photovoltaics The Present Presages the Future, "*The Electricity Journal,* April 1992, pp 34-41

take this risk. The Amoco/Solarex-Enron venture is an intermediate step that would both scale production up to 10 MW/year by 1997 and rely on a variety of tax supports to reach its cost goals. The leap in scale to achieve low-cost manufacturing is a very significant obstacle for PV manufacturers.

There are, however, a variety of high-value niche markets, such as remote or distributed utilit y applications (see below), for which PVs can effectively compete today. This provides near-term markets that can help scaleup manufacturing to the levels ultimately needed to compete for longer term bulk power markets. This perspective is becoming a key element of the PV industry strategy for scaling up manufacturing.

Research, Development, and Demonstration Needs

RD&D needs include further development in many areas: current PV materials and designs, including multiple junctions and composite materials; new materials and PV device structures; building-integrated PVs and other techniques to lower support structure and other costs; advanced manufacturing equipment; improved encapsulation technologies; lower cost and higher performance balance of system components; and better grid-integration technologies. Advanced manufacturing processes are an important element of a balanced RD&D portfolio. As demonstrated by the past 15 to 20 years of high-technology competition with Japan, manufacturing processes are, in many cases, as important as innovative devices. Continued R&D is an essential component of any PV development and commercialization strategy.

The PV industry, with total 1994 revenues of' roughly $150 million,[48] would not be able to fund RD&D at the $75 million amount that it received from the federal government in FY 94. Further, the record has shown very few deep-pocketed U.S. firms willing to support the long-term RD&D needed, despite the enormous potential of PVS. Foreign firms, however, have already purchased a number of U.S. PV firms (chapter 7) and are likely to purchase other important U.S. PV innovations and firms should the opportunity arise.

Estimates of the net present cost to bring PV technology to a competitive status versus conventional baseload equipment on an accelerated schedule (over the next 15 to 20 years) range

[48] Assuming $6,000/kW and 25 MW of PVs produced. See "Worldwide PV Shipments Top 60 MWp; U.S. in Lead But Europe Catching Up," *Solarletter, vol. 5, No. 6,* Feb. 17, 1995, p. 53.

BOX 5-7: Photovoltaic Technologies[1]

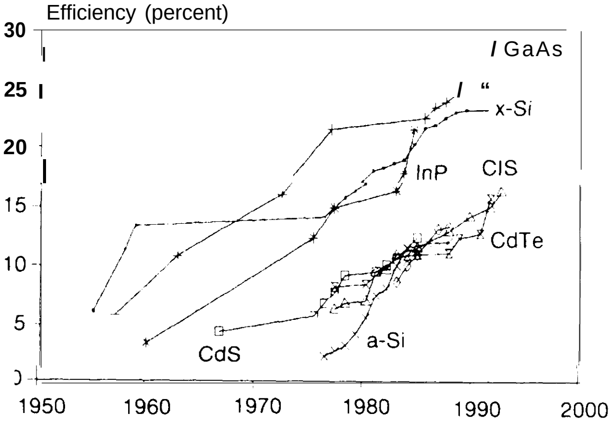
A PV cell is made by depositing layers of various materials so as to create an intrinsic (and permanent) electric field inside When light strikes the material, It can free an electron from weak bonds that bind it Once freed, the electric field then pushes the electron out of the PV and sends it through an external wire to do work—for example, to power a light, refrigerator, or an industrial motor—before returning to the PV cell, completing the circuit

The development of PVs presents difficult engineering choices between making the cell more efficient while keeping costs down. A number of technologies are used including thin-film flat plates, single crystal and polycrystalline flat plates, and concentrator systems These follow a progression from lower efficiency/ lower cost to higher efficiency/higher cost. At the current state of technology, all these approaches provide electricity roughly the same cost

Thin film PVs use little PV material—typical thicknesses of the film are 4/100,000 of an inch thick or 1/1 00 of a human hair—on a low-cost substrate such as glass, metal, or plastic Thin-film materials such as amorphous silicon (a-Si), copper indium dilselenide (CIS), and cadmium telluride (CdTe) potentially offer relatively high efficiency and easy fabrication (see figure 1) The efficiency of CIS is currently at 164 percent, the highest of any thin film, and stabilized large-area a-Si has reached 102 percent,[2] A joint venture between Energy Conversion Devices of Troy, Michigan, and Canon of Japan is constructing a manufacturing plant in Virginia to produce this high-efficiency a-Si, for which costs are expected to be 16¢/kWh in 1995, eventually dropping to 12¢/kWh[3]

Crystalline and polycrystalline flat-plate PVs of silicon are the most common and the most mature type of PV Nonconcentrating cells of silicon are now at 235 percent efficiency and nonconcentrating cells based on gallium arsenide (GaAs) have reached 295 percent.[4]

Efficiency of Photovoltaic Cells, 1954-94



NOTE: Shown here are the efficiencies of laboratory cells of single crystal silicon (x-Si), gallium arsenide (GaAs), indium phosphide (InP), cadmium sulfide (CdS), amorphous silicon (a-Si), cadmium telluride (Cd-Te), and copper indium diselenide (CIS). The wide range of PV materials, manufacturing processes, collector configurations, and systems designs provide confidence that some paths will succeed in reaching low-cost goals.

SOURCES: Paul Maycock, PV Energy Systems, Inc., personal communication, December 1993; Ken Zweibel, National Renewable Energy Laboratory, personal communication, January 1994; George Cody, Exxon Corporate Research Laboratory, personal communication, January 1994; and Masafumi Yamaguchi, "Present Status and Future Prospects of InP Solar Cells," paper presented at the 20th IEEE Photovoltaic Specialists Conference, 1988, Las Vegas, NV, Sept 26-30, 1988.

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[1] An excellent overview of photovoltaic issues is provided by Ken Zweibel, *Harnessing Solar Power The Photovoltaics Challenge* (New York NY Plenum Press, 1990) a more recent and somewhat more technical review can be found in Thomas B Johansson et al (eds), *Renewable Energy Sources for Fuel and Electricity* (Washington, DC Island Press, 1993) A technical introduction to PV science is given by Martin A Green *Solar Cells Operating Principles, Technology and System Applications* (Englewood Cliffs NJ Prentice-Hall Inc 1982) For more detailed technical information on photovoltaic technologies, see IEEE Photovoltaic Specialists Conference European Community Photovoltaic Solar Energy Conference, and the Photovoltaic Science and Engineering Conference Each of these is held roughly every 18 months

[2] Anthony Catalano National Renewable Energy Laboratory personal communication May 3,1994

[3] Jerry Bishop New Silicon Cell Can Halve Cost of Solar Energy, " *Wall Street Journal* Jan 19, 1994 p B5

[4] Catalano op cit footnote 2

(continued)

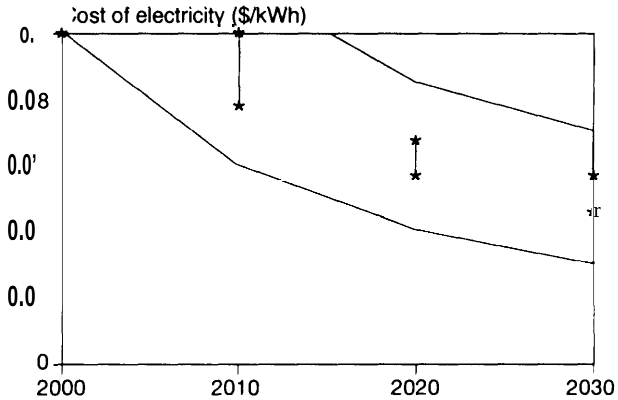
BOX 5-7 (cont'd.): Photovoltaic Technologies

Concentrator systems use low-cost mirrors or lenses[5] to focus light on a small, high-efficiency (but expensive) PV. Concentrator systems are more complex and are only able to use the direct component of sunshine. On the other hand, sufficiently low-cost lenses can compensate for the higher cost and complexity of tracking systems; sufficiently high-efficiency concentrator PVs can compensate for the loss of diffuse radiation and losses of light passing into and through the lens. Together, these can lower the overall cost of electricity from PVs. Because concentrator systems are more complex, they generally will need to be deployed in somewhat larger units than flat-plate PVs, which can be made use of in units as small as desirable.

Projected costs for photovoltaics are shown in figure 2. In the near to mid-term, these costs would make PVS competitive in a variety of niche markets, gradually expanding to important utility markets as costs continue to decline in the longer term, There are several factors that suggest that PVs will be able to meet these cost projections:

- *High efficiencies,* PV cells under development have demonstrated efficiencies sufficiently high to make these costs potentially achievable. Good progress has also been made in translating laboratory advances into commercial products, although the lag time is often five years or more.
- Alternative paths. There are numerous alternative PV materials and manufacturing processes, as well as many system designs, providing confidence that at least some technology and engineering paths will prove successful in reaching these goals.

Cost Projections for Photovoltaic-Generated Electricity



NOTE: The cost of PV-generated electricity is expected to drop to the range of 10¢ to 20¢/kWh by the year 2000, and continue to decline rapidly in following years depending in large part on the scale of manufacturing. Longer term cost reductions also depend on lowering the costs of other system components and installation methods. Some recent projections indicate costs could be lower by the year 2000. The shaded range encloses most of the expert estimates reviewed, with all estimates in constant 1992 dollars and, where necessary, capital cost and other estimates converted to ¢/kWh using discount rates of 10 and 15 percent (with 3 percent inflation). High and low values developed by the Department of Energy are shown as *.

SOURCE: Office of Technology Assessment, based on: U.S. Department of Energy, "Renewable Energy Technology Evolution Rationales," draft, October 1990; Thomas B. Johansson et al. (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993); John Doyle et al., *Summary of New Generation Technologies and Resources* (San Ramon, CA: Pacific Gas and Electric Co., 1993); and Bechtel Group, Inc., *Engineering and Economic Evaluation of Central-Station Photovoltaic Power Plants*, EPRI TR-101255 (Palo Alto, CA: Electric Power Research Institute, December 1992).

[5] Lenses are generally used with PVs while mirrors are generally used with solar thermal systems The reason for this difference in approach is that concentrating cells need to be cooled in order to maintain their high efficiency Passive cooling technologies are preferred due to their simplicity, but these require large heat fins to allow effective convective heat transfer With a mirrored system, these large heat fins would naturally lie between the sun and the mirror, blocking some of the incoming sunlight With lenses, these heat fins naturally lie behind the cell and thus do not cause any shading. In addition, PVs are sensitive to hot spots—where the light is more highly concentrated—due to imperfections in the mirror or lens. Such imperfections are more easily controlled with lenses than with mirrors.

BOX 5-7 (cont'd.): Photovoltaic Technologies

- *Low-cost materlas.* Both thin-film and concentrator PVs use very small amounts of active electronic materials This minimizes the cost of production
- Design studies Detailed engineering design estimates for the near to mid-term show that dramatic cost reductions are possible with just modest improvements in commercial products and the advantages of mass productlon,[6]
- Additional *manufacturing cost reductions* Will include Improvements in polycrystalline ingot casting, improved sawing for slicing ingots; the development of ribbon technologies to improve handling of wafers and reduce silicon waste, Innovations to allow continuous deposition of thin film PV layers; and various strategies for reducing the cost of solar-grade silicon

Environmental Impact

A variety of toxic chemicals are used in the manufacture of PVs, but emisslon of these toxics are routinely minlmlzed[7] and PV production facilities pose little risk for their surroundings Although some toxic materials such as arsenic and cadmium are contained within some types of PVs, studies indicate that they are well Immobilized within the cell and pose very little threat to the environment[8] PVs also generate no greenhouse gas emissions during operation, Overall, PVs are perhaps the most enbotonmentally benign of all the renewable energy technologies

6 W J Stolte, "Engineering and Economic Evaluation of Central-Station Photovoltaic Power plants, ' EPRI f+@ TR-101255 December 1992 Daniel S Shugar et al Pacific Gas & Electric Co , Comparison of Solar Thermal Troughs with Photovoltaics as a PG&E Central Statlon Resource in the 1990s " 1991 Yutaka Hayashi et al 'Design Option for a Crystalline Silicon Solar Cell "*Technical Digest of the International PVSEC-5* (Kyoto Japan 1990), G Darkazalli et al "Sensitivity Analysis and Evaluation of Manufacturing Cost of Crystalline Silicon PV Modules paper presented at the 22nd IEEE Photovoltaic Specialists Conference Las Vegas NV, October 1991, D E Carlson, Low-Cost Power from Thin-Film Photovoltaics " Johansson et al (eds) op cit footnote 1 J Wohlgemuth et al Solarex Corp 'Cost Effectiveness of High Efficiency Cell Processes as Applied to Cast Polycrystalline Silicon ' n d and Paul D Maycock, personal communications, 1992 and 1993

7 P D Moskowitz et al Safety Analysis for the Use of Hazardous Productlon Materials in Photovoltaic Applications Advances *in Solar Energy* vol 8, Morton Prince (ed) (Boulder CO American Solar Energy Society, 1992), pp 345-396

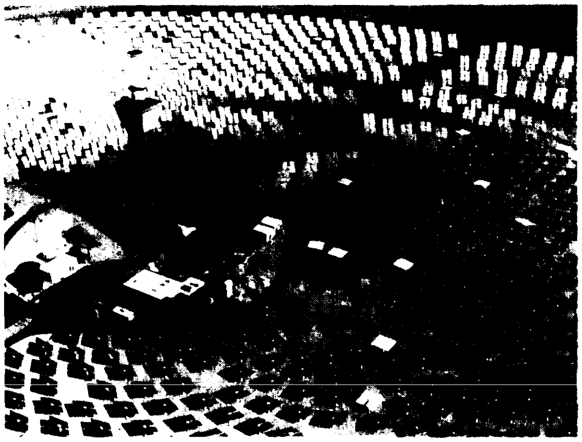
8 Kenneth Zweibel and Richard Mitchell "$CuInSe_2$ and CdTe Scale-up for Manufacturing, " *Advances in Solar* Energy, vol 6 Karl W Boer (ed) (Boulder Co American Solar Energy Society 1990) pp 485-579

around $5 billion to $9 billion (globally) for both additional RD&D and commercialization supports.[49] Such estimates are based on rough extrapolations of the observed learning curve for PV and other industries. Estimates of the return on R&D specifically have not been possible, however, given currently available data.[50] Although this is a Significant expenditure, it is just one-fifth to one-tenth that projected for the U.S. investment alone

49 G.D. Cody and T.J. Tiedje, "The Potential for Utility Scale Photovoltaic Technology in the Developed World: 1990-2010, " *Energy and the Environment*, B. Abeles et al. (eds.) (River Edge, NJ: World Scientific Publishing Co., 1992); World Energy Council, *Renewable Energy* Resources, *Opportunities and Constraints 1990 -2020* (London, England: September 1993); and Robert H. Williams and Gregory Terzian, *A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology*, Report No. 281 (Princeton, NJ: Center for Energy and Environmental Studies, October 1993).

50 Kenneth Richards, *Dynamic Optimization of the Photovoltaic Commercialization Process* (Washington, DC: Battelle, pacific Northwest Laboratories. June 30, 1993), p. 51 and following.

SOLAR ENERGY INDUSTRIES ASSOCIATION



The Solar One Central Receiver test facility in California. This 10-MW facility provided much valuable data over six years of testing and is now being upgraded to test improved receivers and thermal storage, heliostat design, and other technologies.

to develop a prototype fusion reactor and determine the technical and commercial feasibility of that energy resources.[51]

Solar Thermal

Solar thermal electric plants use mirrors to concentrate sunlight on a receiver holding a fluid or gas, heating it, and causing it to turn a turbine or push a piston coupled to an electrical generator.[52] Solar resources are described in box 5-6 and solar thermal technologies are described in box 5-8. The basic forms of solar thermal collectors are shown in figure 5-2.

Some 354 MW of solar parabolic trough thermal powerplant capacity were installed in California's deserts between 1984 and 1991, and demonstrated increasing reliability and performance and decreasing costs with each generation. The levelized cost of electricity for the most recent generation of plant dropped to roughly 10¢ to 12¢/kWh, with expectations that the next generation plant could reach costs as low as 8¢/kWh.[53] Further development of this type of solar thermal electric system has been significantly delayed by the bankruptcy of Luz, Inc., in 1991 (see chapter 6).[54] This experience showed, however, that solar thermal is a technically viable option and could potentially be cost-competitive with many fossil systems.

The Solar One Central Receiver[55] similarly performed well, achieving 99 percent heliostat availability and 96 percent overall availability for the entire powerplant.[56] Its energy production was somewhat lower than predicted, however, and the next generation system now in planning and development, Solar Two, has been designed to sidestep this problem.[57] Advances have been made and tested on direct-absorption receivers, heliostat design and materials, and other components.

Parabolic dish systems have also seen considerable advances, including the development of stretched membranes dishes, advanced receivers, and long-lived stirling engines. Small 7 kW systems are now being developed by Cummins Pow-

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51 U.S. Congress, Office of Technology Assessment, *The Fusion Energy Program: Next Steps for TPX and Alternate Concepts*, OTA-BP-ETI-141 (Washington, DC: U.S. Government Printing Office, February 1995).

52 In some cases, the solar heated fluid or gas may pass through a heat exchanger and heat a separate fluid or gas that actually turns the turbine.

53 This includes cofiring with natural gas.

54 For a history of why Luz went bankrupt, see Michael Lotker, *Barriers To Commercialization of Large-Scale Solar Electricity: Lessons Learned from the Luz Experience*, SAND91-7014 (Albuquerque, NM: Sandia National Laboratory, November 1991); and Newton Becker, "The Demise of Luz: A Case Study," *Solar Today*, January/February 1992, pp. 24-26.

55 This system was commissioned in 1982 and shut down in 1988.

56 Richard B. Diver, "Solar Thermal Power: Technical Progress," in *Progress in Solar Energy Technologies and Applications: An Authoritative Review* (Boulder, CO: American Solar Energy Society, January 1994).

57 Power generation by Solar One was lowered in large part due to passing clouds causing the generator to trip off-line. In Solar Two, this is being avoided primarily through the use of molten salt thermal storage, which will provide energy through disruptions by passing clouds.

er Generation, a subsidiary of Cummins Engine Company, in a joint venture with DOE/Sandia National Laboratory and are slated for commercialization in 1996.

Parabolic trough and central receiver systems are generally large-scale systems, typically 50 to 200 MW, and so will be operated much as conventional large-scale fossil plants are today. Parabolic dish systems can be operated in small units and can then be used in remote or distributed utility applications (see below); larger dishes could be operated in large-scale grid connected systems. All of these systems can be operated as hybrids. most often using natural gas to supplement and extend the solar energy that is collected. This is particularly important for extending power output into evening peak hours.

The solar thermal electric industry consists of a mix of large and small firms. Luz, a relatively small independent firm, was the primary developer of parabolic trough systems until its bankruptcy. Unable to interest utilities in buying turnkey projects,[58] Luz turned to manufacturing, developing, and operating parabolic trough systems itself, with financing from large institutional and corporate investors. Following the bankruptcy of Luz, the investors formed or contracted separate operating companies to maintain and operate the plants at Kramer Junction, Daggett, and Harper Lake, California. Although much interest has been expressed around the world in developing additional parabolic trough systems, with a number of feasibility studies under way, no firm commitments have yet been made.[59]

Central receivers have been primarily supported by large firms such as Bechtel and Rockwell International, although some small firms such as Advanced Thermal Systems have also played roles. Currently, central receiver development is proceeding through the 10-MW Solar Two project, cost-shared between DOE and a number of utility and other partners, including Southern California Edison, Sacramento Municipal Utility District, Los Angeles Department of Water and Power, Idaho Power Company, Pacific Gas and Electric, Electric Power Research Institute, and Bechtel. At least three firms-Bechtel, Rockwell International, and Science Applications International—are developing a joint business plan for commercializing 100- to 200-MW central receivers in the late 1990s.

Dish stirling systems are now receiving considerable support from large companies such as Cummins Engine, Detroit Diesel. and Science Applications International, as well as by small firms such as Solar Kinetics, Accurex, and Industrial Solar Technology. There is a significant industry commitment, cost-shared with the federal government, to commercializing this technology. Cummins Power Generation, a subsidiary of Cummins Engine, has been developing a small-scale (7-kW) parabolic dish system since 1988; commercialization is planned in 1996. Under the Utility-Scale Joint-Venture program, Science Applications International and others are developing a 25-kW dish system that is expected to produce power at 6~/kWh; commercialization is planned for 1997. Some 56 dish systems will be manufactured and demonstrated at U.S. utilities under this program.

Research, Development, and Demonstration Needs

RD&D needs include better materials and lifetimes for stretched membrane mirrors and other optics, improved selective surfaces, advanced receiver designs, long-lived and high-efficiency stirling and other engines, and improved control systems. Much of this RD&D is focused on basic materials issues beyond the scope of individual firms now developing solar thermal systems.

58 Hamrin and Rader, op. cit., footnote 7.

59 Countries currently examining the feasibility of installing parabolic trough plants, with some already applying for World Bank support, include: India, Iran, Israel, Mex ice, Morocco, and Spain. David Kearney, Kearney and Associates, personal communication, Au:. 24, 1994.

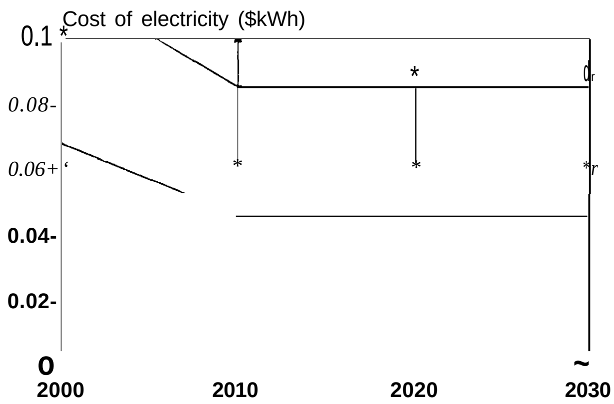
BOX 5-8: Solar Thermal Technologies

Solar thermal systems are typically categorized by the type of collector used parabolic trough, central receiver, parabolic dish, and solar pond, '

Parabolic trough systems currently account for more than 90 percent of the world's solar electric capacity. These systems have long (100 meters or more) trough-shaped mirrors with a tube at the focal line along the center The trough tracks the sun's position in the sky. The tube is clear glass with a black metal pipe carrying heat-absorbing fluid down the middle. To minimize heat loss from the black absorbing pipe back to the outside, the pipe has special coatings (selective surfaces) that reduce the amount of heat it radiates and the space between the absorbing pipe and the glass tube is evacuated to prevent heat conduction by air molecules. The fluid heated in the pipe is then pumped to where it can either indirectly (through a heat exchanger) or directly expand through a turbine to generate electricty. The potential of solar troughs is limited by the relatively low concentration ratios and receive temperatures (400°C or 750°F) that can be realized, leading to relatively low turbine efficiencies,

Central receivers have a large field of mirrors, known as heliostats, surrounding a fixed receive mounted on a tower. Each of the heliostats Independently tracks the sun and focuses light on the receiver where it heats a fluid or gas This fluid or gas is then allowed to expand through a turbine, as before, Key technical developments have been the development of stretched membrane mirrors to replace the glass and metal mirrors previously used.[2] The stretched membrane consists of a thin sheet of highly reflective material (plastic) held in a frame and curved to the desired shape.[3] They weigh much less than the glass and metal mirrors used previously, saving materials and reducing the weight on and the cost of the supporting frame. Stretched membranes have been developed that hold up well

Cost Projections for Solar Thermal



NOTE. The cost of solar thermal—parabolic trough, central receiver, and parabolic dish—generated electricity is expected to drop to the range of 7¢ to 12¢/kWh by the year 2000, with long-term costs of 4.5¢ to 9¢/kWh for the more efficient central receiver and parabolic dish systems, depending on the particular technology, the use of storage or natural gas backup, and other factors. The shaded range encloses most of the expert estimates reviewed, with all estimates put in constant 1992 dollars and, where necessary, capital cost and other estimates converted to ¢/kWh using discount rates of 10 and 15 percent (with 3 percent inflation). High and low values developed by the Department of Energy are shown as *.

SOURCE: Office of Technology Assessment, based on: U.S. Department of Energy, "Renewable Energy Technology Evolution Rationales," draft, October 1990; Thomas B. Johansson et al. (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993); and John Doyle et al., *Summary of New Generation Technologies and Resources* (San Ramon, CA: Pacific Gas and Electric Co., 1993).

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[1] Solar pond systems use a large shallow pond with a high density of dissolved salt to absorb and trap heat at the bottom, they do not use concentrating mirrors An extensive network of tubes then circulates a special fluid 10 absorb this heal The fluid then expands and turns a turbine Because of the very low temperatures revolved, typically around 90°C, solar pond systems are necessarily very low efficiency and require extensive piping networks to capture the heat absorbed Solar @rids also use huge amounts of water, perhaps 30times that of a conventional powerplant Their costs are likely to remain high for the foreseeable future and their applications are likely to be limited; they will not be considered further here DOE funding for solar ponds was terminated in 1983

[2] Some are examining mirror systems consisting of, for example, plastic membranes and glass reflecting elements

[3] The space behind the stretched membrane is typically partially evacuated, i e held at a lower air pressure, so that the air pressure outside pushes the membrane into a curve that focuses the light

BOX 5-8 (cont'd.): Solar Thermal Technologies

to gusty winds, but overall lifetimes are still short (5 to 10 years), the reflective coating is easily scratched, and effective low-cost cleaning techniques could use further refinement The design of the receiver is also undergoing extensive research, with much of the emphasis on molten salts as the working fluid. The molten salt would provide thermal storage to allow better matching of system output to utility needs and to carry system operation through brief passing clouds Central receivers achieve temperatures of typically 650°C (1 ,200°F)

Parabolic dish systems use a large dish or set of mirrors on a single frame with two-axis tracking to reflect sunlight onto a receiver mounted at the focus, Most commonly, a free piston stirling engine is mounted on the receiver, but hot fluids can also be piped to a central turbine as in the parabolic trough and central receiver systems Current research is focusing on lowering the cost of the mirror systems through the use of stretched membranes and to Improve the reliability and performance of the stirling engine.[4] Stirling engine lifetimes of 50,000 hours (about 10 years) with little or no maintenance are needed and are being developed.[5] In comparison, the typical automobile engine must have minor maintenance every 250 hours or so, and a major overhaul perhaps every 2,500 hours.[6] Parabolic dishes can achieve the highest temperatures (800°C or 1,500°F) and thus the highest efficiencies of concentrating solar thermal systems Parabolic dish systems currently hold the efficiency record of 31 percent (gross) and 29 percent (net) for converting sunlight into electricity[7]

All of these systems concentrate the sunlight to increase the operating temperature of the absorbing fluid and thus increase the efficiency of the turbine or engine that is driven, Concentration works only with the direct beam component, so regions with clear, dry air—such as the American Southwest—are preferable, although operation in other climates is possible[8]

Central receiver and parabolic dish systems have higher concentration ratios than solar troughs, and therefore the potential to achieve higher efficiencies and lower costs for generated electricity Projected costs for solar thermal technologies generally are shown in the figure and are expected to be competitive with fossil systems in a variety of applications in the mid- to longer term.

Environmental Impact

Solar thermal technologies can potentially impact the environment in several ways, including affecting wildlife habitat through land use, using large amounts of water in arid regions, or releasing heat transfer fluids or other materials into the environment, Proper siting and controls can minimize these potential impacts Natural gas cofiring produces nitrogen oxides and carbon dioxide emissions, but these emissions would be proportionately less for a solar thermal hybrid than for conventional fossil fuel use alone Overall environmental impacts appear to be quite low

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[4] Charles W Lopez and Kenneth W Stone, "Design and Performance of the Southern California Edison Stirling Dish," *Solar Engineering,* vol 2 1992, pp 945-952, and Graham T Reader and Charles Hooper, *Stirling Engines (New* York, NY E & F N Spon 1983)

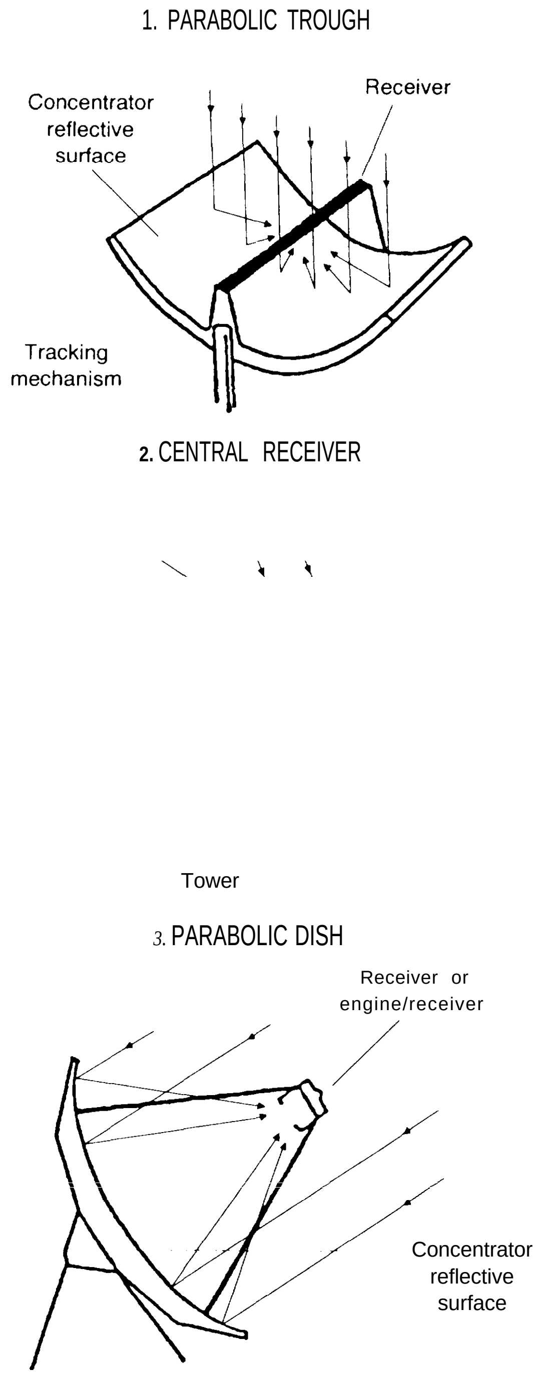
[5] Pascal De Laquil Ill et al "'Solar Thermal Electric Technology," *Renewable Energy Sources for Fuels and Electricity,* Thomas B Johansson et al (eds) (Washington DC Island Press, 1993)

6 For an automobile, an 011 change every 7,500 miles corresponds to 250 hours of operation, assuming an average operating speed of 30 mph Similarly a major overhaul every 75,000 miles corresponds to 2,500 hours of operation

7 William B Stine, Progress *in Parabolic D@ Technology,* SERI/SP-220-3237 (Golden, CO Solar Energy Research Institute, June 1989)

8 For example a dish stirling project has been operated in Lancaster Pennsylvania to pump water See "Solar Thermal Power Generation Is Viable in the Northeast *Solar Industry Journal,* vol 3, No 4, 1992, pp 14-15

FIGURE 5-2: Solar Thermal Collectors



SOURCE: Office of Technology Assessment, 1995.

| Wind

Wind energy systems use the wind to turn their blades, which are connected to an electrical generator. Wind energy resources and technologies are described in box 5-9.

Wind technology improved dramatically during the past decade. Costs for wind-generated electricity were reduced from over $ 1/kWh in 1981 to 5¢ to 6¢/kWh today, with the best plants now coming in as low as 4.3¢/kWh on a real levelized basis in areas with high-quality wind resources.[60] A number of factors contribute to these gains, including: advances in the design of wind turbine blades (15 to 30 percent energy gain); advances in and cost reductions of power electronics (5 to 20 percent energy gain); improved designs and materials to lower operations and maintenance costs; and better understanding of wind energy resources and siting needs. More than 1,700 MW of wind capacity were installed in California, where more than 1.5 percent of all electricity consumed is now generated by the wind---enough electricity to supply all the residential needs of one million people. Worldwide, a wind capacity of 3,200 MW is now connected to electricity grids.[61] Wind systems are now poised to enter large-scale markets in many areas. Recent U.S. commitments include Northern States Power for 425 MW, Lower Colorado River Authority for 250 MW, and Portland General Electric for 100 MW.

Wind systems provide intermittent power according to the availability of wind. Small, stand-alone wind systems, often backed up with battery storage, can be used in a variety of remote applications. Large wind turbines can be sited individually, or more commonly in "wind farms," and connected to the electricity grid. The extent to which wind power can offset other electricity-generating capacity then depends on its match

[60] The Northern States Power 25-MW project now online costs 4.7¢/kWh and the Sacramento Municipal Utility District system 4.3¢/kWh. Randy Swisher, American Wind Energy Association, personal communication, May 1994.

[61] Gerald W. Braun and Don R. Smith, "Commercial Wind Power: Recent Experience in the United States," *Annual Review Of Energy and the Environment, vol. 17, 1992,* pp. 97-121.

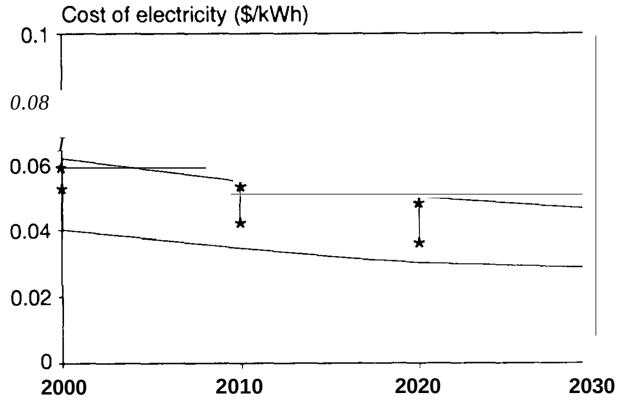
BOX 5-9: Wind Energy Resources and Technologies

Three key factors distinguish wind energy resources the variation in the power of the wind with its speed, the variation in available wind speeds at a given site over time periods ranging from seconds to months, and variations in wind speed with height above the ground. These have Important implications for wind turbine design and operation.

The power available in the wind Increases with the cube, i.e. V^3, of the wind speed Because of the factor V^3, wind turbines must handle a huge range of power. From the speed at which the turbine reaches its rated power to the speed at which the turbine is stopped (cut-out speed) to prevent damage, the power in the wind Increases by typically more than six times This variation in wind power with wind speed has led to the development of a variety of techniques to aid efficient collection of power at low speeds and to lilmit and shed excess wind power from the turbine blades at high speeds. Because the wind rarely blows at very high speeds, building the wind turbine strong enough to make full use of high winds is not worthwhile,

The sensitivity of wind power to wind speed also requires extremely careful prospecting for wind sites. A 10-percent difference in wind speeds gives a 30-percent difference m available wind power.

Cost Projections for Wind Energy



NOTE The cost of wind-generated electricity has dropped from over $1/kWh in 1981 to as low as 4.3¢/kWh in 1994, and is expected to continue to drop to 3¢ to 4¢/kWh for a large range of wind resources by 2030 The shaded range encloses most of the expert estimates reviewed, with all estimates put in constant 1992 dollars and, where necessary, capital cost and other estimates converted to ¢/kWh using discount rates of 10 and 15 percent (with 3 percent inflation) High and low values developed by the Department of Energy are shown as *

SOURCE Off Ice of Technology Assessment, based on U S Department of Energy, "Renewable Energy Technology Evolution Rationales ' draft, October 1990, Thomas B Johansson et al (eds.), *Renewable Energy Sources for Fuels and Electricity* (Washington, DC Island Press 1993), and John Doyle et al *Summary of New Generation Technologies and Resources* (San Ramon, CA Pacific Gas and Electric Co , 1993)

Wind speeds can vary dramatically over the course of seconds and minutes (turbulence), hours (diurnal variation), days (weather fronts), and months (seasonal varilatlons), The best locations are those with strong, sustained winds having little turbulence Finding such locations requires extensive prospecting and monitoring

Although the power output of any particular wind turbine will fluctuate with wind speed, the combination of many wind turbines distributed over a geographic area will tend to smooth out such fluctuations. This "geographic diversity" is an Important factor in system Integration. On the other hand, in a large array of wind turbines—a "wind farm"—the Interference of one wind turbine with its neighbors must be taken into account by carefully spacing and arranging the turbines.[1]

Winds also vary with the distance above ground level, this is known as "wind shear" Typically, winds at 50 meters will be about 25 percent faster and have twice the power as winds at 10 meters. The cost-effectivess of tapping these higher winds is then a tradeoff between the cost of the higher tower and the additional power that can be collected.

[1] Michael J Grubb and Niels I Meyer "Wind Energy Resources Systems, and Regional Strategies *Renewable Energy Sources for Fuel and Electricity,* Thomas B Johansson et al (eds) (Washington, DC Island Press, 1993)

(continued)

BOX 5-9 (cont'd.): Wind Energy Resources and Technologies

Wind shear places great stress on turbine blades. For a rotor with a diameter of 25 meters and its center (hub) 25 meters off the ground, the variation in wind speed with height above the ground will result in a nearly 50-percent variation in wind power between the top and bottom of the rotor arc. This, plus the effects of gravity, wind turbulence (gusts), the "tower shadow" on down-wind turbines, and other factors, severely flexes and thus stresses the rotor during every revolution. Over a 20- to 30-year lifetime, the rotor will go through perhaps 500 million such stress cycles.[2] This is a level of stress that is virtually without equal in humanmade systems, and poses severe requirements on rotor materials and blade design,[3]

Locations with favorable wind resources in the lower 48 states are shown m figure 5-3. The plains states have a particularly large available wind resource, with the potential to generate 1.5 times as much electricity as is currently consumed in the United States. Large wind resources have also been found in many other countries.[4]

Technology

Wind turbines take two primary forms defined by the orientation of their rotors the familiar propeller style horizontal axis wind turbine (HAWT) and the less common vertical axis wind turbine (VAWT).[5] The HAWT accounts for over 93 percent of the Installations in California.

Turbine blades must manage the very high levels of stress, described above, while efficiently collecting energy; they must do so with long lives and at low installed cost. To meet these demanding criteria, designers have turned to innovative designs[6] and materials for the turbine blades. Researchers at the National Renewable Energy Laboratory, for example, have developed a new family of blade designs that produce an overall 30-percent annual energy gain compared to conventional blades and are relatively unaffected by roughness due to dirt and bugs, yet automatically limit rotor peak power at high winds much more effectwely than conventional blades.[7] Composite materials such as fiberglass and wood/epoxy now account for most rotor blades currently in use in California,[8] and researchers are looking to advanced materials for blade construction.[9]

2 Based on a 4,000-hour Operation per year, a rotational speed of 35 or 70 rpm For example, N = (70 rpm)*(60 minutes/hour) *(4,000 hours/year)* (30 years) = 500 million

3 National Research Council, Assessment of Research Needs for Wind Turbine Rotor Materials Technology (Washington, DC National Academy Press, 1991)

4 Strategies Unlimited, "Study of the Potential for Wind Turbines in Developing Countries, " March 1987 The identified countries Include Argentina, Brazil, Chile, China, Colombia, Costa Rica, India, Kenya, Pakistan, Peru, Sri Lanka, Tanzania, Uruguay, Venezuela, Zambia, and Zimbabwe; California Energy Commission, "Renewal [sic] Energy Resources Market Analysis of the World, " CEC P500-87-015, n d , p 34

5 FloWind is currently working on an advanced VAWT with DOE and has prototypes under test at Tehachapi, CA

6 Rotor blades typically take a variety of forms They maybe rigid with a fixed pitch (fixed orientation), but with a specially designed blade shape to limit how much energy they capture from the wind They may have a variable pitch, in which the blade is rotated along its long axis in order to change the blade orientation with respect to the wind and thus limit energy capture They may be teetered, in which the rotor hub is allowed to rock up or down slightly in order to reduce stress on the drivetrain They may have ailerons built m, like flaps on an airplane wing, to control them More advanced forms may use small holes in the surface of the blade through which air can be blown to control the aerodynamics of the blade Each of these has certain advantages and disadvantages in terms of complexity, cost, performance, stresses, excess vibration, and other factors Alfred J Cavallo et al , "Wind Energy Technology and Economics, " in Johansson et al (eds.), op cit , footnote 1, and National Research Council, op cit footnote 3

7 J Tangier et al, *Measured and Predicted Rotor Performance for the SERI Advanced Wind Turbine Blades* (Golden, CO National Renewable Energy Laboratory, n d), and J Tangier et al *SERI Advanced Wind Turbine Blades* (Golden, CO National Renewable Energy Laboratory, February 1992)

8 Gerald W Braun and Don R Smith, "Commercial Wind Power Recent Experience in the United States, " *Annual Review of Energy and the Environment, VOl* 17, 1992, pp 97-121

9 National Research Council, Op cit , footnote 3

BOX 5-9 (cont'd.): Wind Energy Resources and Technologies

A particularly Important development is the use of advanced electronics to convert variable frequency power0[10] into a constant voltage and frequency for the electricity grid. Developed and marketed for large-scale wind turbines in the United States by Kenetech-U. S. Windpower—they received an R&D 100 award in 1993 for this technology—and others,[11] such systems reduce the cost of wind-generated electricity in two ways Variable-speed systems have a higher conversion efficiency at a lower wind speed and maintain it over a broader wind speed range, allowing more wind energy to be captured. They also greatly reduce the stresses on the rotor and drivetrain---allowmg them to be downsized and cutting their capital costs and maintenance requirements.

The capital and operations and maintenance costs for large grid-connected wind turbines have been dropping steadily throughout the 1980s. The capital cost of large turbines has already dropped to as low as $850/kW [12] The best wind turbines in California achieve a 97-percent availability Capacity factors depend on the wind at the site, but some are as high as 40 percent.[13] Projected electricity costs are shown in the figure; [14] these are potentially highly competitive.

Environmental Impact

Large land areas are required for siting wind farms, but the turbines, access roads, and related equipment *rarely* take more than 5 percent of the actual land area. The remainder can continue to be used for farming, ranching, or other purposes with little or no change Land values have substantially Increased in Altamont pass in California due to the additional income generated by royalties from the wind turbines

Noise was a problem with some early windmill designs. For the current generation of windmills, the noise problem is often no longer significant, in Denmark, for example, regulations limit windmlll-generated noise at the nearest dwelling to less than that found inside a typical house during the day A single 300-kW wind turbine can meet this standard when sited just 200 meters from the home, 30 such machines would need to be sited 500 meters away. [15]

Bird kills due to hitting the rapidly turning rotor blades have been a problem in some areas, including Altamont pass where raptors have been killed Some studies have concluded that these bird kills are substantially less than those from high voltage transmission lines, radio and TV towers, highway collisions with cars, or other such hazards.[16] Nevertheless, bird kills are of ongoing concern and efforts to understand and reduce this problem are under way

In some areas, particularly those with a high scenic value, the visual impact of wind farms may also be a concern

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10 Current turbine designs fix the rate of rotation of the rotor to a specific speed corresponding to the 60-cycle frequency of the utility grid

11 Such systems have been used in Europe for several years and have been used on Small wind turbines in the United States and elsewhere for more than a decade Paul Gipe "Windpower's Promising Future, " *Independent Energy,* January 1993 pp 66-72

12 Dale Osborne, Kenetech Inc , personal communication, Mar 22, 1993

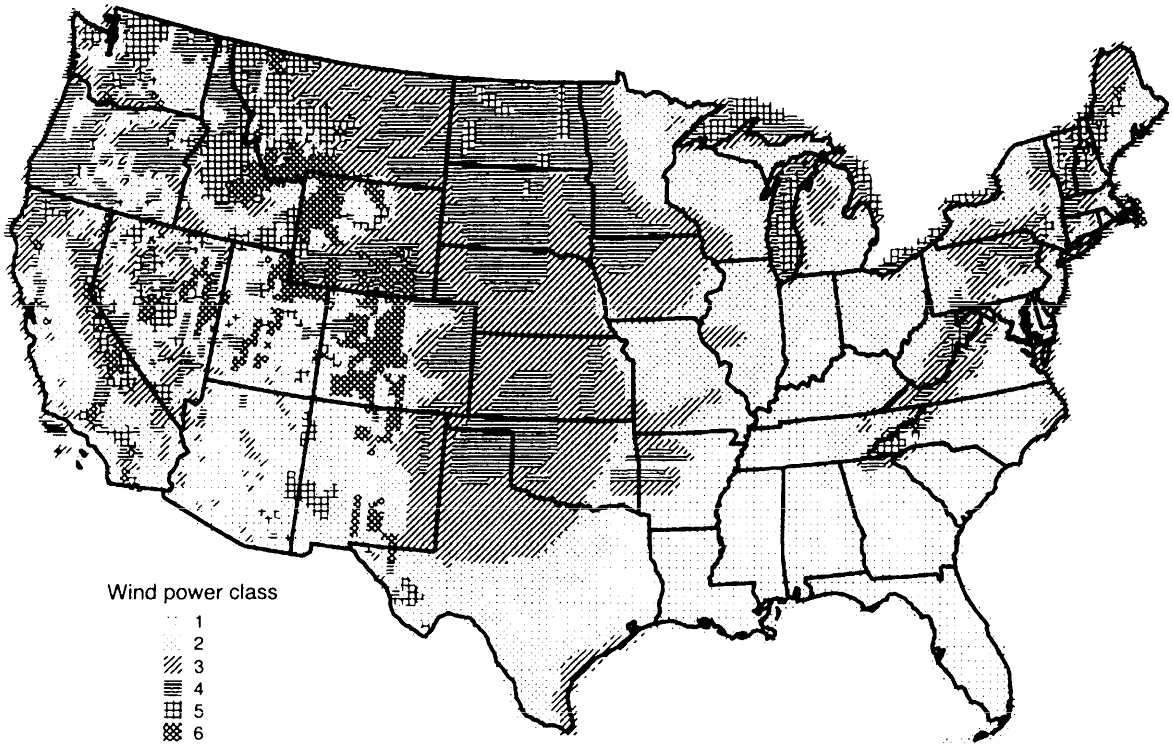
13 The Whitewater Hill site outside Palm Springs reportedly has a capacity factor of 40 percent Randy Swisher, American Wind Energy Association, personal communication, May 23, 1994

14 Al Cavallo, in Johansson et al (eds), op cit footnote 1

15 Michael J Grubb and Niels I Meyer, "Wind Energy Resources, Systems, and Regional Strategies, " in Johansson et al (eds), op cit footnote 1

16 A J M van Wijk et al World Energy Council, Study Group on Wind Energy, "Wind Energy Status, Constraints and Opportunities," sixth draft, July 1992, and Paul Gipe, Paul Gipe and Associates, "Wind Energy Comes of Age m California" n d

FIGURE 5-3: Average Annual Wind Resources



SOURCE. D.L. Elliott, Pacific Northwest Laboratory, "Wind Energy Resource Atlas of the United States," Nov. 8, 1994.

with the utility load and potential complementary combinations with other generation resources. Selecting wind sites with good matches to the utility load and gathering wind over a wide geographic area or combining it with other intermittent RETs (iRETs) such as solar may substantially smooth its variability.

The wind industry was strongly driven during the early to mid- 1980s by the Public Utility Regulatory Policies Act, federal and state tax credits, and by California Standard Offer 4 contracts. Initially, with extensive tax benefits available, projects were often financed through third-party limited partnerships; following the reduction in tax benefits, support has been provided more by institutional investors in non-recourse project financing (see chapter 6).

By one estimate, more than 40 wind energy developers installed turbines between 1982 and 1984.[62] The number of developers has gradually decreased over time, with about two dozen now active at some level, and six--Cannon Energy, F1oWind, Kenetech-U.S. Windpower, New World

62 Williams and Porter, op. cit., footnote 6. Note that some estimates of the number of manufacturers and developers active at some level vary widely and are generally much higher. For example, some estimate that more than 50 manufacturing companies and 200 development companies were involved in wind development in the early 1980\. See Hamrin and Rader, op. cit., footnote 7, p. B-27.

Power, SeaWest, and Zond—accounting for about three-quarters of total installed wind capacity in the United States.[63]

The number of manufacturers has also decreased over time, with just one large U.S. manufacturer—Kenetech-U .S. Windpower—and several smaller manufacturers/project developers—including Zond, FloWind, Cannon Energy, and Advanced Wind Turbines—now producing or developing utility scale turbines.[64] Small standalone turbines are produced by firms such as Bergey Windpower, Northern Power Systems. and World Power Technologies.[bs]

Of all the wind turbines installed in the United States as of 1990, some 40 percent were imported.[66] The decline in the value of the dollar, however, is making it more difficult for European and Japanese firms to compete in the U.S. market.

Several large firms such as Boeing and General Electric participated in the early development of very large turbines (up to 4.5 MW) sponsored under DOE, but then left the industry as these turbines encountered significant technical problems, federal support was cut back, and energy prices dropped. Some large firms, such as Westinghouse, are now becoming active again in the wind industry, and considerable interest has been expressed by the aerospace industry. Kaiser Aerospace, for example, recently entered an agreement to manufacture turbines for Advanced Wind Turbines, Inc.

With increasingly competitive electricity markets and the shift toward competitive bidding (chapter 6), wind turbine manufacturers and developers require much greater capitalization and marketing depth/skill to survive. Many in the industry, such as Kenetech-U.S. Windpower, Zond, FloWind, and Cannon Energy, have responded by becoming increasingly vertically integrated, with the same firm manufacturing turbines, and developing and operating projects. Others. such as SeaWest and New World Power, have more extensively tapped outside sources of capital.

Research, Development, and Demonstration Needs

RD&D needs have been identified and discussed above, including ongoing wind resource assessment and improving the ability to forecast winds: improved materials for turbine blades: advanced airfoil design: improved towers; advanced computer models of wind turbine aerodynamics, particularly of wind turbulence and unsteady flows: and smart controls. The required expertise in basic materials and aerodynamic modeling is beyond the scope that is currently feasible by the wind industry.

The DOE wind R&D program is focused on joint ventures with industry to improve existing installations, develop advanced wind turbines, and upgrade the technology base through applid research. Initiatives include: the Advanced Wind Turbine (AWT) Program, a collaboration with utilities to evaluate state-of-the-art hardware and facilitate its deployment; the Utility Integration Program, which addresses concerns of grid integration; the Collaborative Wind Technology Program, which provides for cost-shared research with industry in the design, development, testing, and analysis of operational problems of current turbine technology; the Value Engineered Turbine Program, which focuses cost-shared efforts with industry on re-engineering or remanufacturing of conventional turbine configurations: and the Ap-

63 Randall Swisher, American Wind Energy Association, persona] communication, Aug. 25, 1994.

64 Others include Atlantic Orient, Wind Eagle, and Wind Harvest.

65 For a more complete listing of wind industry firms, see American Wind Energy Association, Membership *Directory* (Washington, DC: 1994).

66 Edward T.C. Ing, *Attorney* at Law, in letter *to* Deborah *Lamb,* Trade Counsel, Senate Committee on Finance, May 24, 1991. Note that this percentage has not significantly shifted since 1990.

TABLE 5-1: Examples of Cost-Effective Remote Applications of RETs

Agriculture
Pumping water for livestock or agriculture
Electric fences
Instrumentation

Rural homes or communities
Powering Ilihts, appliances, and communications equipment
Water heating system circulation pumps

Communications
Telephone systems, including cellular phones and emergency call boxes
Remote fiberoptic Installations
UHFA/HF radio and TV repeaters

Infrastructure
Parking lot and street lighting
Highway and railroad sign and signal lighting
Cathodic protection of e.g., bridges, pipelines
Navigational aids e.g., beacons, buoys, lighthouses, tower warning lights
Environmental monitors e g , meteorological, water level, and environmental quality

Transmission and distribution equipment for electric and gas utilities
Sectionalizing switches
End-of-feeder support
Dynamic thermal rating sensors
Pipeline flow meters and valve actuators
Medical and health care (remote medical clinics)
Refrigerators and freezers for vaccines and other medical supplies
Equipment for sterilizing medical Instruments
Improved lighting
Backup power and emergency communications

SOURCE Off Ice of Technology Assessment, 1995

plied Research Program, to develop the fundamental design tools for advanced wind turbines.

RENEWABLE ENERGY SYSTEMS

Three different renewable energy systems are examined here. These are systems for remote applications, utility applications where large-scale renewable energy plants are integrated into the grid, and distributed utility applications of small-scale RETs.

Remote Systems

Even relatively expensive renewable energy technologies can be cost-effective today in a variety of remote—at a distance from the existing electricity grid—applications (table 5-1). Their cost-effectiveness in particular applications is determined by the extent to which they reduce the use of fossil fuels that have to be hauled in at considerable expense or avoid the installation of costly transmission lines to provide power from the electricity grid.

These remote applications are a high-value use that is beginning to provide an important early market for RETs. Remote applications provide manufacturers a means to develop a distribution and maintenance infrastructure, important information about how best to design and market products for a particular area and application, and a network of contacts and loyalties. Similarly, remote applications provide users the opportunist y to test these technologies; train personnel; gain early technical, managerial, and operational experience; and build confidence in the technology. For example, remote app ications have been the primary market for developing the PV industry and have provided much valuable experience for both producers and users.

Improved understanding of the structure of the market for remote applications is very important in order to map an evolutionary path for the development of corresponding renewable technologies. For example, for a particular RET at a specific price: how large is the market and what are the key market opportunities; what factors determine the purchase of a particular RET (such as a PV lighting system); and what productivity gains and financial returns might be realized by using a particular RET (such as for agricultural water pumping)? Increased analytical effort is necessary for these factors to be adequately understood and an effective national strategy for remote applications—particularly in developing countries—to be developed. Given the limited resources of most renewable energy firms, public-private collaboration may offer a useful means of proceeding.

Remote applications require complete energy systems, which provide electric power (and energy services) when it is needed and in the form needed—at the specified voltage, current, and quality[67] of power required by the application. In contrast, many of the individual technologies described above, particularly the solar and wind RETs, provide alternating current (ac) or direct current (de) at some voltage-depending on the particular technology—when the resource is available. The form of power and the time when it is avai able may not match the application requirements.

Renewable energy systems typically consist of: 1) a RET to gather the energy resource and generate electricity; 2) a power conditioning unit to convert the electricity to the desired current (dc or ac), voltage, and quality needed for the application: 3) backup equipment (i.e., storage such as batteries or a generator such as a diesel engine[68]) to provide power when the renewable resource (such as wind or sun) is not available; and 4) control equipment to do all of this safely and efficiently.

The design and cost of these system components depend on the specific application. A PV water pumping system may need little or no backup while a PV lighting system may operate completely off battery storage.

Three primary considerations determine the relative size of the backup (storage or other) capacity: 1) the timing and size of the powerdemand (the load curve); 2) the availability-day-night, weather-related (cloudy or windy days), or seasonal-of the resource (intermittence); and 3) the acceptable risk of not having power (the reliability). These factors are interrelated.

Remote loads can be served either by extending transmission and distribution (T&D) lines from the existing electricity grid or by onsite generation.[69] Grid extension is a large fixed investment that is relatively insensitive to the load and that increases with distance .70 In contrast. the cost of re-

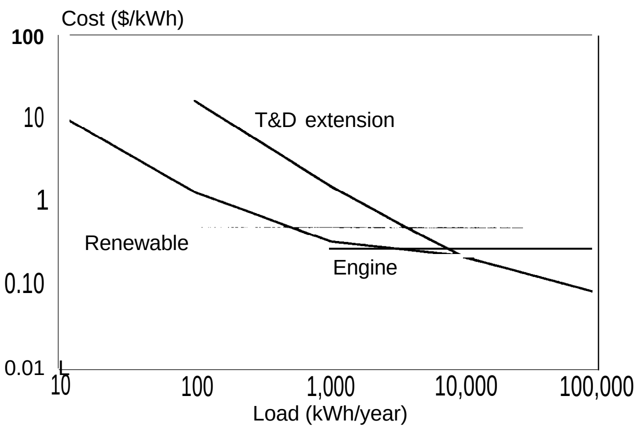
67 High-quality power has a nearly sinusoidal single-frequency (i.e., 60 Hz) waveform (with few harmonic frequencies); little variation in average voltage; no voltage spikes or switching transients (sudden changes in the voltage waveform due (o the switching of certain power electronic devices in the power conditioning unit); or other deviations. High-quality power is important to prevent damage to equipment; to prevent interference with communications, computer, or other equipment; and to ensure efficient operation.

68 Renewable systems coupled with conventional engine generators are usually called hybrid systems.

69 See, e.g., J.E. Bigger and E.C. Kern, Jr., '" Earl y, Cost- Effective Photovoltaic Appl i cations for Electric Utilities," paper presented at Soltech 90, Mar. 21, 1990, Austin, TX; and M. Mason, "Rural Electrification: A Review of World Bank and USAID Financed Projects," background paper for the World Bank, April 1990, p. 27.

70 Most of the cost in Putting the system into place is in the power poles, labor, right-of-way, and so forth. In a particular case, typically less than roughly 10 percent of the total cost is determined by the wire or the transformers-i. e., the load-carrying capability.

FIGURE 5-4A: Cost-Effectiveness of T&D Extension, Engine Generators, and PVs, by Electricity Load



NOTE: At a given distance from the utility grid, a RET such as PV is the lowest cost source of power at relatively low electricity demands, an engine may be the lowest cost generator at intermediate demands, and grid extension will be the lowest cost source of power at high demands. As PVs drop in price, they are cutting into the market for engine generators (the horizontal line for PVs shifts down), prompting some manufacturers of engine generators to develop RETs such as dish stirling in order to protect their market in the future. The calculation illustrated here assumes a 1-km line extension at a cost of $15,000 with 4-percent annual maintenance, a 30-year lifetime, a 10-percent cost of capital, and 7¢/kWh for electricity. The engine is assumed to cost $700/kW, 2¢/kWh for operations and maintenance (O&M), 15¢ to 23¢/kWh for fuel (depending on the size), and has a 66-percent capacity factor, a 10-year lifetime, and a 10-percent cost of capital. The PV system is assumed to have an installed cost of $10,000/kW, O&M costs of 5¢/kWh, and a capacity factor of 20 percent. Actual values in the field can vary considerably from those assumed here.

SOURCE: Office of Technology Assessment, 1995.

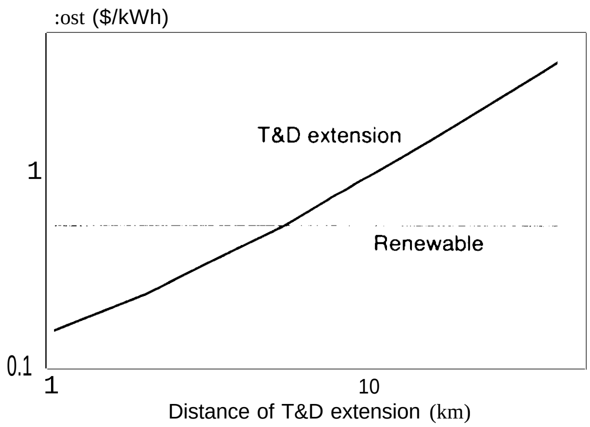
mote generation is little affected by distance from the grid and scales directly with the load. For a particular load, at some distance+ ailed the break-even distance—the cost of grid extension exceeds that of remote generation.

Onsite generation is most commonly done today by a small diesel or gasoline engine coupled to a generator. This technology has a relatively low initial cost, is widely available, can be installed anywhere, and uses a familiar technology. It is dependent on fossil fuel, however, which may be difficult and expensive to transport to the site. Consequently, for a range of conditions a particular RET will have lower total costs to generate electricity y.

In many cases, hybrids consisting of a RET and battery storage system backed up with an engine generator can be considered. This can reduce the need to oversize the RET and battery storage to handle extended periods without any renewable energy input, improves reliability, and reduces the high cost and unreliability of transporting large quantities of fuel to the site for a generator alone.

These alternatives-T&D extension or on-site generation by engines or renewable systems--can be compared in several ways, as shown generically in figure 5-4. The cost and performance tradeoff between these alternatives is determined by the load, the distance to the site, and a host of other factors. Estimation of the cost and performance of specific remote power projects must include site-

FIGURE 5-4B: Cost-Effectiveness of T&D Extension and PVs, by Length of Grid Extension



NOTE: At an intermediate level of power demand (20 MWh/year), corresponding to a village power system, extending the T&D grid will be most cost-effective over short distances (up to about 5 km), while PV-generated electricity will be most cost-effective at longer distances from the grid. The crossover point shown here is quite sensitive to the power demand. Lower power demands, for example, make the PV system cost-effective at distances closer to the grid. Parameters are the same as in figure A.

SOURCE: Office of Technology Assessment, 1995.

specific factors and current RET costs using one of the many computer packages or design handbooks available.[71] System reliability depends on the local renewable energy resources, the RET, and its backup, compared to the likelihood of T&D lines being downed, or to the reliability of both the engine generator and the fuel transportation infrastructure.

Industry

The PV industry relies almost exclusively on remote applications for its sales (chapter 7). Segments of the windpower industry, such as Bergey Windpower, Northern Power Systems, and World Power Technologies, also concentrate on remote markets and have numerous turbines in the field. Similarly, some solar thermal firms see remote applications as an important market opportunity and are specifically developing RETs for this market. An example is the 7-kW dish stirling system being developed by Cummins Power.

| Utility Systems

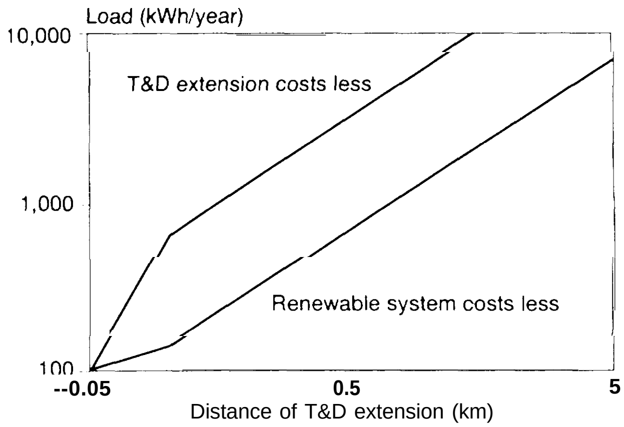
RETs have unique characteristics that present both problems and opportunities when integrated into an electricity grid. These include intermittence, power quality, site specificity, and modularity.

Intermittence

Use of intermittent renewable resources—such as solar and wind energy-offsets fuel use by conventional generating technologies. In addition, iRETs can reduce the need for conventional generating capacity. The factors that determine how much reduction is possible include:[72]

- *The match between the renewable resource and the local utility peak loads.* Good matches, such as PV or solar thermal matching summer air conditioning demands,[73] have higher capacity value.

FIGURE 5-4C: Cost-Effectiveness of T&D Extension Versus PV Systems as a Function of Power Load and Distance from the Utility Grid



NOTE At high levels of power demand and 'or relativelyshort distances from the utility grid, T&D grid extension can be the lowest cost option conversely at low levels of power demand and/or longer distances from the utility grid a stand-alone RET such as a PV system can be the lowest cost option The upper line assumes a high cost of grid extension ($1 5,000/km) and a low Installed cost foraPVsystem($6000/kW), the lower line assumes a low cost for grid extension ($7,500/km) and a high Installed cost for a PV system Parameters are the same as in figure A

SOURCE Off Ice of Technology Assessment 1995

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71 See, e.g., Photovoltaic Design Assistance Center, *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices*, SAND87-7023 (Albuquerque, NM: Sandia National Laboratories, November 1991). The National Renewable Energy Laboratory, Golden, CO, is also developing such tools.

72 See, e.g., Yih-huei Wan and Brian K. Parsons, *Factors Relevant to Utility Integration of Intermittent Renewable Technologies*, NREL/TP-463-4953 (Golden, CO: National Renewable Energy Laboratory, August 1993); Michael J. Grubb and Niels I. Meyer, "Wind Energy: Resources, Systems, and Regional Strategies, " in Johansson et al. (eds.), op. cit., footnote 3; Henry Ken y and Carl J. Weinberg, "Utility Strategies for Using Renewable," in Johansson et al. (eds.), op. cit., footnote 3; Adrianus Johannes Maria Van Wijk, Utrecht University, "Wind Energy and Electricity Production," 1990; and M.J.Grubb, "The Integration of Renewable Electricity Sources," *Energy Policy*, September 1991, pp. 670-688.

73 As structures and their surroundings tend to warmup over a period of time, peak air conditioning loads occur in the afternoon, generally after the peak solar resource, and also depend on the humidity.

PAUL GIPE

Zond, Inc. wind farm at Tehachapi, California, using wind turbines manufactured by Vestas of Denmark.

- *The level of iRET penetration into the grid.* High levels of penetration may tend to saturate their potential capacity value.
- *Geographic diversity.* Gathering renewable energy over a large area can moderate local fluctuations and increase capacity value.
- *The match between different renewable energy resources.* Wind and solar, for example, may complement each other in some areas and provide capacity value that individually they could not.

The extent to which an iRET can offset conventional capacity helps determine its economic attractiveness. Some utility planning models and policies, however, may not fully credit the iRET with potential capacity savings. Although further study of the capacity value of iRETs is needed, there are many cases today where a reasonably accurate value can be determined.

The variability of intermittent renewable may, in some cases, complicate utility operations by requiring greater cycling up and down of conventional generation equipment (load following) in order to meet demand. (See box 5-3 for a discussion of utility operations.) This may require operation of conventional equipment at lower (and less efficient) loads in some cases and may increase wear and tear. The same factors as above—the match with the load, penetration level, geographic diversity, use of complementary resources, and others-can all influence the amount of cycling necessary. Experience with wind farms in California has shown that the electric utility system can operate normally when 8 percent of the system demand is met by wind.[74] Further, some modeling suggests that intermittent could provide much higher fractions of utility capacity without causing difficulties.[75] Improved understanding of these factors will be very important.

The intermittence of wind and solar can be moderated or circumvented by using natural gas or other fuels or stored resources (such as hydropower, compressed air, and batteries) to provide backup power. Solar thermal parabolic trough plants in California, for example, use natural gas backup to provide dispatchable peaking power.[76] Other combinations include natural gas hybrids with biomass or geothermal, biomass cofired with coal, and wind coupled to compressed-air energy storage or pumped hydro. The feasibility and cost-effectiveness of these or other hybrids depends on the particular case.

At high levels of penetration, the intermittence of some RETs may complicate utility planning and operations, but it is a challenge that utilities are familiar with in form if not in degree. Utilities now deal with a variety of plants using different resources—such as coal, oil, gas, nuclear, hydro, and municipal solid waste—with varying availabilities—for example, from baseloaded nuclear to gas peaking. Utilities have well-developed procedures for ensuring system reliability and efficiency with the current wide mix of resources and generation technologies.

74 Wan and Parsons, op. cit., footnote 72.

75 Kelly and Weinberg, op. cit., footnote 72.

76 The amount of natural gas that can be used is limited by Public Utility Regulatory Policies Act regulations.

Power Quality

Concerns have been raised that renewable energy equipment could disrupt the quality of power provided by the electricity grid. These problems have largely been overcome. For example. some older RETs, particularly wind turbines, used induction generators, resulting in large reactive power[77] that can create problems on the electricity grid if not adequately corrected.[78] The current generation of variable-speed wind turbines avoids this problem and can actually reduce the amount of reactive power on the grid.

Some RETs, particularly PVS and advanced variable-speed wind turbines, use electronic power conditioners to convert dc or variable frequcncy ac to 60 Hz ac power. Early generations of equipment to do this could cause unwanted harmonics, switching transients, or other power quality problems that could reduce efficiency, shorten lifetimes of equipment, or interfere with communications and computer equipment. Extensive experience at a number of sites in the United States and other countries has shown that well-designed equipment can avoid these problems.[79]

With a large penetration of RETs into the grid, particularly small distributed units, power flow could be reversed in some segments from the direction originally intended. This can potentially cause problems with equipment protection devices; these may need to be modified or replaced over time.

In some cases, RETs distributed throughout a electricity grid can continue to generate power even when the primary power from the central station is lost (such as when a power line is down).[80] This poses potential safety problems to utility workers trying to repair downed power lines that they do not expect to be energized (or raises costs if they have to work on live lines), and it poses potential equipment problems when the downed lines are reconnected.

Site *Specificity*

Renewable have mixed impacts on electricity transmission and distribution requirements due to their highly diverse nature. Renewable installations such as geothermal, biomass, solar thermal, and wind are often tens of megawatts to 100 MW or more in size and are often located at a distance from populated areas. To transport the power they generate to load centers may require a long transmission line extension just to reach an existing transmission line as well as upgrading the transmission system. Developing T&D systems for RETs can significantly raise overall costs. In contrast, although coal or nuclear plants may be located at a distance from their load center, they can often be located to minimize additional T&D costs.

Further, for iRETs such as wind or solar thermal, the T&D system will operate at a relatively low-capacity factor-carrying little power for extended periods when there is little wind or sunshine. but sized for the full rated power generated when winds or sunshine are strong. These low-capacity factors raise the relative T&D costs for these systems. In some cases, backup with other

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77 Reactive power, in this case, is caused by the creation and collapse of magnetic fields in the induction generator as It generates 60-cycle power.

78 Correction is readily done, for example, by using large banks of capacitors. There is a cost associated with this. however.

79 John J. Bzura, "Residential Photovoltaics," in *Photovoltaics: New Opportunities for Utilities*, DOE/CH 10[]93- 113 (Washington, DC: U.S. Department of Energy, July 1991).

80 In [he longer term, this may be a desirable characteristic as it could improve the reliability of providing power to customers in that area, even with the main power cut off.

generation systems or with energy storage systems[81] may be cost-effective in raising these low T&D capacity factors.

In contrast, small-scale renewable such as small wind, PVs, and dish stirling can be widely dispersed within the utility service area and may then be able to reduce peak loading on the T&D system, increasing reliability and reducing T&D investment and other costs (see below).

Reliability

Renewable may have mixed impacts on system reliability. The often smaller size of renewable generating units, such as biomass, geothermal, and wind, compared with conventional coal, nuclear, or other units, could increase reliability because loss of a small unit poses less of a threat to the system. Similarly, very small units distributed throughout the utility service area (see below) can potentially increase reliability. On the other hand, iRETs may, in some cases, increase cycling of conventional equipment and thus raise the likelihood of reliability problems, at least until these resources and their integration into the electricity grid are better understood and until automatic dispatch incorporating intermittent renewable is well developed.

The relatively small, modular size and rapid installation times for many RETs also means that capacity can be added as needed rather than in large lumps as with conventional powerplants. This can reduce the risk of building a large powerplant, beginning many years in advance, that may or may not be needed when the plant is completed. Advanced gas turbines and fuel cells, however, also provide the advantage of modular, relatively small units and are substantially eroding this advantage of renewable.

Distributed Utility Systems

In the conventional utility, power is generated at central locations and is transmitted to users through long-distance transmission lines, substations, and distribution lines. In recent years, utility systems have increasingly included smaller scale (10s of MWs) generation by nonutility generators.

The distributed utility (DU) concept[82] would take this trend substantially further, spreading very small generators (kWs to MWS) throughout the utility T&D system. In the DU, the central utility is still likely to provide a large share of the power as well as ensure overall system integrity. The distributed generation equipment will provide important supplemental and peaking power. Potential generators include PVS, dish stirling, wind systems, and other RETs at sites-depending on the technology—such as rooftops, local substations, and transmission rights-of-way. Engine generators or fuel cells, perhaps fueled with natural gas, may be strong competitors for these DU applications.

The DU concept is based on several simple, but important issues:

- T&D is a growing share of the total cost of utility systems due to increasing costs such as for rights-of-way and construction, and declining construction of baseload plants.
- T&D systems are often substantially underutilized most of the time, operating only briefly at high loads[83] (see figure 5-5). Sizing T&D systems to handle these brief periods of high demand is expensive. Locating small generators

81 A.J. Cavallo et al., Center for Energy and Environmental Studies, Princeton University, "Baseload Wind power from the Great Plains for Major Electricity Demand Centers," March 1994.

82 The distributed utility concept has been examined extensively in Electric Power Research Institute, National Renewable Energy Laboratory, and Pacific Gas and Electric, "Distributed Utility Valuation Project," August 1993; P.R. Barnes et al., *The Integration of Renewable Energy Sources in/o Electric Power Distribution Systems, 2 vols., ORNL-6775* (Oak Ridge, TN: Oak Ridge National Laboratory, June 1994); and Electric Power Research Institute, *Advancements in Integrating DMS and Distributed Generation and Storage into T&D Planning: Proceedings from the Third Annual Workshop,* EPRI TR-104255 (Palo Alto, CA: September 1994).

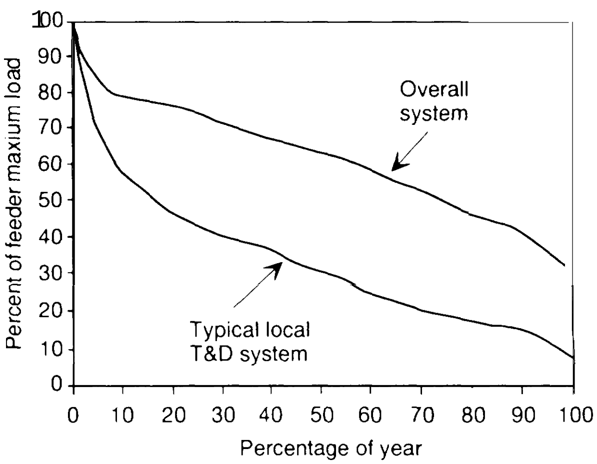
83 In part, this may be due to zoning regulations as they tend to concentrate similar loads—residential, commercial, industrial-in the same areas.

close to demand may reduce peak loads on the T&D system, improving capacity utilization. This is particularly important where peak loads are approaching T&D capacity limits. In this case, investment in local generation might cost-effectively allow a delay in upgrading the T&D system.

- Most (perhaps 95 percent) customer service problems-outages and power quality--occur not at the generating plant but in the distribution system. Distributed generation may reduce these problems with substantial economic benefit.[84]
- Environmental and other regulatory constraints, such as siting, are increasingly significant for conventional powerplants in some areas. These constraints may be less for many small, environmentally benign RETs.

For these and other reasons, interest is growing in the distributed utility as a potentially useful tool for improving overall utility cost and performance. Following analysis of the potential of distributed generation,[85] Pacific Gas and Electric (PG&E) installed a 500-kW PV plant near Fresno, California, as part of the PV for Utility Scale Applications (PVUSA) project. The plant was intended to generate energy, contribute capacity value, delay investment in substation equipment, and improve system reliability. Initial field data have confirmed a value of at least $2,900/kW of installed PV capacity.[86] Other utilities have calculated values for DU equipment ranging from less than $2,000/kW to more than $ 10,000/kW at various sites.[87] In comparison, a typical coal-fired central station powerplant has a capital cost of roughly $ 1,500/kW.[88] Thus, the value of distrib-

FIGURE 5-5: Capacity Utilization of a Typical Local T&D System



NOTE A typical local T&D system carries a high load for only very short periods of the year For example, the figure here shows that the local T&D system may carry a load 60 percent or more of its maximurn capacity for just 10 percent of the year corresponding to rare peak demands such as due to air conditionmg loads during summer heat waves In contrast, the overall generation system carries a much higher load throughout the year The low capacity factor of the local T&D system opens the opportunity of using distributed generation to meet the rare peak loads and thus reduce the investment necessary in the T&D system

SOURCE Joseph J Ianucci and Daniel S Shugar, "Structural Evoltion of Utlity Systems and Its Implications for Photovoltaic Applications, " paper presented at the 22nd IEEE Photovoltaic Specialists Conference, Las Vegas, NV, 1991

84 Narain G. Hingorani and Karl E, Stahlkopf, "High Power Electronics," *Scientific American,* November 1993, pp. 78-85; and A.P. Sanghvi, Electric Power Research Institute, "Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs," Report EL-6791, 3 vols., April 1990.

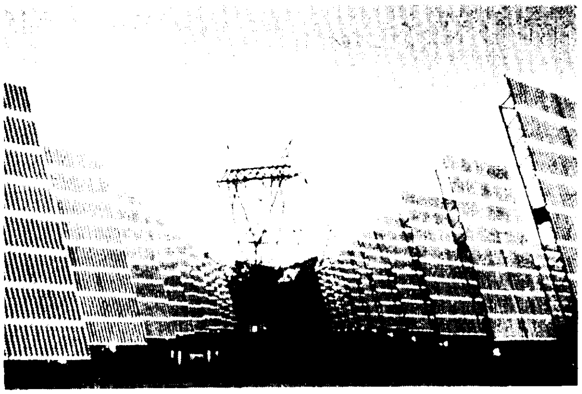
85 D.S. Shugar, "Photovoltaics in the Utility Distribution System: The Evaluation of System and Distributed Benefits," paper presented at the 21st IEEE PV Specialists Conference, Kissimmee, FL, May 1990.

86 Preliminary data show a plant peak power availability of 82 percent, annual and peak load reductions in power output losses of 5 Percent and 8 percent, a four-year extension of transformer life, and a 12-year extension of transformer load tap changer life. Other potential benefits now being evaluated have a predicted value of an additional $3,000/kW. See Paul Maycock, "Kerman Grid Support Plant Provides Twice the Value of Central PV," *PV News*, vol. 13, No. 6, June 1994.

87 "Economic Evacuation of pV-Grid Support is Changing," *Solar Industry Journal,* 3rd quarter, 1994.

88 Note that this cost is not exactly Comparable as it does not include fuel costs and certain other factors.

SOLAR ENERGY INDUSTRIES ASSOCIATION



A grid-connected PV *powerplant* in California.

uted generation equipment can be much higher than that of central station powerplants. This creates a potential high-value market niche for technologies such as PVS that can be used in distributed generation applications.

PG&E and others have done subsequent analyses to identify promising areas for installing PVS for DU grid support, and the potential appears to be quite large.[89] For example, the Utility Photovoltaic Group estimated the market for distributed PV capacity at more than 8,000 MW at an installed price of $3,000/kW.[90]

Many questions remain, however, about how to plan, build, interconnect, and operate such a system while maintaining reliability and performance. Similarly, little is known about the range of conditions for which the DU might be economic, or how to find and evaluate such opportunities. Screening, planning, and evaluation tools need to be developed, particularly with sufficiently fine detail to capture the technical and financial benefits and costs of DU technologies on the local level while still providing a sufficiently broad scale to evaluate systemwide effects. Much technical development is also needed, such as hardware, software, and communications equipment for automating the DU. Field demonstrations are needed to validate these analyses and technologies.

It may also be possible to use intelligent controls to integrate PV or other RET power generation with the use of household appliances such as air conditioners and with the local electric utility. Some household appliances might be controlled by how much renewable energy was being supplied. If a passing cloud cut off PV output, certain appliances could also be shut down temporarily. Such devices could be easily integrated at low cost into adjustable-speed electronic drives now entering the household appliance market.[91] The development of standard protocols among appliance and other manufacturers is needed for such control systems to be developed and widely implemented. Such intelligent controls would also provide valuable demand-side management (DSM) capabilities to the local utility.

Recent work on the DU concept has been motivated, in part, out of interest in the potential of RETs. Space at urban substations is at a premium, however. RETs such as PVS maybe less practical at some of those sites than compact energy storage and generation systems—particularly if these systems are only operated for short periods during the year to reduce T&D system peak loading. Rooftop PV systems scattered throughout the area maybe desirable for high-penetration levels of DU systems.

OVERCOMING BARRIERS

The use of RETs for the generation of electricity is growing, but further action is needed to bring

89 Power distribution areas were examined, first to determine where there was a good match between the local load and the local solar resource and, second, to determine which of those areas are at or near their T&D capacity limits. These screens selected areas in PG&E's service territory with some 120 MW of load. Daniel S. Shugar et al., "Photovoltaic Grid Support: A New Screening Methodology," *Solar Today,* September/October 1993, pp. 2 I -24.

90 "DOE and Utilities," *NREL: PV Working with Industry,* fall 1994, p. 1.

91 Samuel F. Baldwin, "Energy -Efficient Electric Motor Drive Systems, "in Thomas B. Johansson et al. (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

RETs into widespread use and must be tailored for particular classes of RETs.[92] This section discusses ways to make RETs more cost-effective and to encourage their use.

Research, Development, and Demonstration Needs

Opportunities for RD&D in individual technologies as well as in remote, utility, or distributed utility systems are briefly sketched above. Overall, no insurmountable technical barriers have yet appeared that might prevent RETs from maturing into broadly competitive energy resources, but much RD&D remains to be done.

Federal RD&D funding for RETs has increased over the past several years, after a decade of declining and/or low budgets. Most of this support is focused on developing the technologies themselves and, in a few cases, improving associated manufacturing technologies. Additional support for high-priority RD&D of these technologies, balance of systems equipment, and manufacturing technologies could allow more rapid development.

Few utilities have been actively involved in the RD&D or commercialization of RETs.[93] The total RET R&D budget for the Electric Power Research Institute was just $9 million in 1993—2.8 percent of its budget.[94] EPRI did, however, provide important continuity in funding for RETs during the 1980s when the federal government cut back. More recently, pressure to generate near-term results has forced EPRI to reduce its longer term RD&D portfolio in areas such as PV.

Demonstration programs have often been one-of-a-kind and generally limited to very low-cost systems. Necessarily larger scale systems. such as integrated biomass gasification advanced gas turbine systems, solar thermal central receivers, and others have had a difficult time obtaining private or public support due to their size and cost. For example, development of advanced bioelectric systems might typically progress from the R&D phase to a $1 O-million pilot demonstration unit, to a $50-million engineering development unit, to a $200-million pioneer plant, followed by commercialization. The level of public support could be reduced at each stage, but would still be substantial even for the pioneer plant. However, such demonstrations are essential to eventual commercialization.

Private cofunding of such demonstrations is a key element to their eventual success. Utilities, however, may be discouraged by state regulators from trying new technologies as this could risk ratepayer funds. In response, some have proposed that a "safe harbor" be provided utilities that choose to experiment with and invest in RETs so that they can be assured of recovering their costs as long as they have acted responsibly. Currently, utilities face numerous risks—technical, financial, regulatory—in developing RETs. Even with the most careful management of a new technology program, the utility may face cost disallowances. Such risks may seriously constrain a utility's ability and willingness to try new technologies. Safe harbor rules would provide a mechanism to allow such experimentation.[95]

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92 Technologies that are relatively immature primarily require RD&D. Premature commercialization might fail to reduce costs sufficiently to attract a large market, and strand the technology at high costs with insufficient revenue to adequately support further development.

93 Detailed reviews of difficulties in considering renewables within the utility framework are provided by National Association of Regulator-y Utility Commissioners, Committee on Energy Conservation, Subcommittee on Renewable Energy. "Renewable Energy and Utility Regulation," April 10, 199 1; and Hamrin and Rader, op. cit., footnote 7.

94 Electric Power Research Institute, "Research, Development & Delivery plan 1993- 1997," January 1993.

95 David Moskovitz, "Renewable Energy: Barriers and Opportunities; Walls and Bridges," paper prepared fOr the World Resources Institute, July 1992.

Increasingly competitive electricity markets, particularly the possibility of retail wheeling,[96] may make such alternatives as safe harbors more difficult to develop (see chapter 6). For example, some argue that ratepayer-funded RD&D may be anticompetitive because it may strengthen utilities vis-a-vis independent power producers that have no such access to ratepayer funds.[97] Independent power producers, however, are investing very little in RD&D. Electricity sector restructuring also appears to be significantly reducing RD&D. The California Energy Commission, for example, estimates that RD&D in advanced-generation technologies by California Investor Owned Utilities will decline 88 percent in 1995, compared with 1993; overall RD&D will decline by 32 percent compared with 1992.[98] Alternative RD&D funding mechanisms may therefore be needed to ensure the long-term technological vitality of the electricity sector.

Regardless of how they are supported, demonstrations of these technologies are very important. Relative to conventional technologies, data on cost and performance, experience, and siting of RETs is not adequate. For example, there are no commercial-size, advanced biomass gasification pkmts on which utility executives can "kick the tires. " They are not necessarily biased against these technologies, they simply have no experience.

R&D is also needed on full-fuel-cycle energy efficiencies and environmental impacts for various conventional and renewable technologies (see chapter 6). Some of this has been done[99] and could be usefully extended.

Manufacturing Scaleup

A key challenge to large-scale RET production and use is needing a large market to scaleup production and thus lower costs, but needing low costs to develop a large market. Manufacturing scaleup and the resulting economies of scale and learning have been widely observed to reduce the cost of new technologies.] w

Several recent analyses of PV production for various periods between 1965 and 1992, for ex-

96 Retail wheeling is the theoretical process of allowing individuals the opportunity to purchase their electricity frOm particular utilities or independent power producers, thus allowing them to shop around for the lowest price or for other features that they value. This is often crudely characterized as similar to the individual customer's ability to shop around for a long-distance telecommunications company. In fact, retail wheeling of electricity is not well defined and cannot be described by so simple an analogy. For a discussion of these issues, see, e.g., *The Electricity Journal,* April 1994, entire issue; Richard J. Rudden and Robert Hornich, "Electric Utilities in the Future, " *Fortnightly,* May 1, 1994, pp. 21 -25; and Public Utilities Commission of the State of Cal ifomia, *Order Instituting Rulemaking and Order Instituting Investigation* (San Francisco, CA: Apr. 20, 1994).

97 See, e.g., Public Utilities Commission of the State of California, Division of Ratepayer Advocates, "Report on Research, Development, and Demonstration for Southern California Edison Company General Rate Case," Application No. 93-12-025, March 1994, pp. 3-3 to 3-4.

98 California Energy Commission, *Restructuring and the Future of Electricity RD&D,* Docket No. 94-EDR-1 (Sacramento, CA: Jan. 31, 1995).

99 See, e.g., Marc Chupka and David Howarth, *Renewable Electric* Generation: *An Assessment of Air Pollution Prevention Potential,* EPA/400/R-92' 005 (Washington, DC: U.S. Environmental Protection Agency, March 1992).

100 See, e.g., Ernst R. Berndt, The *Practice of Econometrics: classic and Contemporary* (Reading. MA: Addison-Wesley publishing Co., 199 I); and Linda Argote and Dennis Epple, "Learning Curves in Manufacturing," *Science, vol.* 247, Feb. 23, 1990, pp. 920-924. Indeed, failure to realize expected economies of scale and learning in new coal and nuclear plants during the past several decades has been a significant source of difficulty for the electric utility industry. P.L. Joskow and N.L. Rose, "The Effects of Technological Change, Experience, and Environmental Regulation on the Construction Cost of Coal-Burning Generating Units," *Rand Journal of Economic. i, vol. 16, No. 1,* spring 1985, pp. 1 *-27;* George S. Day and David B. Montgomery, "Diagnosing the Experience Curve," *Journal of Marketing, vol. 47,* spring 1983, pp. 44-58; and Martin B. Zimmerman, "Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power," *The Bell Journal of Economics, vol. 13, No. 2,* autumn 1982, pp. *297-310.*

ample, found that every cumulative doubling of production reduced real costs to roughly 80 percent of the previous value. [101] This effect could have a significant impact on PV markets. For example, if projected business-as-usual PV market growth rates of about 15 percent were realized, the global PV market would be about 1 GW/year in 2010, [f the 80 percent progress ratio continued over this period. the cost of PV-generated electricity would then be about 10¢kWh. In contrast. if the market were to grow at an accelerated rate of 35 percent per year, the global market in 2010 would be 18 GW and, with the same 80 percent progress ratio, the cost of PV electricity y would be 6.5¢/kWh. By one estimate, the additional cost of such an accelerated development strategy would be about $5.4 billion (1992 dollars) for additional RD&D and market support.[102] Other estimates range from $5 billion to $9 billion (see above). Such a strategy might have significant environmental, international competitiveness (see chapter 7), and other benefits.

Simply producing more PVs, however, will not necessarily lower costs at an 80 percent progress ratio. RD&D in technologies, systems, and manufacturing to achieve such cost reductions would be fundamental to any accelerated development strategy.

The PV Manufacturing Technology Project, a joint venture between DOE and industry, is intended to reduce PV manufacturing costs. DOE support for PV manufacturing improvements is $19 million in fiscal year 1995.

| Resource Assessment

Renewable resources have several defining characteristics, including site specificity, intermittence, and intensity. These factors. their implications, and strategies for dealing with them are discussed above and in chapter. [103]

Although resource data are being developed. additional efforts could provide valuable information for potential users. Of particular interest is more detailed information on site-specific resources, geographic variation for individual resources. and regional correlations between resources. Further development and dissemination of analytical tools that can make effective use of this data may also be of great interest to those considering using RETs, particularly for determining the capacity value of iRET resources, and the impacts of iRETs on utility system operations and on T&D requirements. Analytical tools for forecasting renewable resources are also needed.

| Commercialization

Several strategies for helping develop markets in parallel with manufacturing scaleup were listed in chapter 1, including developing market niches, aggregating purchases across many potential customers, and more aggressively pursuing international markets (chapter 7). One perspective of the market opportunities for PVs is shown in tigure 5-6, developing gradually from remote systems, to grid support, peaking, and finally bulk power. Market development paths for other RETs could differ.

Remote markets are of particular near- and mid-term importance for several RETs, including small wind systems, PVs, and small solar thermal powerplants. Developing these markets offers the opportunist y for substantial scale up in manufacturing volume and thus will significantly influence the evolution of these technologies. Additional research is needed to better understand the remote power market, including specific applications,

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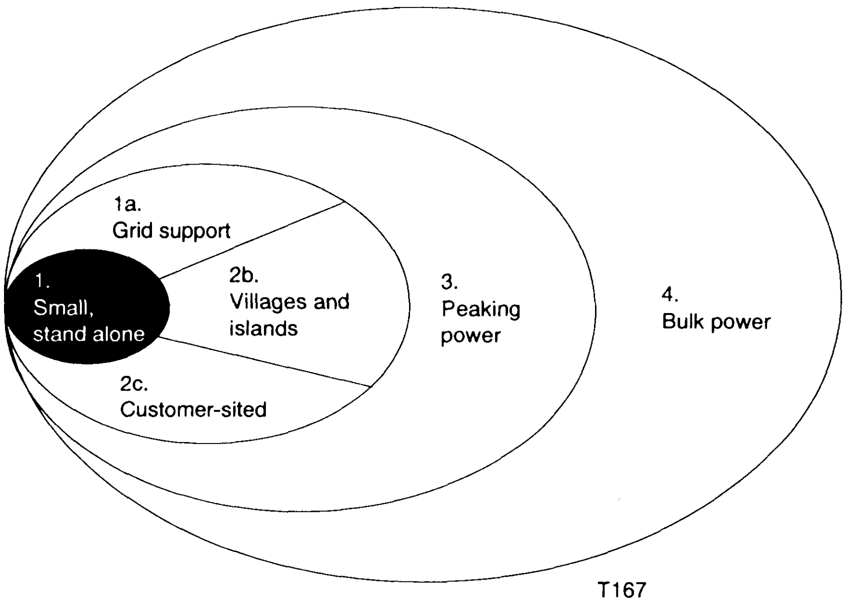
[101] The values of this progress ratio were 80, 81, and 81.6 percent, depending on the period examined. See Richards, op. cit., footnote 50; Cody and Tiedje, op. cit., footnote 49; and Williams and Terzian, op. cit., footnote 49.

[102] Williams and Terzian, op. cit.. footnote 49.

[103] For example, site specificity requires extensive long-term resource evaluation and the development of appropriate analytical tools such as geographic information systems. Intermittence} can be addressed by collecting the energy over a larger geographic area, combining the resource with other complementary resources, or forming hybrids with other generation technologies (e.g., fossil, hydro, biomass) and or storage.

FIGURE 5-6: Market Evolution Model for PVs



NOTE: One model for the market evolution of the PV industry is a gradual movement from high-value stand-alone projects to somewhat lower value grid support, and village-size systems, to medium-value peak power applications, and ultimately to bulk power. The potential production volume grows rapidly as these new markets open up.

SOURCE: Joseph J. Ianucci and Daniel S. Shugar, "Structural Evolution of Utility Systems and Its Implications for Photovoltaic Applications," paper presented at the 22nd IEEE Photovoltaic Specialists Conference, Las Vegas, NV, 1991.

their number and value, and how to best develop them.

Grid support (distributed utility) also offers a substantial near- to mid-term opportunity, but remains poorly understood. Better analytical tools are needed that can screen for such opportunities, and more detailed analysis is needed to determine the full value of these applications. RETs such as PVs are likely to face significant competition for these grid support markets from fuel cells, diesel engines, and other fossil-fueled technologies.

Peaking and bulk power represent huge markets, but are also more competitive. Fossil power technologies are advancing and will remain strong competitors (box 5-1). To be competitive, RETs may need to be appropriately credited for their actual capacity value, environmental benefits, ability to lower fuel cost risks, and other advantages, as well as charged for their disadvantages compared with fossil fuels. Electricity sector planning models currently in use may not be easily adaptable to these or other aspects of RETs, such as their often small capacity increments or T&D requirements. Case-by-case inclusion of these considerations for RETs in the planning process may carry high overhead; better analytical tools are needed to allow consideration of these factors with minimal cost and effort.

Many of DOE's market conditioning initiatives are implemented through joint venture project activities. Joint ventures, as well as project activities with decision makers and organizations representing PV target market sectors, are the major focus for translating RD&D activities into market impact. Through its joint venture activities, DOE has demonstrated willingness to share risk with those that invest in current technology at present-day prices while committing to high-volume, lower cost product purchase in the future. Developing relationships with stakeholders in this way is anticipated to lead to significant cost reductions while strengthening the market base for suppliers.

In 1992, the Electric Power Research Institute, the American Public Power Association, the Edison Electric Institute, the National Rural Electric Cooperative Association, and approximately 40 utilities formed the Utility Photovoltaic Group (UPVG) to promote early commercialization of photovoltaics. In September 1992, DOE agreed to provide up to $800,000 for the first 18 months of UPVG's activities. UPVG and DOE have started TEAM-UP (Technology Experience To Accelerate Markets in Utility Photovoltaics), a $500-million (two-thirds privately financed) joint venture to purchase 50 MW of PV over six years.

The PVUSA project is a field test of large PV installations intended to demonstrate the viability of PV systems in a utility setting. PV-BONUS is a DOE program that was recently funded as a public-private effort to develop cost-effective PV products, applications, and product-supply and product-user relationships in the buildings sector. This sector is expected to be another steppingstone to the bulk power market and holds promise of becoming a substantial market in its own right. Phase I is a concept development stage, requiring a minimum 30-percent cost share by the private participant, and up to $1 million is expected to be provided for preliminary market assessment and product development tasks and evaluation in this phase. Phase II will include product development and testing, and Phase III will be field demonstration and performance verification. Overall program funding will require 50-percent cost-sharing by private participants. Total DOE support for market conditioning activities is $35 million in fiscal year 1995.

Many people, including policy makers at the state and federal level, are unaware of how rapidly the performance and cost-effectiveness of many RETs are improving, the magnitude of the locally

KRAMER JUNCTION CO

Solar thermal-natural gas hybrid electricity-generating system in the Mojave desert, California.

available renewable resources, or the practical aspects of system design, integration, and finance. For rapidly advancing technologies such as wind or PV, data two or three years out of date may be of little value. The lack of information has been a particularly serious problem at the state regulatory level where the embryonic renewable energy industry has not had the resources to present its case. Most public utility commission staffs tend to be small and have often not been able to collect and keep current the necessary information.[104] Equally important is providing a credible independent source of information to balance the excessive claims of some renewable energy advocates. The decline in federal support for renewable energy during the 1980s reduced the dissemination of relevant information in an appropriate format.

Initiatives to support RET commercialization must take into account change occurring in the electricity sector (see chapter 6). Restructuring and greater competition may entail unbundling of services, thereby opening a variety of market niches such as grid support. On the other hand, separation of generation from transmission and

104 National Association of Regulatory Utility Commissioners, Committee on Energy Conservation, Subcommittee on Renewable Energy, *Renewable Energy and Utility Regulation* (Washington, DC: Apr. 10, 1991).

distribution may impede identification and use of such distributed applications. The net effects of these opposing forces are unclear.

POLICY OPTIONS

Support for the technical development of RETS in the electricity sector has been provided for some two decades and has contributed significantly to the dramatic improvements in the cost and performance of many RETs over this period.

Federal RD&D in RETs has increased in recent years (see table 1-4 and figure 2 in appendix l-A) after declining in the 1980s. The focus of present RD&D efforts is primarily mid- to longer term RD&D, with some support for public-private, cost-shared commercialization activities. This will allow more rapid technical development of RETs than would occur without federal support, but RET contribution to U.S. electricity supplies (now about 11 percent, mostly from hydropower) is likely to remain a relatively small proportion of the total over the next 15 years. During this period, however, this support will help provide the technical foundation for more rapid expansion of RETs after 2010. Total nonhydro RET electricity generation is projected by the Energy Information Administration (EIA) to increase from about 46 billion kWh in 1993 to 112 billion kWh in 2010.[105] Such estimates are highly uncertain, however, and could be far too optimistic or pessimistic depending on the public policies chosen in the next few years. For example, a focused public-private effort to develop bioenergy crops in order to offset farm supports could encourage the development of perhaps two to three times as much generation capacity as is currently projected by EIA for 2010.

Reductions in RD&D supports for RETs could save some federal outlays in the near term, but are likely to significantly reduce the rate of development of these technologies. As noted above, the RET industry is too small to support this level of RD&D itself, and many potential outside partners are reducing their RD&D investments, particularly for longer term, higher risk technologies such as many renewable. Slowing these programs significantly risks both losing important international markets to foreign competitors and the sale of innovative U.S. RET firms and technologies to these foreign concerns. If RD&D supports must be reduced, it will be important to protect core RD&D activities including public-private partnerships to demonstrate technologies.

Strategies that would allow additional cost-effective applications of RETs to be captured sooner are outlined below. Adoption of such strategies could help strengthen U.S. manufacturers in international markets (chapter 7), allow a more rapid transition to nonfossil forms of energy should global warming or other factors make this necessary, and diversify energy supplies and reduce exposure to the risk of any future fuel cost increases (chapter 6). However, these strategies would require greater federal outlays, depending on the particular policies pursued. Many of these activities are relatively low cost and have potentially high leverage. These include resource assessment, much R&D, the development of design tools and information programs, and standards. Demonstration programs are generally higher cost, but should be leveraged—as should many other activities—with public-private partnerships. The activities discussed below, for which DOE would have prime responsibility at the federal level, are likely to be particularly effective: whatever strategy or budget level is selected, ensuring the maximum contribution from RETs in the future will depend on choosing policies with the greatest leverage.

Resource Assessment

- Renewable resource assessment and the development of appropriate analytical tools is essential for potential users to identify attractive

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

opportunities. The FY 1995 appropriation for solar resource activities is $3.95 million—up from the FY 1994 level of $2.2 million. This increase in funding will allow an expansion of the resource monitoring network, the development of a more comprehensive database, and support data integration and geographic analysis.

- Additional monitoring sites could improve understanding of how large the resources are, how they vary at specific sites and between different sites, and to what extent different resources—such as sun and wind—may be complementary.[106] In turn, this data and appropriate analytical tools might be used to determine iRET capacity values, improve utility planning and operations with iRETs, and provide other benefits.

Research, Development, and Demonstration Programs

- *R&D.* Overall program budgets for RD&D are listed by RET in table 1-4. These supports have increased from the low in 1990 of$119 million to a FY 1995 level of about $331 million. '07 (Half of this increase occurred in 1991 and 1992 following the Bush Administration's development of the National Energy Strategy.) When this funding is spread across the full range of RETs, however, these programs continue to be substantially constrained. Support for high-leverage R&D opportunities could be directed to particular RET technologies, balance of system components, hybrid systems, system integration, and RET manufacturing technologies, as discussed above.
- *Demonstraticns.* Demonstrations of larger scale systems, particularly bioenergy, geothermal, and solar thermal central receiver systems, have not been possible even though they would have been smaller than many fossil fuel systems that have been funded in recent years.


SOLAR ENERGY INDUSTRIES ASSOCIATION

A parabolic dish stirling engine system under test. A variety of dish stirling designs have been developed and tested and a joint DOE-Cummins Power Generation venture is in the final stages of developing a 7.5 kW system for commercialization.

Such demonstrations have been and must continue to be driven by private sector interest in commercializing these technologies, but federal involvement maybe necessary to get projects under way.

- Safe *harbors.* While the federal government does not have direct authority to create safe harbors for utility or independent power producer RD&D, it could encourage states to provide them, provide useful information, or perhaps provide seed money or tax considerations for doing so. Consideration might also be given to other mechanisms to encourage private sector

[106] That is, t. what extent one resource increases when the other decreases, thus compensating in part for each others' natural variability.

[107] This overall funding level also includes Some support for solar building and other activities. Note that a number of activities listed in the DOE Solar and Renewable Energy budget are not specifically related to renewable energy and are not included in these budget numbers here.

RD&D in electricity sector technologies, such as sectorwide kWh or emissions taxes to support RD&D and focused tax credits.

Design, Planning, and Information Programs

- *Design and planning tools.* Support, leveraged with private sector funds, might be provided for the development of electricity sector design and planning tools that adequately incorporate consideration of renewable resource availabilities, RET capacity factors, T&D requirements, distributed utility benefits, environmental benefits, fuel cost risk reductions, and other factors.[108] This includes geographic information systems that enable long-term planning of energy infrastructure—such as T&D systems or gas pipelines—to consider potential future siting of RETs so as to minimize costs of future infrastructure access. These tools would be of considerable value to utilities, non utility generators, public utility commissions, federal policymakers, and others.
- *Information.* Support could be provided for information programs to develop data, particularly from field studies, and to put it into an appropriate format for use by policy makers and others at both the state and federal level. As noted above, this can encourage use of rapidly advancing RETs as well as check the excessive claims of some RET advocates.

Standards Programs

- Support might be provided for the development of technical standards for some equipment. This might include helping to support the establishment of control and communications protocols for use in home and office appliances and equipment that will allow smart controls to adjust appliance power demand as needed by utility demand-side management or distributed utility programs.

Finance and Commercialization Programs

- *Market aggregation.* Public-private partnerships can increase market volume so that manufacturers can scale up production processes. Several initial efforts of this type have been launched, such as the Utility Photovoltaic Group. More importantly, a longer term technology development, manufacturing scaleup, and market development strategy is needed, perhaps along the lines of what has become known as "Sustained Orderly Development."[109] This would help provide manufacturers the assurance that there would be markets for them to compete for in the future, and would help them attract capital and scaleup manufacturing facilities in order to capture economies of scale and learning. If such a program is begun in the near term, additional RETs will be ready for large-scale commercialization as the large number of aging U.S. powerplants retire over the next decade or more.
- *Market analysis and development.* Overseas markets for RETs are potentially large, but are not yet well understood or developed. Support to analyze these markets and to develop them through trade missions, trade shows, resource assessments, technology demonstrations, and technical assistance could enhance exports and U.S. production.
- *Power marketing authorities.* The federal government could direct the Power Marketing Ad-

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108 Relatively little has been done in this area. DOE recently supported, however, the development of such tools for policy-level analysis. See, e.g., U.S. Department of Energy reports: Panel on Evaluation of Renewable Energy Models, Office of Utility Technologies, "Evacuation of Tools for Renewable Energy Policy Analysis: The Ten Federal Region Model," and "Evaluation of Tools for Renewable Energy Policy Analysis: The Renewable Energy Penetration Model," April 1994.

109 See, e.g., Donald W. Aitken, "Sustained Orderly Development," *Solar Today*, May/June 1992, pp. 20-22.

ministrations to develop all cost-effective RETs where practicable.[110]

- *Federal procurement. The* federal government could more vigorously pursue its mandate to use cost-effective RETs where practicable..[111]

CROSSCUTTING ISSUES

The importance of electricity throughout the U.S. economy opens numerous opportunities for cross-sectoral benefits from the use of RETs. For example, RET electricity could provide an early and important high-value market for bioenergy produced by the agriculture and forestry sector, be integrated with building demand-side management programs. be integrated with building structures, power electric transport, or provide an important niche market for fuel cells to be later used in the transport sector. Smart controls within buildings and within electric-vehicle recharging stations might allow much better integration of intermittent RETs into the electricity grid. These opportunities may offer important high-value market niches for earl y use of RETs that can help leverage manufacturing scaleup and cost reductions.

CONCLUSION

The development and integration of renewable energy technologies into the electricity grid poses a variety of technical, economic, planning, operational, and institutional challenges. Many of the technical challenges are being overcome, but much work remains. The cost-effectiveness of these systems varies widely. Some technologies are competitive in bulk power markets today: others are competitive only within higher value niche markets (without crediting their environmental or fuel diversity benefits). Costs are highly site- and resource-specific and must be evaluated on a case-by-case basis. Improved models and methodologies for evaluating the cost-effectiveness of these technologies would facilitate this evaluation and provide better decision making tools for determining the best use of RETs in the electricity sector. Development of these technologies will also play an important role in international markets. in which competition is becoming increasingly intense, as countries around the world have begun to focus on RETs as a key market for the 2 1st century.

110 Including, e.g., environment], fuel diversity, and other costs and benefits.

111 For example under the Department of Defense PV Implementation program formed in 1985 some 21,000 cost-effective applicati On\ Of PVS were identified in [he Navy alone which, if fully implemented, would provide net annual savings of about $175 million. The majority of these have reportedly not yet been implemented, with some 3,000 systems installed to date. See, e.g., Sandia National Laboratories, *Photovolta-ics for Military Applications: A Decisions-Maker's Guide,* SAND 87-7016 (Albuquerque, NM: May 1988); Sandia National Laboratory, *Photovoltaics Systems for Government Agencies*, SAND 88-3149 (Albuquerque, NM: May 1989); and John Ryan and Richard Sellers, "Overcoming Institutional Barriers."' *Solar Today*, March April 1992, pp. 18-20.

Electricity: Market Challenges 6

A large amount of electricity-generating capacity will have to be built over the coming years to replace retiring units and meet new demand. Renewable energy technologies (RETs) are already competitive for some of this capacity, and further technical development and commercialization support (see chapter 5) could expand their share. However, the rate of growth for RETs will also depend on factors such as economic and regulatory changes within the electricity sector, availability of financing, taxes, perceptions of risk, and the rate of change in conventional technologies. This chapter discusses those factors and approaches for further commercializing RETs for electricity generation.

ELECTRICITY SECTOR CHANGE

Structural and regulatory changes in the electric utility industry have, in the past, encouraged the development of today's renewable energy industry and are likely to play a key role in how the renewable energy industry develops in the future. Many of these changes were set in motion by increasing strains on the utility industry in the 1970s.

Utilities generally enjoyed stable growth and declining costs of electricity production until the early 1970s. Then these histori-

[1] The Energy Information Administration estimates that utilities will build a total of about 110 GW (and retire 60 GW) and nonutility generators (not including cogenerators) will build 72 GWe by 2(I 10. See U.S. Department of Energy, Energy Information Administration, *Supplement to the Annual Energy* Outlook, *1994*, DOE/EIA-0554(94) (Washington, DC: March 1994), p.183.

cal trends were reversed due to reduced economies of scale[2] for new large coal-fired plants,[3] the oil shocks, inflation and high apparent costs of capital, sharp reductions in demand growth, increased environmental regulation, and problems with advanced technology such as supercritical boilers and nuclear plants.[4] These and other problems led state regulatory agencies to disallow (i.e., not include in the rate base) more than $10 billion worth of utility investment during the 1980s.[5] Regulators and utilities became interested in alternative approaches in order to avoid heavy capital investment in new generation facilities.

One such approach was to encourage independent entrepreneurs and companies other than utilities to generate power. Another was to tap alternative resources, renewable in particular. Federal policy addressed these issues through the Public Utility Regulatory Policies Act (PURPA) of 1978. Title II of PURPA established a class of electricity suppliers—"qualifying facilities" (QFs)—based on cogeneration and renewable, and outside conventional profit regulation. It required utilities to purchase power generated by QFs at a rate based on the utility's *incremental* cost[6]---more commonly termed *avoided* cost--of power.'

For a variety of reasons, the response to PURPA was mixed, especially for RETs, as described in box 6-1. Price was a key factor. Where the avoided cost level was high, the industry was deluged with offers; where low, no offers were made. Another factor was the terms under which electricity was to be purchased. Some states simply set tariffs for electricity purchase depending on the current avoided cost level. Since these could change frequently, private investors were unwilling to risk their capital on long-term projects whose return could vary dramatically. Other states allowed long-term contracts, which provided the more certain financial climate developers needed

[2] Laurits R. Christensen and William H. Greene, "Economies of Scale in U.S. Electric Power Generation, "*Journal of Political Economy*, vol. 84, No. 4, pt. 1, 1976, pp. 655-676; Thomas G. Cowing and V. Kerry Smith, "The Estimation of a Production Technology: A Survey of Econometric Analyses of Steam-Electric Generation," Land *Economics, vol.* 54, No. 2, May 1978, pp. 156- 186; Edward Kahn and Richard Gilbert, Universitywide Energy Research Group, University of California, Berkeley, "Competition and Institutional Change in U.S. Electric Power Regulation," Report PWP-011, May 2, 1993; Richard F. Hirsh, *Technology and Transformation in [he American Electric Utility Industry* (Cambridge, England: Cambridge University Press, 1989); and David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990), p. 32.

[3] One study found that going from a 400 MW to an 800 MW unit reduced cost per kW installed by just 5 percent (or 10 percent on the additional kW). See "How Much Do U.S. Powerplants Cost?" *Electrical World,* March 1985, reporting on a study of 491 recently completed and commercially operating fossil and nuclear plants by University of Tennessee's Construction Research Analysis group for Edison Electric Institute.

[4] Paul L. Joskow and Nancy L. Rose, "The Effects of Technological Change, Experience, and Environmental Regulation on the Construction Cost of Coal-Burning Generating Units, " *Rand Journal of Economics,* vol. 16, No. 1, spring 1985, pp. 1 -27; and Martin B. Zimmerman, "Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power," *Bell Journal of Economics, vol.* 13, No. 2, autumn 1982, pp. 297-310.

[5] Oak Ridge Nationa] Laboratory, "Prudence Issues Affecting the U.S. Electric Utility Industry," 1987, and "Prudence Issues Affecting the U.S. Electric Utility Industry: Update, 1987 and 1988 Activities," 1989; and Ed Kahn, University of California, Berkeley, personal communication, May 1994.

[6] See *section* 210 of the Public Utility Regulatory Policies Act of 1978.

[7] The term *incremental cost* of power has been interpreted in different ways by various utilities, leading to varying payments to QFs. See, e.g., Daniel Packey, "Why Does the Energy Price Increase When Cheaper-Than-Avoided-Cost DSM Is Added," *Utilities Policy,* vol. 3, 1993, pp. 243-253.

BOX 6-1: Lessons Learned in State Renewable Energy Development

States vary dramatically in their development of renewable energy technologies (RETs) in the electricity sector California has more than 6 GW of installed RET capacity, Maine is second with about 850 MW, and Florida is third with about 820 MW The top 10 states account for nearly three-quarters of U S RET development This development is often largely unrelated to state renewable resource endowments For example, the Midwest has very large wind energy resources but little wind energy development Instead, most wind development has taken place in California where wind resources are relatively limited although there are a few particularly good sites

Key factors determining RET development include the planning, contracting, and procurement policies of the states These were well described in a recent report published by the National Association of Regulatory Utlity Commissioners Of particular value were the following

Standard contracts with (or guidelines for) the terms and conditions for capacity and energy sales to utilityies This greatly reduces the expense and delay of negotiations, reducing transaction costs and the time required to obtain a financeable contract

Long-run contract price based on avoided new utility plants. Long-run contracts (extending for 15 to 30 years) based on the cost of new resources are more likely to provide a sufficient revenue base for nonutility generat ion development than contracts based on short-term energy and capacity.

Both capacity and energy values paid. It is difficult for new projects to recover costs unless they receive payment for their capacity value

Fixed or predictable payment stream This is critical for any nonutility developer to obtain financing

Availability of /eve//zeal or front-loaded payments This allows developers of capital-intensive renewable energy projects to pay debt service on the loan, which is generally 10 to 15 years, compared to 30 years for utilities

No *dispatchability or minimum capacity factorscreens* This meant that renewable resources having an irtermittent/low capacity factor (hydro wind, solar) and nondispatchable resources (geothermal) were not excluded from participating Regulatory mechanisms reflected the benefits that these resources provide to the consumer

Special rates set for renewab/es Two of the states created special rates through legislation (New York for all qualifying facilities and Connecticut for municipal solid waste)

SOURCE Jan Hamrin and Nancy Rader Investing in the *Fufure A Regulators Guide to Renewables* (Washington DC National Association of Regulatory Utility Commissioners February 1993)

to raise capital and develop a project. Standard offers, or contracts, contributed to this confidence and also reduced the transaction costs of developers.[8] In California, the combination of PURPA, federal and state tax credits, and/or standard offers together with favorable renewable resources led to substantial development of several RETs. including biomass, geothermal, solar thermal, and wind, beginning in the early 1980s.

PURPA introduced a degree of competition into the electric ity sector. In the mid- 1980s, rcgulators and utilities investigated competitive bid-

[8] Standard offers define the terms and conditions+. g., energy and capacity payments, dispatch ability, and reliability —under which utilities will buy power. They set the transaction price at the avoided cost determined by the state regulatory authority. Some of the standard contracts entered into in the early 1980s resulted in prices for QF power that were above utilities" actual avoided costs when oil and gas prices crashed in the mid- to late 1980s. On this basis some argue that it was inappropriate to provide long-term—e.g.,10-y ear—standard contracts. That energy prices might decline was, of course, a risk when these contracts were entered into. At that time, however, energy prices were expected to rise and contracts reflected that expectation. Investment in natural gas-fueled powerplants today similarly faces risks should natural gas prices escalate more rapidly than expected in a decade. These fuel cost risk issues suggest the need for resource diversity and f'or proper allocation of risk and reward. This is discussed below.

ding as a way to control costs of new plants. Utilities in some 25 states have conducted competitive bidding. Nonutility generators (NUGs) responded to these opportunities by building about 57 GW of generation capacity through 1992, including some 16 GW of RET capacity.[9] The record of low cost, rapid construction, and reliability of many of these projects has encouraged further opening up of the electricity sector to competition.

The Energy Policy Act of 1992 (EPACT) continued this policy direction by creating a new class of power producers known as Exempt Wholesale Generators that are exempted from certain traditional utility requirements.[10] EPACT also addressed a variety of related transmission access issues (see below). Finally, California and several other states are considering an investigation of the possibility of "retail wheeling" to determine the feasibility of creating an even more competitive market.[11] Whatever form these varied actions ultimately take, it is likely that there will be substantial further structural changes in the electricity sector, in particular, higher levels of competition in electricity generation.

The impact of increased competition on RETs is uncertain. Greater competitive pressures may reduce investment in research, development, and demonstration (RD&D) and could diminish interest in capital-intensive, long-term generating technologies such as RETs. The low cost and high performance of combustion turbines fired with natural gas have great appeal in a competitive market. To the extent that market competition ignores benefits such as lower environmental impact or reduced exposure to fossil fuel cost increases, RETs may be disadvantaged. Furthermore, separation of generation from transmission and distribution (T&D) could increase the difficulty of implementing applications that benefit the system as a whole, such as the distributed utility. On the other hand, increased market competition may help differentiate energy markets by value, potentially opening up new higher value market niches for which particular RETs can effectively compete.

Competitive bidding for electric power supply typically proceeds in three steps. First, the utility projects the need for new electricity supply, including how much new capacity (MWS), what kind (baseload, load following, peaking), and when it will be needed. Second, a solicitation for competitive bids is made. Third, the tendered bids are screened and/or ranked on the basis of several factors, usually beginning with price and followed by operational issues, cost structure, and environmental impacts.

In practice, there has been less development of renewable energy under the competitive bidding approach than had occurred under earlier PURPA avoided cost/standard offer methods. As of 1990 (before a significant number of competitively bid projects came online), renewable fueled 6.6 GW out of a total of 9.1 GWNUG noncogeneration ca-

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9 U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1993*, DOE/EIA-0384(93) (Washington, DC: July 1994). p. 251. About 32 GW were under PURPA and 25 GW under competitive bidding and other means.

10 As governed by the Public Utility Holding Company Act of 1935.

11 Retail wheeling is proposed to allow individuals the opportunity to purchase their electricity from any utility or independent power producer—thus allowing them to shop around for the lowest price or for other features that they value. This has been characterized as similar to the individual customer's ability to shop around for a long distance telecommunications company. In fact, retail wheeling of electricity is not well-defined and cannot be described by so simple an analogy. For a discussion of these issues, see, e.g.: *The Electricity Journal,* April 1994, entire issue; Richard J. Rudden and Robert Homich, "Electric Utilities in the Future," *Fortnightly,* May 1, 1994, pp. 21-25; and Public Utilities Commission of the State of California, "Order Instituting Rulemaking and Order Instituting Investigation," Apr. 20, 1994. In addition to California, Nevada has a limited program in place, and Michigan and New Mexico have called for rulemaking on more limited programs to introduce greater competition. See, e.g., Peter Fox-Penner, "Critical Trends in State Utility Regulation," Natural Resources & *Environment,* winter 1994, pp. 17-19, 51-52.

pacity (73 percent) .12 In contrast, just 12 percent of successful competitive bids to date have been based on renewable, totaling a little over 2 GW.[13]

Several factors may have contributed to this difference. QFs were limited to RETs and cogeneration, unlike competitive facilities that can use any fuel. In addition, fossil fuel prices have dropped to near historic lows, reducing the incentive for choosing RETs. Some have also suggested, however, that the low rate of adoption of renewable under competitive bidding practices may in part be due to the screening/ranking factors not adequately reflecting the substantial benefits of renewable.[4]

These changes are exposing what some perceive to be a fundamental conflict between two different philosophies for utility regulation: 1) using regulatory interventions in the utility sector to advance social goals such as a cleaner environment through greater investment in and use of efficient and/or renewable energy technologies, and 2) reducing and/or changing regulation in the utility industry to allow greater competition in generation and consequently more efficient and lower cost provision of electricity.[15] These are not necessarily conflicting goals, and means of realizing both are discussed below.

Other changes will also affect RETs. Increasing concern over the environmental impacts of fossil fuel use has led to consideration of RETs in policy initiatives such as the Clean Air Act Amendments of 1990,[16] EPACT, and the Climate Change Action Plan. Half the states now incorporate environmental externalities in their electricity sector planning and operations either qualitatively or quantitatively, and other states are considering this. Such environmental concerns are likely to increase over time, and will generally benefit most RETs.

Some RETs may also have a significant influence on the structure of the electricity sector. In particular, as photovoltaics (PVs—or other small-scale technologies such as fuel cells) are developed, they may be distributed throughout a T&D net work. That could lead to substantial] y different T&D requirements and might affect the technical and financial structure for the electric utility. '7 Accommodating this change will require much better models and understanding of actual power flows so that the corresponding costs can be unbundled and assigned appropriately to ensure efficient use of the T&D system.[18]

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12 Energy Information Administration, Op. cit., footnote 1.

13 Blair G. Swezey, National Renewable Energy Laboratory, "The Impact of Competitive Bidding on the Market Prospects for Renewable Electric Technologies," draft, January 1993.

14 Ibid.

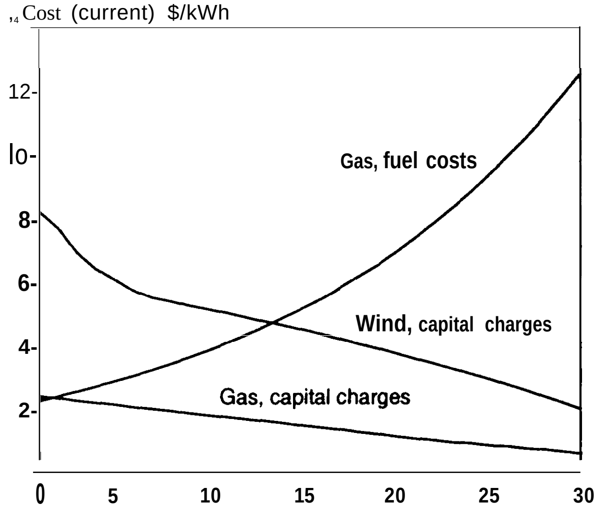
15 This issue has recently been highlighted by the California order instituting an investigation and rulemaking on retail wheeling. For a flavor of some of the debate, see *The Electricity Journal,* April 1994, entire issue.

16 See, e.g., U.S. Environmental Protection Agency, *Energy Efficiency and Renewable Energy: Opportunities from Title IV of the Clean Air Act,* EPA 430-R-94-001 (Washington, DC: February 1994).

17 For example, who might own rooftop PV systems: utilities, homeowners, or third parties? If distributed power is a significant fraction Of the system, the answer to this question could influence the structure of the electricity sector.

18 A variety of different means are being explored to achieve better understanding of and workable models and contracts for unbundling transmission services. Steven L. Walton, "Establishing Firm Transmission Rights Using a Rated System Path Model, " *The Electricity Journal,* October *1993,* pp. 20-33; W. Hogan, "Contract Networks for Electric Power Transmission," *Journal of Regulatory Economics,* vol. 4, No. 3, 1992, pp. 21 I -242; and Kahn and Gilbert, op. cit., footnote 2.

FIGURE 6-1: Capital Carrying Charges and Fuel Costs for Conventional and Capital-Intensive Renewable Energy Projects



NOTE: The capital carrying charges for the utility-owned wind powerplant modeled here are initially about four times those of the modeled natural gas combined-cycle powerplant, and drop to about three times after the period of accelerated (five-year) depreciation for the wind equipment. This illustrates the high front-loaded costs for capital-intensive RETs. In contrast, the natural gas system has high fuel costs and operates more in a "pay-as-you-go" manner. Overall, the wind system modeled here has a slightly lower lifetime levelized cost of electricity at 5.22¢/kWh than the natural gas system at 5.47¢/kWh.

The capital carrying charges include the return on debt, the return on equity, federal and state income taxes, book depreciation, property taxes, and insurance. The methodology used here followed that of the Electric Power Research Institute. All costs are in current dollars in order to appropriately value tax benefits. Parameters used are wind capital costs of $900/kW, capacity factor of 28 percent, and natural gas combined-cycle capital costs of $650/kW, capacity factor of 70 percent, and heat rate of 7,700 Btu/kWh. Other parameters are as indicated in tables 6-1 to 6-3.

SOURCE: Office of Technology Assessment, 1995.

POWERPLANT FINANCE[19]

A typical fossil fuel project—such as a natural gas-fired combined-cycle powerplant-will have a relatively low capital cost per unit power output compared with a typical nonfuel-based[20] renewable project, but faces continual (and potentially increasing) fuel costs. A typical renewable energy project will have high capital costs but little or no fuel cost (see figure 6-1). Over the lifetime of the project, the low operating (fuel) costs of the RET can more than make up for its high capital costs—depending on factors such as the cost of capital, fuel, operations, and plant life. Nevertheless. the RET can cost more than the fossil plant during the first years of the project under common financial accounting methods.

Effectively, the RET power is paid for in advance through the capital charges, in contrast to the pay-as- you-go nature of fossil fuel. The higher front-end cost of the renewable poses the risk of overpaying for power should the project fail prematurely (see figure 6-2). Conversely, costs of the non-fuel-based RET could be lower in the future than for a fossil fuel system, particularly if fuel prices escalate as projected (figure l-A-4).

| Utility Finance[21]

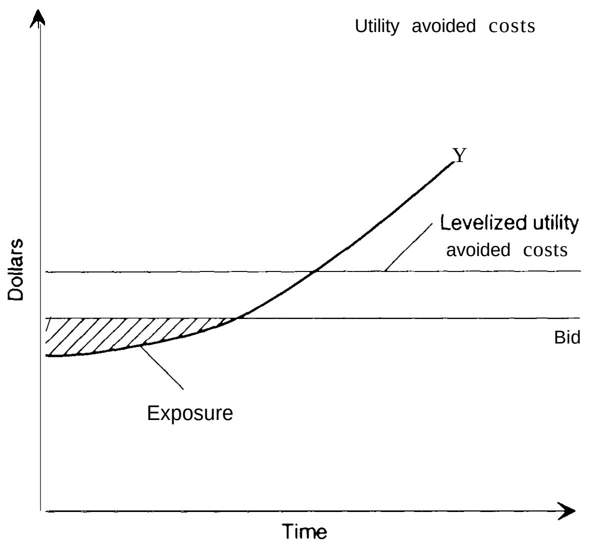
Electric utilities are monopolies regulated primarily by states. The retail price at which the utility sells electricity is set through a regulatory review process that allows the utility to recover all operating expenses, including taxes, and to earn a "fair" return for its *prudent* investments. The review typically consists of two stages: 1) a review of utility capital investments that can be a lengthy, arduous process (especially if questions are raised

19 Analysis of the financial situation of the electricity sector more broadly, including market-to-book value ratios, price/earnings ratios, and other measures of financial health are beyond the scope of this study; they can be found elsewhere. See, e.g., Edward Kahn, *Electric Utility Planning and Regulation* (Washington, DC: America nCouncil for an Energy Efficient Economy, 1991); Leonard S. Hyman, *America's Electric Utilities: Past, Present, and Future* (Arlington, VA: Public Utilities Reports, Inc., 1983); and Harry G. Stoll, *Least-Cost Electric Utility Planning (New* York, NY: John Wiley and Sons, 1989).

20 Biomass-fueled renewable energy projects are likely to have capital and fuel costs similar to those of fossil fuel projects, unlike capital-intensive nonfuel-based RETs such as geothermal, hydro, solar, and wind.

21 Only investor-owned utilities will be discussed here, as public utilities are exempt from federal taxes and tax incentives.

FIGURE 6-2: Potential Rate-Payer Exposure with Front-Loaded Cost Structures



NOTE The front loaded cost structure resulting from typical carrying charges shown in figure 6-1 can result in" rate-payer exposure" in that they pay for the plant upfront but run the risk that the plant does not operate for as long or al the performance level expected Proper structuring of the contracts can reduce this risk

SOURCE Ed Kahn et al Lawrence Berkeley Laboratory, Evaluation Methods in Competive Bidding for Electric Power, ' LBL-26924 June 1989

over the prudence of investments); 2) and much less detailed reviews of automatic adjustment of fuel costs.

The cost of owning and operating a utility-generating plant is affected by a variety of federal and state/local tax provisions as discussed below. Current federal tax policy variously provides investor-owned utilities[22] (IOUs) 5-, 15-, and 20-year accelerated depreciation, and a 10-year 1.5¢/kWh renewable electricity production credit (REPC) according to the particular technology, as listed in table 6-1. State and local governments may also levy income, sales, property, and other taxes.

The impact of federal and state/local taxes at the generating plant (not including, for example, fuel mining and transport) can be calculated using standard financial models .23 Representative taxes carried by different powerplants are shown in figure 6-3, based on the parameters in tables 6-1,6-2, and 6-3. (A more detailed analysis of taxes over the entire fuel cycle for two specific regions in the United States is given in the following section.)

Current law (which provides five-year accelerated depreciation for many RETs) sets the federal tax burden per kWh of generated electricity for RETs and most fossil technologies in the range of roughly 0.1 ¢- 1.0¢/kWh, depending on the particular technology, its capital cost, and other factors. This does not include the REPC[24] or upstream taxes from, for example, fuel mining or transport (see below). Within this range there is considerable variation between technologies in taxes paid per kWh generated. Coal-generated electricity (which receives 20-year tax depreciation) carries a federal tax burden in this scenario of about 0.4¢kWh, as illustrated in figure 6-3a.

If capital-intensive RETs instead had the same depreciation schedules as coal-fired plants, they would generally pay significantly higher taxes per kWh generated than fossil fuel plants (for the generating plant itself, not including fuel mining and transport costs—see below). The reason is that federal taxes are based on income, utility income is based in part on capital investment—for example, the rate base, and RETs require a higher capi-

22 Investor-owned utilities generate about three-quarters of U.S. electricity and will be the focus of this discussion. Other types of utility ownership include public utilities, cooperatives, and federally owned facilities. These other types are not discussed here as they are generally exempt from federal and state taxation.

23 This analysis was done by OTA using a model similar to that of the TAG™ method of the Electric Power Research Institute. This spreadsheet model was also compared with and validated by several other standard methods such as those in: U.S. Congress, Office of Technology Assessment, *New Electric Power Technologies: Problems and Prospects for the 1990s, OTA-E-246* (Washington, DC: U.S. Government Printing Office, 1985); and Harry G. Stoll, *Least-Cost Electric Utility Planning (New* York, NY: John Wiley & Sons, 1989).

24 The REPC, part of EPACT, credits wind and closed-loop biomass facilities placed in service between 1994 and 1999 with 1.5¢/kWh.

TABLE 6-1: Current Tax Factors for Selected Electricity Sources

	Investor-owned utilities					Nonutility generators				
	Book life	Tax life	Method	ITC percent	REPC[a] ¢/kWh	Book life	Tax life	Method	ITC percent	REPC ¢/kWh
Coal	30	20	150YODB		—	30	20	150%DB	.	—
Gas turbine	30	15	150%DB	—	—	30	15	150%DB		
Nuclear	30	15	150%DB	—	—	30	15	150%DB	—	
Biomass-plantation	30	20	150%DB		1.5	30	20/5[b]	150/200%DB		1 5
Biomass-waste	30	20	150%DB		—	30	20/5	150/200YoDB	—	
Geothermal	30	5	200%DB	—	—	30	5	200YODB	10C	
Hydro	50	20	150YODB	—	—	50	20	150%DB		—
Solar-PV	30	5	200%DB		—	30	5	200%DB	10	—
Solar thermal	30	5	200%DB		—	30	5	200%DB	10	—
Wmd	30	5	200%DB	—	1.5	30	5	200%DB	—	1.5

[a]This credit was enacted by EPACT section 1914 The REPC of 15¢/kWh is limited to wind and closed-loop biomass facilities placed in service during the period 1994 to 1999; it is provided only during the first 10 years of plant operation, it is phased out linearly as costs increase from 8¢/kWh to 1 1¢/kWh it is adjusted for inflation and it is reduced by other grants and credits

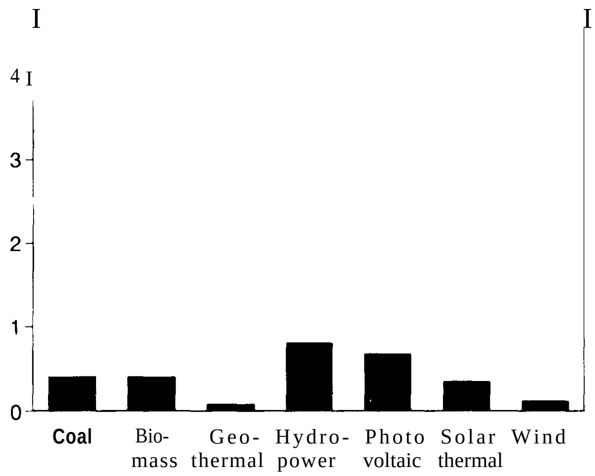
[b]Five-year 200%DB tax depredation is available only for qualifying facilities under the Public Utility Regulatory Policies Act

[c]The 10 percent ITC for solar and geothermal property was made permanent by EPACT, section 1916 It applies only to nonutility generators, however, as utilities were previously made ineligible fOr the credit

NOTES DB=declining balance ITC-investment tax credits for 10 percent of cost of qualified solar and geothermal property and was permanently extended under the Energy Policy Act of 1992 (EPACT); REPC= renewable electricity production credit of 1 5¢/kWh for energy produced by wind and closed-loop biomass facilities

SOURCES E Bruce Mumford and Blake J Lacher, "The Equity Stake " *Independent Energy,* March 1993, pp 8-10, 16 Stanton W Hadley et al *Report on the Study of the Tax and Rate Treatment of Renewable Energy Projects,* Report ORNL-6772 (Oak Ridge, TN Oak Ridge National Laboratory December 1993), and Internal Revenue Service, IRS Code, Sec 168(e)(3) Rev Proc 88-22, 1988-1 CB 785, IRS Code Sec 168(b)(l)

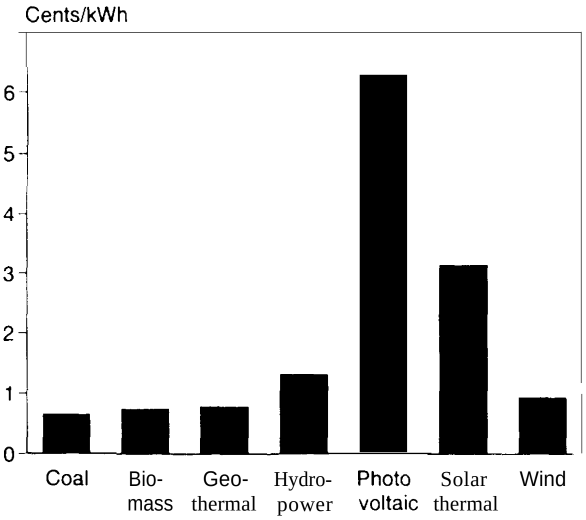
FIGURE 6-3A: Levelized Federal Tax Burdens on Various Technologies Owned and Operated by an Investor-Owned Electric Utility



NOTE: On a per kWh basis, the federal tax burden carried by various technologies under utility ownership varies considerably between technologies. Without accelerated depreciation for RETs, their tax burden would generally be significantly higher than that for conventional coal- or gas-fired powerplants. The calculations used a revenue requirement methodology following that of the Electric Power Research Institute, and were based on the parameters listed in tables 6-1, 6-2, and 6-3. The analysis includes the effect of accelerated depreciation; it does not include the impact of energy production credits as provided by the Energy Policy Act of 1992.

SOURCE: Office of Technology Assessment, 1995.

FIGURE 6-3B: Levelized State Tax Burdens on Various Technologies Owned and Operated by an Investor-Owned Electric Utility



NOTE On a per kWh bass state and local taxes carried by various technologies also vary significantly of these, property taxes can be particularly significant determinants of overall tax burders. The calcula tions used the same methodology and parameters as figure 6-3A The bass for calculating property taxes can vary significantly befween states and localities depending on how the cap [al is assumed to depreciate in value over time how inrflation in capital values is treated and other factors The scenario modeled here assumed that the property bass would Increase with inflation the share of that property on which the tax is levied is assumed to deprecate at a straight- me book life rate

SOURCE Off Ice of Technology Assessment 1995

tal investment per power output than fossil plants.[25] Accelerated depreciation for capital-intensive RETs only partially compensates for basing taxes on capital investment rather than kWh generated.

Although further reducing federal taxes—which total less than 1 ¢/kWh (not considering the REPC)—might correspondingly provide a small competitive boost for technologies such as biomass, geothermal, hydro, and wind that are now competitive or nearly so, it would have little competitive benefit for solar thermal or photovoltaics (chapter 5).

This analysis shows a gap in policy instruments between RD&D and tax policy to support largc-scale commercialization. RD&D is often the first factor that reduces the cost of a technology. As commercial manufacturing increases with ncar-

[25] In practice, utility rate regulation is far more complex than this, and utilities have incentives for choosing low total cost, rather than high capital cost options.

TABLE 6-2: Assumed Financial Parameters for Investor-Owned Utility Powerplant Financial Analysis

Global parameters	Rate	
Inflation	3%	
Insurance	1	
Property tax	3	
State sales tax on fuel	5	
State sales tax on equipment	5	
State income tax	6[a]	
Federal income tax	35	
	Rate	**Share**
Debt	5% real	45%
Preferred stock	5	10
Common stock	8	45

[a]State tax is deductible from the federal return.

SOURCE: Office of Technology Assessment, 1995

competitiveness, economies of scale become the primary factors in driving costs down further, and tax credits can expedite this process. Before a technology can get to this stage, however, it must establish a manufacturing base while it is yet uncompetitive except for niche markets. Mechanisms to support manufacturing scaleup may be an important intermediary step in some cases if costs are to be reduced to more widely competitive levels. The TEAM UP proposal discussed in chapter 5 is such a step. It is important to assure that any such policies actually stimulate investment in large-scale manufacturing, or manufacturers could simply use this assistance to prop up prices for products from existing capacity.

State and local property taxes can impose a heavy tax burden on capital-intensive RETs because they are levied as a percentage of capital[26] and because they are levied annually. Sixteen states exempt some renewable energy equipment from property taxes (see table 6-4) and some provide tax credits; this can reduce the state tax burden. The basis for such property tax exemptions in part depends on how taxes are viewed—as a tax on "wealth" or to pay for "benefits," serving effectively as a user's fee. Viewed as a benefits tax, for example, property taxes provide on average roughly three-quarters of local tax revenues and serve to cover the costs of roads, schools, and other public services for the employees of the facility being taxed. The level of such public services required, however, varies significantly with the type of powerplant. Conventional powerplants may require substantial infrastructures for fuel transport and water supply, as well as schools and hospitals for many employees. In contrast, some RETs may require little or no transport of fuel and may operate with relatively fewer personnel at the powerplant per unit of capital investment than conventional powerplants.[27] Detailing these differences would be a useful next step for making decisions about taxing RET property at the state and local level.

| Nonutility Generator Finance

NUGs typically finance generation expansion through *project* finance in which the lender is repayed and the loan secured through the cash flows

26 How capital is determined varies from state to state, depending on how the capital is assumed to depreciate in value over time, how inflation in capital values are treated, and numerous other factors. The scenario modeled assumed that the property basis would increase with inflation; the share of that property on which the tax is levied is assumed to depreciate at a straight-line book life rate.

27 This does not necessarily imply that the renewable energy system might generate less employment. In fact, several studies suggest that some RETs may generate more employment. The difference, however, is where this employment is distributed across the fuel cycle. Capital-intensive RETs may have more employment associated with manufacturing and less associated with fuel production or power-plant operations and maintenance than do fossil fuel systems.

TABLE 6-3: Baseline Cost and Performance Parameters for Utility Powerplant Financial Analysis

Coal	10	70	1,500	1.6	1,0	1 0	0 5
Gas turbine	13	15	400	2.5	3.0	1 0	0.5
Biomass-plantation	10	70	1,500	2,5	0.0	1.0	0.5
Biomass-waste	10	70	1,500	2.0	0,5	1.0	0.5
Geothermal	—	80	2,400	—	.	2.0	0.5
Hydro	—	40	2,000	—	—	0.5	0.5
Solar-PV	—	25	6,000	—	—	0.5	0.5
Solar thermal	—	25	3,000	—	—	2,0	0.5
Wind	—	28	1,000	—	—	1.0	0.5

NOTE All values have been rounded off reflecting uncertainties due to substantial technological advances taking place and uncertain future fuel prices Values represent 1994 technology status and current fuel cost projections, and do not incorporate the projected performance improvements indicated in chapter 5.

[a]Both fixed and variable operating costs are combined here as capacity factors are assumed to be fixed.

SOURCE: Office of Technology Assessment, 1995.

TABLE 6-4: State incentives for Solar Technologies

	Tax credit	Sales tax exemption	Property tax exemption	Industry recruiting	Loan	Grant	Other
Arizona	—	✓	—	✓[a]	✓	—	—
California	10%	—	—	—	✓[b]	✓[c]	—
Hawaii	35%[d]	—	✓[e]	✓	—	—	—
Idaho	—	—	—	—	✓[f]	—	Income tax[g]
Indiana	—	—	✓	—	—	—	—
Iowa	—	—	✓[h]	—	✓	—	—
Massachusetts	15%[i]	✓	✓	—	—	✓	Corporate tax
Minnesota	—	✓	✓[j]	—	—	—	Accelerated depreciation
Mississippi	—	—	—	—	✓[k]	—	—
Montana	—	—	✓	—	—	—	—
Nevada	—	✓[l]	✓				
New Hampshire	—	—	✓[m]	—	—	✓[n]	—
New Jersey	—	✓	—	—	—	v	Permit fee exemption
New York	—	—	✓	—	—	—	—
North Carolina	25%[o]	—	—	✓[p]	—	—	—
North Dakota	15%	—	✓	—	—	—	—
Ohio	—	—	✓	—	—	—	—
Oregon	35%	—	✓[q]	—	✓[r]	—	—
Pennsylvania	—	—	—	—	—	✓[s]	
Rhode Island	—	v	—	.	—	—	—
South Dakota	—	—	✓	—	✓[t]	—	—
Tennessee		—	—	—	✓	—	—
Texas	—	—	✓	—	—	✓[u]	Accelerated depreciation
Utah	25%[v]	—	—	—	—	—	—
Virginia	—	—	✓[w]	✓[x]	—	—	—
Wisconsin	—	—	✓	—	—	✓[y]	—
Wyoming	—		—			✓[z]	

[a]Offers a 10-percent tax credit for construction costs of "qualifted enwronmental technology facilities, " including renewable energy plants

boffers 5-percent loans to small businesses.

Grants to local governments, schools, and hospitals.

[d] Maximum credit of $1750 for single family homes and $350 for multifamily units

[e] For systems installed between 1976 and 1981

[f] Offers loans of up to $50000 for six years at 5 percent interest

[g] The entire cost of residential solar system can be deducted up to a maximum of $20000

[h] Exempt for five years

[i] Maximum credit of $1,000

[j] Photovoltaic (PV) systems are exempt

[k] Maximum loan is $200,000 and term is seven years

[l] Deferred up to five years

[m] Offered at the discretion of individual towns

[n] Grants of up to $10,000 for up to 100 percent of innovative projects

[o] Residential and commercial active or passive solar systems with a maximum credit of $1 000

[p] Offers 20-percent tax credit to any PV manufacturing facility

[q] For passive and active solar water and space heating

[r] Maximum loan is $20 million over 10 to 15 years at 7 to 10 percent interest

[s] Up to $100000 for residential, commercial, and institutional solar projects

[t] Loans at 3 percent interest for RETs with a payback of less than 10 years

[u] Matching grants

[v] Maximum credit of $1,500

[w] Offered at the discretion of individual towns

[x] Credit of 75¢/W for PV modules manufactured in Virginia and sold between 1995 and 1999

[y] Grants of 10 to 20 percent of the cost of solar projects with a payback of less than 10 years, up to $75,000

[z] Up to $2,500 for PV projects

NOTE Many of these state incentives apply to residential and/or commercial use of passive architecture, solar thermal space or water heating, and other such building applications

SOURCE Larry E Shirley and Jodie D Sholar, "State and Utility Financial Incentives for Solar Applications," *Solar Today,* July/August 1993, pp 11-14 and the assets of the individual project.[28] This is the form of financing used in many wind (see box 6-2) and solar thermal projects (see box 6-3), for example. In contrast, utilities typically finance generation expansion through *corporate* finance in which the loans are secured by all the corporation's assets.[29] NUGs also typically carry higher debt,[30] in part because of overall lower perception of risks [31] These differences in financial structure and taxes affect NUG investment in RETs in several ways.

First, NUG project finance is typically limited by lenders to 15 years or less-compared with project lifetimes of perhaps 30 years—and may have reopener clauses that require renegotiation of terms if utility avoided costs or other factors change sufficiently. This may make it more difficult for NUGs to invest in long-term, capital-intensive RETs.

Second, lenders must be assured the economic viability of the NUG project, including that the cash flow will always cover debt service payments. Project finance loans then often require financial reserves to ensure that debt service can be covered and may have a variety of other restrictions on cash flow.[32] These requirements may be particularly stringent for capital-intensive RETs, and may result in NUGS being required to post additional financial security or have greater demands placed on other components of the project bid.[33]

Third, as for utilities, NUG finance may be influenced by a variety of tax considerations (see table 6-1). The impact of accelerated depreciation and state/local taxes is similar to the case of utilities, as discussed above. In addition, recent analyses for the U.S. Department of Energy suggest that the 10-year 1.5¢/kWh REPC for closed-loop biomass and wind has the potential to improve NUG rate-of-returns, and may thus encourage investment in these technologies. The Alternative Minimum Tax (AMT)[34] may, however, limit a NUG from taking full advantage of these tax incentives. While the Office of Technology Assessment (OTA) has not analyzed this issue, at least one study found that "if a NUG is subject to the AMT, . . . [it] becomes a barrier to the adoption of renewable technologies. "[35] Such factors may be particularly important for renewable; as a fledgling industry, it is viewed as having higher risk and can

28 Edward P. Kahn et al., Lawrence Berkeley Laboratory, Energy and Environment Division, "Analysis of Debt Leveraging in Private Power Projects," Report LBL-32487, August 1992.

29 Existing debt covenants, however, limit management's ability to obligate ex isting assets further. Coverage ratios, fOr example, help protect existing bondholders.

30 A project may have as much as 80 percent debt, 16 percent subordinated debt, and just 4 percent equity in the project. See, e.g., Daniel A. Potash, "For What It's Worth . . .," *Independent Energy,* September 1991, pp. *37-40.*

31 The financial community recognizes that NUGs have strong incentive to succeed because otherwise they do not get paid. In addition, NUG projects usually begin with long-term power purchase agreements with utilities, so they do not face demand risks. In such a case, the utility bears the demand risk and may have to buy its way out of an expensive contract if demand is lower than expected. Therefore, even though the NUG pledges only the assets of the specific project, it can carry higher levels of debt than a utility.

32 E.P. Kahn et al. op cit, footnote 28; Roger F. Naill and William C. Dudley, "IPP Leveraged Financing: Unfair Advantage?" *Public Utilities Fortnightly,* Jan. 15, 1992; and Roger F. Naill and Barry J. Sharp, "Risky Business? The Case for Independents," *Electricity Journal,* April 1991, pp. 54-63.

33 Blair G. Swezey, National Renewable Energy Laboratory, "The Impact of Competitive Bidding on the Market Prospects for Renewable Electric Technologies," Report No. NREL/TP-462-5479, September 1993.

34 For a discussion of how the AMT works, see Stanton W. Hadley et al., *Report on the Study of Tax and Rate Treatment of Renewable Energy Projects, ORNL-6772* (Oak Ridge, TN: Oak Ridge National Laboratory, December 1993), p. 1-12.

35 Ibid.

BOX 6-2: Wind Energy Development in California

Until recently, the development of the U.S. wind Industry had taken place primarily in California due to particularly favorable tax and rate treatment there in the early to mid-1980s In addition to the federal 10-percent Investment tax credit, a 15-percent business energy investment tax credit,[1] and five-year accelerated depredation for wind systems,[2] this included a state energy Investment tax credit of 25 percent,[3] and favorable power purchase agreements with California utilities under the Public Utility Regulatory Policies Act. In particular, California Standard Offer *4* locked in escalating energy prices for a period of 10 years,[4] based on the expectation that conventional energy prices were also going to escalate The advantage of this form of contract was that 10-year debt financing could then be obtained from various instltutional investors who were assured of the necessary income stream to retire the debt This price Iock-in reduced Investor uncertainty and led to a "stampede of potential power producers signing contracts with utilities "[5]

These tax benefits were generous. By one estimate, "most Investors could recover about two-thirds of their Investment through the reduction of their taxes in less than three years, even with no sales of electricity "[6] Consequently, these returns attracted a wide range of manufacturers, financiers, and wind farm developers of varying capabilities and motivations, By one estimate, more than 40 wind energy developers installed turbines between 1982 and 19847 In 1980, the California Energy Commission set a goal of having 500 MW of wind capacity online by 1987, 1,436 MW were actually online in that year.

There was, however, relatively little base of supporting wind technology research, development, and demonstration (RD&D), much of the previous federal technology RD&D had been focused on very large (1 MW or larger) systems and little on the relatively lower risk and lower cost Intermediate scale (50 to 250 kW) systems that were put in by private developers Consequently, many early wind systems failed to perform as expected. For example, wind systems produced just 45 percent of industry electricity generation projections in 1985 This poor performance of many U. S.-made turbines opened the door for the entry of large numbers of Imported turbines, totaling some 40 percent of the cumulative Installed capacity as of 1990 These foreign turbines—largely Danish in origin—were noted for their heavier and high-quallty construction and their high reliability.

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[1] The business investment tax credit for certain energy properties was enacted under the Energy Tax Act of 1978 (Public Law 95-61 8)

[2] This was established under the Economic Recovery Tax Act of 1981

3 As state taxes are deductible the effect of this tax credit is reduced

4 This was followed by a drop to perhaps 90 percent of avoided cost over the remaining (20) years of the contract At the end of the 10 years avoided cost payments covered operations and maintenance and other costs and returns

[5] Alan J Cox et al Wind Power in California A Case Study of Targeted Tax Subsidies, " Regulatory Choices *A Perspective on Developments in Energy Policy,* Richard J Gilbert (ed) (Berkeley, CA University of California Press 1991), p 355

6 Ibid p 349

[7] Susan Williams and Kevin Porter, *Power Plays Profiles of America's Independent Renewable Electricity Developers* (Washington DC Investor Responsibility Research Center 1989) Estimates of the number of manufacturers and developers active at some level vary widely and are sometimes much higher For example some estimate that more than 50 manufacturing companies and 200 development companies were involved in wind development in the early 1980s See Jan Hamrin and Nancy Rader, *Investing in the Future A Regulator's Guide to Renewables* (Washington, DC National Association of Regulatory Utility Commissioners, February 1993) p B-27

(continued)

BOX 6-2 (cont'd.): Wind Energy Development in California

Federal and state tax credits were significantly reduced beginning in 1986, This led to a winnowing of wind system manufacturers and developers and sharply slowed the rate of installation. Just eight developers Installed wind turbines in 1988, for example, and about two dozen are now active at some level. Six of these—Cannon Energy, FloWind, Kenetech-U.S. Windpower, New World Power, SeaWest, and Zond—account for about three-quarters of total installed wind capacity in the United States.[8] Manufacturers went through a similar winnowing process, with just one large U.S. manufacturer—Kenetech-U.S. Windpower—and several smaller manufacturers/project developers—including Zond, FloWind, Cannon Energy, and Advanced Wind Turbines—now producing or developing utility-scale turbines.[9] Work continued throughout this period, however, with continuing gains in cost and performance, Federal RD&D support, in partnership with private firms, have enabled U.S. wind companies to take the global lead in wind turbine technology, cost, and performance, but these firms continue to struggle in international markets, where most sales are now occurring.

Overall, the history of the development of the wind power industry has both negative and positive aspects. On the negative side, at least one detailed analysis Indicates that more was spent to develop wind technology during this period than was necessary or efficient.[10]" Using tax and rate incentwes, in effect, to support RD&D, and Installing many poor performing machines was not an efficient means of developing and commercializing wind energy technology. Tax-based financing also sometimes resulted in year-end Investment decisions, making planning and manufacturing difficult, On the positive side, a cost-effective and environmentally friendly technology has been developed and a viable industry is beginning to take shape, in part due to favorable tax and rate treatment that allowed the industry to get started,

8 Randall Swisher, American Wind Energy Association, personal communication, Aug 25, 1994

9 Others include Atlantic Orient, Wind Eagle, and Wind Harvest

10 Cox et al Op cit footnote 5

have more difficulty attracting capital than well-established competitors.

UTILITY FULL FUEL-CYCLE TAX FACTORS

An analysis done for OTA examined taxes—including both federal and state income taxes, sales taxes, fuel taxes, property taxes, and taxes on labor—across the entire fuel cycle of fuel extraction and supply, fuel transport, and utility generation.[36] It included the embedded taxes on capital, labor, and land directly involved within each of these activities. Capital, labor, and land taxes in secondary industries were not separately considered. This analysis included modeling of the financial structure of each of these entities and consideration of construction costs and how they are included in the ratebase.

Two utilities were modeled using data provided by specific east and west coast investor-owned utilities. Table 6-5 summarizes the results of this analysis for each of the fuel cycles. This table highlights several issues. First, taxes on upstream coal and the development and transport of the natural gas supply are a relatively small portion of the total fuel-cycle taxes; most of the taxes occur at

36 This section primarily draws on the work of Dallas Burtraw and Pallavi R. Shah, Resources for the Future, "Fiscal Effects of Electricity Generation Technology Choice: A Full Fuel Cycle Analysis," report prepared for the Office of Technology Assessment, March 1994.

BOX 6-3: The Rise and Fall of Luz International, Ltd.

Between 1984 and 1991, Luz International, Ltd. installed 354 MW of parabolic trough solar thermal electric-generating capacity in California's deserts. The technology demonstrated increasing reliability and performance and decreasing costs with each generation. For example, the levelized cost of electricity dropped by roughly a factor of three between the first and last generations. Nevertheless, these parabolic trough systems are not cost-competitive given the drop in energy prices beginning in the mid-1980s, particularly compared to using natural gas in advanced gas turbines.

Financing of solar thermal plants was possible due to a combination of federal and state tax incentives and favorable utility power purchase rates (just as for wind power; see box 6-2). Tax benefits for solar thermal investment consisted of a 10-percent federal investment tax credit, a 15-percent federal business energy investment tax credit, and five-year accelerated depreciation; and a 25-percent California energy investment tax credit[1] and exemption from property taxes. Power purchase rates were initially under California Standard Offer 4 (SO4) contracts and included 10-year fixed rates at high levels based on the expectations for conventional fuels.

Luz developed, manufactured, and operated (through subsidiaries) the parabolic trough systems, with support from large institutional and corporate investors through project financing. As a consequence, Luz financing was highly leveraged—it owned little of the powerplants; most of the funding came from outside. This made it vulnerable to small changes in the investment climate. For example, when the attractive SO4 contracts were suspended by the California Public Utilities Commission, investors in the Luz plants demanded an increase in their projected aftertax internal rate of return from about 14 to 17 percent.

Energy prices dropped in the mid-1980s; at the same time, the federal investment tax credit of 10 percent was phased out, the federal energy investment tax credit was reduced from 15 to 10 percent, and the California Solar Energy Tax Credit was reduced. Improvements in technology cost and performance just managed to keep up with these tax changes, which were imposed independently of the needs of technology development or to counterbalance swings in the price of energy. Annual extension of the tax credits severely constrained planning and construction schedules for the plants, requiring Luz to wait until the tax credits were extended and then rush to construct the powerplant within the year. This also significantly raised the cost of obtaining finance and building the plants. Extension of the California property tax exemption was delayed into 1991, during which one of the investors pulled out. Low energy prices and uncertain extension of tax credits subsequently prevented other potential investors from entering and ultimately contributed to the bankruptcy of Luz in 1991. The plants Luz built continue to be operated under separate operating companies.

Thus, federal and state policy created the conditions necessary to launch commercialization of solar thermal electric generation but were then withdrawn independently of the needs of developing a commercially viable technology.

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[1] As state taxes are deductible, the net effect of this credit was reduced to roughly 13.5 percent.

SOURCES: Michael Lotker, *Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the Luz Experience,* Report SAND91-7014 (Albuquerque, NM: Sandia National Laboratory, November 1991); and Newton D. Becker, "The Demise of Luz: A Case Study," *Solar Today,* January/February 1992, pp. 24-26.

TABLE 6-5: Full Fuel-Cycle Taxes

	Location				
	west	540	0.16	108	1.24
	east	6.43	0.06	1.27	1 33
Gas	west	4.36	0.16	0.54	070
	east	3.52	0.07	0.44	051
Renewable energy technologies					
Biomass	west	6.01	0.39	1.08	1 47
	east	4.69	0.52	1.00	1 51
Hydro	west[a]	13.43	0.00	3.84	3.84
	east	907	000	208	208
Solar thermal	west[b]	14.33	0.00	1.68	1.68
	east	16.06	0.00	3.05	3.05
Wind	west[c]	6.16	0.00	1.28	1.28
	east	5.55	0.00	1.11	1.11
Renewable energy technologies with the renewable electricity production credit (REPC)[d]					
Biomass/REPC	west	475	0.39	033	0.72
	east	3.44	0.52	0.25	0.77
Wind/REPC	west[c]	4.91	0.00	0.49	0.49
	east	404	000-	023	023

[a]The hydro west plant had an exceptionally high capital cost in data provided by the utility, which led to the high levelized cost of energy and higher taxes listed here.

[b]The solar thermal west plant does not include natural gas cofiring; the solar thermal east plant is for a natural gas hybrid.

[c]The original utility-provided data for the wind west case was significantly outdated. Consequently, the values presented here are updated with current cost data.

[d]The difference in taxes between the no-REPC and with-REPC cases is not the same as the difference in the levelized cost of electricity. The cause of this is that the regulated utility receives a fixed rate of return; providing a tax credit reduces the overall revenue requirement and the cost of electricity even more.

NOTES: This analysis should be considered preliminary. Values listed are based on utility-provided data and may vary significantly from other projects. For details of the assumed parameters, see table source. Values have been rounded off to two decimal places. Fuel costs include state fuel taxes, and embedded mining and transport taxes directly on the corporation as well as on capital and labor income. Plant taxes include federal and state income taxes, state sales taxes, and property taxes directly on the corporation and on capital and labor income.

SOURCE: Dallas Burtraw and Pallavi R. Shah, "Fiscal Effects of Electricity Generation Technology Choice: A Full Fuel Cycle Analysis," report prepared for the Office of Technology Assessment, June 1994.

the powerplant either directly or as embedded taxes on, for example, labor. Second, RETs generally face somewhat higher taxes per kWh of electricity generated than either coal or gas,. if the benefits of the REPC[37] for wind and closed-loop biomass arc not included. With the REPC. taxes for closed-loop biomass and wind are reduced to levels in the range of those now enjoyed by natural gas (see table 6-5). The REPC, however, is scheduled to end in 1999, after which facilities will again face higher taxes. Renewable such as hydro and solar thermal also face much higher taxes per

[37]There arc no AMT limitations in these cases.

kWh than coal or natural gas in some cases. (Photovoltaics would face much higher taxes than conventional systems as well. but were not modeled here.) Third, there is considerable variation between the eastern and western cases in individual tax components and the overall tax rate, and between particular technologies.

DIRECT AND INDIRECT SUBSIDIES

Two recent studies of direct and indirect federal and state subsidies of the energy industry are summarized in table 6-6.[38] The studies agree on most subsidies.[39] Many of the disagreements result from differences in defining a "subsidy," as noted in table 6-6.[40] Subsidies may influence the choice of generation technology in the short term and over the long term.[41]

The direct and indirect federal supports across all energy systems. including electricity, may total somewhere between $10 billion to $20 billion per year. On a unit energy basis these levels of support may make a difference in the choice of technology only within a narrow range of costs. For example. the Alliance To Save Energy estimates that about 60 percent of their total listed in table 6-6 goes to the electricity sector or—assuming a median value of $20 billion—roughly $12 billion. Dividing by the 2.8 trillion kWh generated in 1992[42] gives a total of about 0.4¢/kWh.[43] or about 10 pcrcent or less of the cost of electricity generated by new gas and coal units (see table 6-5). This subsidy may affect the choice of generation technology within this narrow band of costs, but will probably not have much direct impact on the choice of technologies that are outside this range.

The single-year snapshot of supports shoun in table 6-6 does not reflect the historical importance of such supports in creating an industry over time. It also ignores the high leverage that RD&D-spccific supports can have on technological development. Such supports have a cumulative impact. encouraging a host of private as well as other public investment and contributing to a cycle of increasing performance and decreasing unit costs. This strengthens a technology's compctitive advantage. Cumulative direct supports for conventional energy technologies are in the hundreds of billions of dollars.[44] Over time this has had and could continue to have a substantial influcncc on the course of the energy industry.

RISK AND UNCERTAINTY

There are many risks and uncertainties in powcrplant finance, construction, and operation. Some of these are explicitly considered as part of the powerplant financing process and arc incorpo-

[38] U.S. Department of Energy, Energy Information Administration, *Federal Energy Subsidies: Direct and Indirect Interventions in Energy Markets*, Report SR EMEU 92-02 (Washington, DC: November 1992); and Douglas N. Koplow, *Federal Energy Subsidies: Energy, Environmental, and Fiscal Impacts* (Washington, DC: Alliance To Save Energy, April 1993). Earlier reports include Battelle Pacific Northwest Laboratory, *An Analysis of Federal Incentives 1'seal To Stimulate Energy Production*, Report PN'L-2410 REV.I1 (Richland, W'A February 1982).

[39] Note however [hat different base years are used.

[40] There is much debate as to whether accelerated depreciation is a subsidy. Regardless of how it is defined, it does represent a large tax expenditure. Section 3015 of EPACT directed the National Academy of Sciences to analyze energy subsidies, but action has been delayed and alternative efforts arc being considered. This work will hopefully resolve some of these lingering differences.

[41] whether a particular factor is defined to be a subsidy is not of concern here.

[42] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1992*, Report DOE EIA-0384(92) (Washington, DC: June 1993).

[43] This may be substantially more significant if, in fact, most of the subsidy goes to a narrow set of fuel cycles or If the particular fuel cycle supported has captured little of the market—such as the embryonic photovoltaics industry. In fact, however, most of this support goes to conventional fossil and nuclear fuel cycles which generate most of the power. Consequently, this is a reasonable average value for the discussion here, without resorting to differentiating the specific fuel cycles to which funding is applied.

[44] For example, one detailed analysis found direct supports alone for coal. oil, natural gas, nuclear, and electricity to be $440 billion (1992$) between 1918 and 1978. See Battelle Pacific Northwest Laboratory, op. cit., footnote 38.

TABLE 6-6: Direct and Indirect Federal Supports of the Energy Sector

Type of support	EIA, 1992 $billions	ASE, 1989 $billions	Principal disagreements[a]
Accelerated depreciation	NA	2.8-9.6	Not considered to be a subsidy by EIA as the Accelerated Cost Recovery System is available to all business.
Price-Anderson Act	3.0[b]	0.8-2.8	EIA estimated the value listed from the literature but included it separately as a regulatory cost rather than a subsidy. Several other regulatory costs such as unleaded gasoline and oil storage tank safety are not included in this table, nor are their health or other benefits.
DOE energy R&D	2.0	2.0-2.1	
Strategic petroleum reserve	NA	1.7-2.1	EIA considered it a security measure rather than an energy subsidy.
Investment tax credits	NA	0.8-2.0	Not included in EIA estimates as most were eliminated in 1986. They were continued for business investment in solar and geothermal property, however, and this was made permanent by the Energy Policy Act of 1992.
Low-income home energy assistance and DOE conservation assistance	14	1.5	
Tax-exempt bonds for public power	1.1- 7	11-14	
Rural electrification administration	0.8- 2	11-12	EIA values are based on the differences between government and market Interest rates
Uranium enrichment enterprise	03- 5[b]	0.3-1.0	EIA used current outlays and quantified, but did not include in their summary tables, amortization of historic investment. Federal outlays in 1992 were $200,000, but amortizing historic investment raises the level of subsidy to $0.3 billion to $1.5 billion, as listed here.
Utility normalization of excess deferred taxes	NA	00-1.0	Not Included by EIA
Social Security and Department of Labor Black Lung Trust Fund	0 3	11-13	EIA includes only current outlays in excess of trust fund receipts from taxes on coal production. Roughly $600 million of black lung disability payments is collected as a production tax on coal; between $300 million to $400 million comes from general Treasury revenues and is included here.
Office of Surface Mining Reclamation and Enforcement	0.1	09	
BLM and Minerals Management Serwce	03	NA	
Army Corps of Engineers CMI program	05	06	

Bureau of Reclamation power projects	01	NA	
DOE waste management	NA	06	
Power Marketing Administrations/TVA	08-42	04-06	EIA estimate of *$800* million is for current outlays over receipts the value $42 billion corresponds to recapturing historic investment at market rates of interest
Tax exclusion for electric coops	NA	04-06	
Tax-exempt bonds for pollution control equipment	NA	05-06	
Percentage depletion benefits	07-10	04-05	
Alternative fuel credit (methane from coal seams)	07	NA	
Alcohol fuels excise tax exemption	05	**03-05**	
Alcohol fuels tax credits	01	**NA**	
Passive loss restriction exemptions for 011 and natural gas	01	**01-03**	
Tax-exempt pubilcly owned utlities	01-02	03	
Total for those listed here	129-197	177-321	The total listed here for EIA does not subtract excise taxes in excess of current liabilities as done by EIA in their summary total They are Included here because these can be thought of as prepayments of future liabilities. Also, several categories, such as the Price-Anderson Act and Uranium Enrichment Services Investment costs are included here but are not Included in the EIA total EIA summary estimates of subsidies are $5 billion to $10 billion, which is approximately the same as that listed here when the Price-Anderson Act, Uranium Enrichment amortization, and other subsidies are subtracted and when excise taxes m excess of current liabilities are subtracted
Adjusted total	5-10	212-360	The EIA estimate of $5 billion to $10 billion does not Include amortizing historic uranium enrichment or other investment, the Pnce-Anderson Act, and others as noted above, and subtracts excise taxes going to general revenue

[a]Principal disagreements are primarily the result of defining what is and what is not a subsidy

[b]Values that were quantified, but not included in the overall estimate of subsidies by EIA

KEY ASE Alliance To Save Energy, BLM - Bureau of Land Man.] gement DOE U S Department of Fnergy EIA Energy Information Administration N A "not available or not considered a subsidy within the report R&D research and development TVA Tennessee Valley Authority

NOTE Export-Import Bank supports for the export of energy technologies were Included by ASE bu! F 1A considered them to be a trade measure Although these help support U S energy technology manufacturers they were not included here For other differences see the source materials Also note that no estimate of the energy subs idy component of M iddle East military diplomatic or aid support is included No costs for the regulatory controls associated with public health and safety are Included Fstimates of these values range widely

SOURCES U S Department of Energy Energy Information Administration Federal Energy Subsidies Direct and Indirect Interventions in Energy Markets SR EMEU/92-02 November 1992 and Douglas N Koplow Alliance To Save Energy' Federal Energy Subsidies Energy Environmental and Fiscal Impacts April 1993 rated in the cost of capital and various financial arrangements. These include the risks of not completing construct ion on time or on budget, and poor technological performance. These arc considered in the financial packages negotiated by NUGs and affect their access to and cost capital.[45] For utilities, cost overruns may not he recovered if the investment is not deemed prudent and can affect their cost of capital.

Certain other risks and uncertainties, however, may not be fully considered in utility planning or electricity costs. These inciudc the risk of fuel cost incrcascs, which arc largely passed through to ratepayers by fuel adjustmcnt clauscs;[46] long-term liabilities for waste disposal or large-scale accidents;[47] and the risk of capacity not matching demands. The utility planning process and electricity markets can be distorted in favor of generating options that entail risks passed directly to ratepayers and taxpayers rather than being incorporated in powerplant planning or the cost of generated electricity. Conversely, to the extent that other technologies—such as certain RETs—are not credited for their ability to avoid these risks, the planning process and electricity markcts can be distorted against them.

RETs also face various risks. depending on the technology. These include premature technical failures due to the relative immaturity of the technology, day-to-day variability in wind find solar resources, and rare but significant shortfalls in resources due to natural disasters. Technological risks and the day-to-day variability of the renewable resource arc generally fully considered in the design, construction. and financing of renewable energy plants. These risks, however, are generally born by the technology developer (if a NUG) rather than being passed through to the ratepaycr or taxpayer.

Rare events may not be adequately accounted for, however. For example, the volcanic eruption of Mt. Pinatubo injected large quantities of sulfur dioxide into the atmosphere, reducing beam radition to the Earth. Coupled with other weather effects, overall power production from the solar trough thermal power-plants at Kramer Junction in southern California was reduced by 30 percent in the winter and spring of 1992. Total insolation (direct plus diffuse) such as would be used by nonconcentrating flat plate photovoltaics, however, was affected much less---declining roughly 5 percent.[48] EI Niños or other weather events may similarly change wind patterns and reduce the output of wind powerplants.[49] The Midwest floods during the summer of 1993 might likewise have reduced the harvesting of biomass energy crops. And, of course, droughts may affect hydropower plants or biomass growth.

Such events are rare and the maximum impact in these cases occurred over no more than a year or so. In the most sensitive cases. they r-educed pow-

[45] For a detailed discussion, see Kahn and Gilbert, op. cit., footnote 2; Edward P. Kahn, "Risks in Independent Power Contracts: An Empirical Survey," *The Electricity Journal*, November 1991, pp. 30-45; Mason Willrich and Walter L. Campbell, "Risk Allocation in Independent Power Supply Contracts," *The Electricity Journal*, March 1992, pp. 54-63; and Naill and Sharp, op. cit., footnote 32.

[46] On the other hand, that fuel cost risks are passed through may lower the cost of capital to utilities somewhat, in part compensating for this risk.

[47] Risks of nuclear accidents are explicitly covered under the Price-Anderson Act. See table 6-6.

[48] J.J. Michalsky et al., "Concentration System Performance Degradation in the Aftermath of Mount Pinatubo," presented at the 1993 Annual Conference of the American Solar Energy Society, Washington, DC, Apr. 25-28, 1993; J.J. Michalsky et al., "Mount Pinatubo and Solar Power Plants," *Solar Today*, July/August 1993, pp. 21-22; and Roland Hulstrom, National Renewable Energy Laboratory, personal communication, April 1993.

[49] See, e.g., Cutter Information Corp., "Pinatubo, Weird Weather Challenges California's Wind and Solar Thermal Electric Industries," *Energy, Economics, and Climate Change*, July 1992, pp. 2-5. Very few prospective windpower sites have sufficient detailed data to evaluate such variations. For a discussion, see R.W. Baker et al., "Annual and Seasonal Variations in Mean Wind Speed and Wind Turbine Energy Production," *Solar Energy*, vol. 45, No. 5, 1990, pp. 285-289.

er output by just 30 percent over a few months. If long-term climate change due to the use of fossil fuels occurs, however, these shifts in weather patterns could persist and interfere with the operation of RETs located according to current weather patterns. In contrast, fossil fuel prices have varied much more—by roughly three to eight times[50] in real terms over the past three decades—than renewable resource availability, and price increases can remain for years.

Techniques developed for analyzing the value of risks in financial markets are now being applied to evaluate risks in the electricity sector. Developing such analytical tools would help determine how RETs should be valued compared with conventional technologies.

Fuel Cost Risks

Fuel costs will continue to be variable.[51] Gas prices may bc strongly influenced in coming years if there is an economy wiclc-electric utilities, industry, buildings. transport---move toward gas as a clean fuel. Fossil fuel costs might also be affected should certain environmental taxes—such as on carbon emissions—be established.

The Capital Asset Pricing Model (CAPM)[52] has been the principal analytical tool considered for determining the value of the risk of fuel cost variability.[53] It guides the selection of a diversified portfolio which reduces risks. While the application of CAPM to fuel cost risks is intriguing, it may require a stronger analytical foundation if it is to provide detailed quantitative guidance.[54] Other techniques being examined include options valuation[55] and arbitrage pricing theory.[56] Fuel cost risks may become important in the future, but additional work is needed on the analytical tools to value these various risks.

Liability Risks

Although explicit liability-related policies (such as the Price-Anderson Act) provide important benefits to their respective industries, there are many other liabilities that may be implicitly as-

[50]Coal has varied from 60¢/MMBtu (million Btu) in 1968 to $1.71/MMBtu in 1975, oil has varied from $1.50/MMBtu in 1972 to $6.94/MMBtu in 1981, and natural gas has varied from 30¢/MMBtu in 1951 to $2.65/MMBtu in 1982. This ignores the impact of various regulatory and price controls. See Energy Information Administration, op. cit., footnote 42.

[51]Little oil is now used in the electricity sector, so fluctuations in its price are of less direct interest.

[52]Ernst R. Berndt, *The Practice of Econometrics: Classic and Contemporary* (Reading, MA: Addison-Wesley Publishing Co., 1991); and Richard A. Brealey and Stewart C. Myers, *Principles of Corporate Finance*, 4th Ed. (New York, NY: McGraw-Hill, Inc., 1991).

[53]Shimon Awerbuch, "Risk-Adjusted IRP: It's Easy," presented at the NARUC-DOE Fifth National Conference on Integrated Resource Planning, Kalispell, MO, April 1994; Shimon Awerbuch, "New Utility Thinking Creates Opportunities for Solar Energy," *Solar Industry Journal*, 3rd quarter, 1992, pp. 21-26; Shimon Awerbuch, "Testimony Before the Public Utilities Commission, State of Colorado," Docket No. 91R-642EG, Feb. 14, 1992; Shimon Awerbuch, "Measuring the Costs of Photovoltaics in an Electric Utility Planning Framework," *Progress in Photovoltaics*, vol. 1, No. 3, April 1993, pp. 153-164.

[54]For reviews of some of the analytical difficulties of the CAPM model, especially when discount rates are negative, see, e.g.: William L. Beedles, "Evaluating Negative Benefits," *Journal of Financial and Quantitative Analysis*, vol. 13, 1978, pp. 174-176; R.H. Berry and R.G. Dyson, "On the Negative Risk Premium for Risk Adjusted Discount Rates," *Journal of Business Finance and Accounting*, vol. 7, 1980, pp. 427-436; Moshe Ben-Horim and Narayanaswamy Sivakumar, "Evaluating Capital Investment Projects," *Managerial and Decision Economics*, vol. 9, 1988, pp. 263-268; Timothy J. Gallagher and J. Kenton Zumwalt, "Risk-Adjusted Discount Rates," *The Financial Review*, vol. 26, 1991, pp. 105-114; and Bernard Schwab, "Conceptual Problems in the Use of Risk-Adjusted Discount Rates with Disaggregated Cash Flows," *Journal of Business Financing and Accounting*, vol. 5, 1978, pp. 281-293.

[55]Robert S. Pindyck, "Irreversibility, Uncertainty, and Investment," *Journal of Economic Literature*, vol. 29, September 1991, pp. 1110-1148; and Avinash K. Dixit and Robert S. Pindyck, *Investment Under Uncertainty* (Princeton, NJ: Princeton University Press, 1994).

[56]J. Fred Weston and Thomas E. Copeland, *Managerial Finance*, 9th Ed. (Fort Worth, TX: Dryden Press, 1992)

sumed by taxpayers but are largely unrecognized. These include the potential liabilities from site contamination and the associated cleanup Costs.[57]

Since these concerns affect conventional fossil and nuclear fuel cycles to a much greater extent than most RETs. taking them into account could benefit RETs when energy technology choices are made.

Demand Risks

Demand risk is that associated with constructing a powerplant that turns out to be unnecessary for a long time after completion due to slower than projected demand growth. This risk is particularly significant when constructing large, long lead-time powerplants. Unless the investment is deemed imprudent, the costs to the utility (even if the plant is built by a NUG) are largely passed through to ratepayers.

A variety of analytical methods are being developed to determine the value of demand risks. Of these, options valuation appears to be one of the best suited at this time.[58] Some leading utility executives expect it to be an important planning tool.[59] Options valuation is an analytical technique used to value the costs and benefit of waiting to make a large irreversible investment. During the delay, additional information on the need for capacity expansion, fuel costs, technology performance, and other important variables may change the economics of a particular choice.

Including these costs may significantly alter the choice of generation technology. RETs benefit from such considerations as they tend to be small, modular, and quickly installed. They can therefore be added as needed to meet demand growth.

Conventional technologies and strategies are also being adapted to such demand risks. For example, gas turbines tend to be relatively small (100 MW), modular, and quickly installed. Further, construction can be phased, in which a simple-cycle gas turbine is first installed, followed by construction of a combined-cycle system as demand grows. Ultimately, an integrated gasification system may be added so that low-cost coal or biomass can be used.

ENVIRONMENTAL COSTS AND BENEFITS

Crediting the environmental benefits of RETs compared to fossil fuels in energy planning and pricing could better reflect some advantages of RETs compared to fossil fuels. Recent efforts to

[57] For example a report by the Subcommittee on Oversight and Investigations, House Committee on Natural Resources found that tens of thousands of sites—including mine sites, oil and gas wells, and waste disposal sites (many not energy-related)—do not now comply with environmental standards and may be contaminating surface and/or groundwater. The federal government may carry the risk of cleanup if the operator defaults or declares bankruptcy. U.S. Congress, House of Representatives, Committee on Natural Resources, Subcommittee on Oversight and Investigations, "Deep Pockets: Taxpayer Liability for Environmental Contamination," Majority Staff Report, July 1993.

[58] For demand-side applications, see Eric Hirst, "Do Utility DSM Programs Increase Risk'?" *Electricity Journal*, May 1993, pp. 24-31; and Eric Hirst, "Flexibility Benefits of Demand-Side Programs in Electric Utility Planning," *The Energy Journal*, vol. 11, No. 1, January 1990. For supply-side applications, see Enrique O. Crousillat, World Bank, "Incorporating Risk and Uncertainty in Power System Planning," Industry and Energy Department Working Paper, Energy Series Paper No. 17, June 1989; Enrique Crousillat and Spires Martzoukos, World Bank, "Decision Making Under Uncertainty: An Option Valuation Approach to Power Planning." Industry and Energy Department Working Paper, Energy Series Paper No. 39, August 1991.

[59] "New England Electric CEO Calls for Competitive Measures, Environmental Edge," *Electric Power Alert*, Jan. 5, 1994, p. 26.

TABLE 6-7: Estimates of the Value of Environmental Externalities for the Electricity Sector (1989 $/lb)

	SO_x	NO_x	CO_2	CH_4	Particulates
Energy Power Research Institute	$0.20-$1.30	$0.02-$0.23	—	—	—
California Energy Commission	5.80	5.80	$0.01	—	$3.90
Chernick	0.90	1.60	0.042	$0.37	2.60
Hohmeyer	0.20-0.90	0.30-1.50	0.010	0.35	0.20-1.20
Ottinger	2.00	0.80	0.007	—	1.20
Schilberg	0.50-9.20	1.40-12.30	0.03	0.20	—

NOTE: All values have been rounded off. The ranges listed depend in part on the region considered within the particular study, typically urban versus rural.

SOURCE: Jonathon Koomey, Lawrence Berkeley Laboratory, "Comparative Analysis of Monetary Estimates of External Environmental Costs Associated with Combustion of Fossil Fuels," LBL-28313, July 1990 (original sources are cited in this report); and Richard L. Ottinger et al., *Environmental Costs of Electricity* (New York, NY: Oceana Publications, 1990).

quantify some of these environmental costs (see table 6-7) have been examined by OTA in a separate report.[60]

Some 25 states now consider environmental costs in their electricity sector planning and operations either qualitatively or quantitatively, and other states are considering doing So.[61] At the federal level. section 808 of the Clean Air Act Amendments of 1990 requires the Federal Energy Regulatory Commission and the Environmental Protection Agency to quantify and report to Congress the net environment] benefits of RETs compared to nonrenewable energy and to model regulations for incorporating such benefits in the regulatory treatment of RETs.[62]

Federal policy has established minimum standards to protect species and ecosystems. Recently, interest has developed in the use of market mechanisms to most efficiently allocate resources to meet these standards, even creating mtirkcts—such as SO_x tradeable emissions permits under tht Clean Air Act Amendments of 1990---wherc necessary. Such approaches may also be applicablc to other environrnental costs associated with energy use.

Global warming. however, presents additional difficulties. Although there is growing scientific consensus that global warming will occur. it is not known with precision when the impacts will occur, what form they will take, or how they will be

[60] These issues are explored separately in a background report done with in this assessment of RETs. U.S. Congress, Office of Technology Assessment, *Studies of the Environmental Costs of Electricity*, OTA-ETI-134 (Washington, DC: U.S. Government Printing Office, September 1994). See also: Oak Ridge National Laboratory and Resources for the Future, "U.S.-EC Fuel Cycle Study Background Document to the Approach and Issues," ORNL-M-2500, November 1992; D.E. Jones, *Environmental Externalities: An Overview of Theory and Practice* EPRI CU EN-7294 (Palo Alto, CA: Electric Power Research Institute, May 1991); Richard L. Ottinger et al., *Environmental Costs of Electricity* (New York, NY. Oceana Publications, Inc., 1990); Olav Hohmeyer, *Social Costs of Energy Consumption* (New York, NY: Springer-Verlag, 198X}. J, Koomey, Lawrence Berkeley Laboratory, .'Comparative Analysis of Monetary Estimates of External Environmental Costs Associated with Combustion of Fossil Fuels," LBL-28313, July 1990; and Andrew Stirling, "Regulating the Electricity Supply Industry by Valuing Environmental Effects How Much Is the Emperor Retiring')" *Futures*, December **1992,** pp. 1024-1047.

[61] Office of Technology Assessment, ibid.

[62] See, e.g., Federal Energy Regulatory Commission, *Report (m Section 808: Renewable Energy and Energy Conservation Incentives of the Clean Air Act Amendments of 1990* (Washington, DC: December 1992); and Mar-k Chupka and David Howarth, *Renewable Electric Generation: An Assessment of Air Pollution Prevention Potential* (Washington. DC, U.S. Environmental Protection Agency, March 1992).

distributed at the local and regional level. Global warming thus represents the kind of environmental externality that policy makers are least able to deal with: it is very long term---occurring over many decades to hundreds of years; the impact is very uncertain even though potentially severe;[63] and it involvcs things that are difficult to value, such as the survival of particular species.

For the most part, RETs are benign environmentally. In particular, their operation does not emit regulated pollutants or greenhouse gases.[64] Development of RETs might be viewed as a low-cost policy against serious environmental uncertainties, especially since many RET applications will also be economically beneficial.

APPROACHES TO COMMERCIALIZING RETS

A variety of supports has been provided over the past two decades to accelerate commercial adoption of RETs. These have contributed to the relatively rapid increase in the use of certain technologies such as biomass, geothermal, and wind (see box 6-2). Federal commercialization supports for RETs currently include accelerated depreciation, investment tax credits. and the REPC. These are summarized in table 6-1. These supports can help relatively mature technologies, but have much less impact on the commercialization of technologies that are higher cost. Even with these supports, RETs are not expected to make a major contribution to U.S. electricity supplied in the next two decades if present trends continue. For example, the Energy Information Administration projects RET electricity generation will increase from 11 percent of the total in 1990 to 13 percent in 2010 (see chapter 1).[65] If commercialization of RETs is a goal, the following steps could help deal with some of the challenges discussed above.

Competitive bidding and green competitive set-asides

As generation markets continue to open, competitive bidding is likely to play a more important role in these markets. As currently practiced, however, bid selection criteria may not fully credit some of the benefits of renewable. All-source bidding selection criteria could be modified to value more carefully such factors as the risk of fuel cost increases and environmental impact.

In evaluating some of these factors, however, it may not be possible to assign precise values that are widely accepted, or to design a single set of all-source bidding selection criteria that fairly cons iders all technologies. It may therefore be preferable for utilities to solicit bids specifically for certain technologies.

Such technology-specific set-asides could be designed to provide an increasing market demand for each set of technologies over a period of years, providing developers a more certain market and allowing them to scale up manufacturing and reduce prices. The growth in such set-aside capacity could be chosen to bring a particular RET down its cost curve to a fully competitive market position. It would be necessary to ensure that such technology and manufacturing improvements and price reductions actually occurred, however, and that the set-aside did not simply provide higher margins to manufacturers.[66] It is also necessary to ensure that utilities are not encumbered with a large number of high-cost contracts, especially if retail wheeling is introduced. Thus, technology-specific set-asides can support commercialization of even less mature RETs without excessively bur-

[63] See, e.g., U.S, Congress, Office of Technology Assessment, *Preparing for an Uncertain* Climate, OTA-O-567, OTA-O-568 (Washington, DC: U.S. Government Printing Office, October 1993).

[64] The combustion of biomass does release carbon dioxide, but that is balanced by the uptake of growing plants. Thus, the full biomass cycle can be operated on a sustainable basis.

[65] This does represent, however, an increase in nonhydro generation from roughly 50 billion kWh in 1990 to 170 billion kWh in 2010.

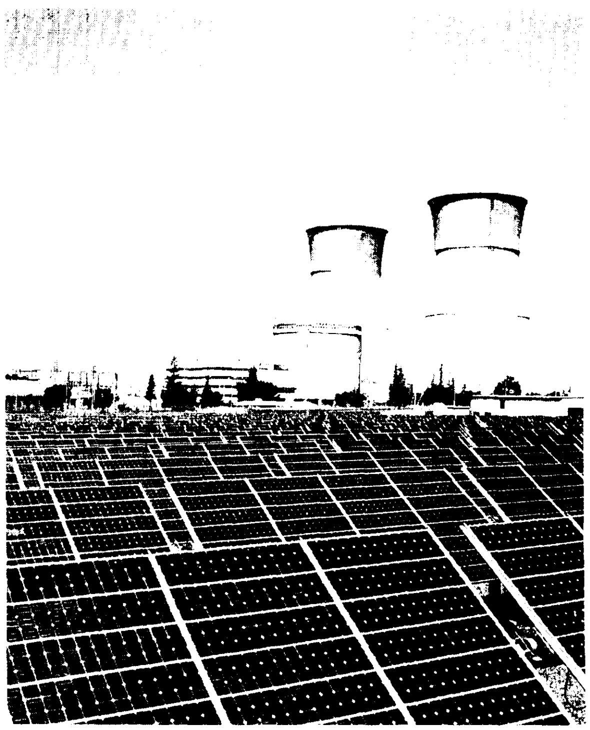
66 Donald W. Aitken, "Sustained Orderly Development," *Solar Today*, May/June 1992, pp. 20-22.

dening ratepayers and utilities. Both will benefit in the long term as RETs become fully competitive.

Technology-specific set-asides could also provide experience to regulators and utilities in preparing/evaluating future proposals and bids for renewables and would help balance their long experience and comfortable familiarity with conventional systems. It would also offer developers and utilities alike the opportunity to train personnel and to establish effective regimens of communication and interconnection supports.

There are several initial efforts with competitive set-asides. California, for example, has mandated renewable energy capacity purchases by utilities. Technologies, however, are not specified and this initiative is not likely to provide support for less mature technologies. The bidding and bid selection processes have also been controversial and the future of the program is in doubt.[67] The New England Electric System made a "green request for proposals" in 1993, but all seven of the selected bids were rejected by the Rhode Island Public Utilities Commission (PUC) in April 1994 as too expensive.[68] Nevertheless, various options to move this program forward are being considered. Other competitive set-asides for RETs include those by the Bonneville Power Administration and the New York State Energy Plan.[69]

Congress could consider directing the Department of Energy to work with the states to establish appropriate levels of technology-specific set-asides for RETs. This could be done first as pilot projects and then on a larger scale—coordinated on a national basis—in order to best capture fuel diversity and environmental benefits while supporting the manufacturing scaleup of their respective industries and thus reduce costs as rapidly and efficiently as possible.



GEORGE TURNER SMUD

The Sacramento Municipal Utility District (SMUD) 2-MW photovoltaic plant is installed at the site of the now closed Rancho Seco nuclear powerplant

Green pricing

Green pricing[70] proposals to support RETs typically place a surcharge of perhaps 10 percent on the monthly utility bill of *voluntarily* participating customers. The surcharge funds are then used to

[67]This approach is a component of a larger strategy that has become known as Sustained Orderly Development. "Wind Receives Large Share of BRPU Preliminary Bid Auction," *Wind Energy Weekly*, vol. 12, No. 577, Dec. 20, 1993, pp. 1. The set-aside has been called into question by the California Public Utilities Commission (PUC) and the Federal Energy Regulatory Commission (FERC). Under its call to investigate retail wheeling, PUC asked the legislature to explicitly reconsider the requirement placed on them to establish set-asides for renewables. In a February 1995 draft decision, FERC ruled that California cannot set avoided costs for QFs above the cost of any source of power, including low-cost purchases. This decision could preclude any preferential treatment of RETs.

[68]Daniel Kaplan, "State Regulator, Renewables Proponents Clash," *The Energy Daily*, Apr. 13, 1994, p. 3.

[69]For details on these and other programs, see Jan Hamrin and Nancy Rader, National Association of Regulatory Utility Commissioners, "Investing in the Future: A Regulator's Guide to Renewables," February 1993.

[70]David Moskovitz, " 'Green Pricing': Customer Choice Moves Beyond IRP," *The Electricity Journal*, October 1993, pp. 42-50.

pay the difference in cost between the renewables and conventional utility power. This provides greater choice to consumers and fits in well with the structural changes now taking place in the electricity sector. Several efforts of this sort have been launched, including the "PV Pioneer" program by the Sacramento Municipal Utility District with a 15-percent price premium for PVs,[71] Public Service of Colorado,[72] Traverse City Light & Power,[73] and a program by Southern California Edison (SCE).

The SCE program is with Kenetech-U.S. Windpower, Inc. They recently announced a preliminary agreement for 500 MW of wind power, the first 250 MW of which would be contingent on sufficient utility customers enrolling in a green pricing plan.[74] This wind capacity would fill about 60 percent of SCE's renewable energy purchases mandated under the California renewable energy set-aside, if that program moves forward.

Green pricing is attractive because it is voluntary, but it is unlikely to achieve the level of support for RETs that set-asides could. In addition, ratepayers who volunteer will be paying for the environmental and risk benefits gained on behalf of everyone in the region.

Incentives to purchase RETs

Most utilities have little or no incentive to purchase RETs or to purchase RET-generated electricity from NUGs rather than conventional fossil power: whatever source of power is used, the utility earns the same return. Regulatory changes to allow a slightly higher rate of return for the use or pur-chase of reasonably cost-effective rcnewables would provide incentive and help utilitics gain experience with RETs while reducing fuel cost risks to ratepayers and environmental impact.[75] As an example, the Wisconsin Public Service Commission recently granted regulated utili ties the right to provide their shareholders an additional return of 0.75¢/kWh for power generated by wind, photovoltaics. or solar thermal plants over 20 years for projects brought online between 1993 and 1998.[76] Although this is primarily a state regulatory issue, federal policy might play a supporting role.

Although they appear to have significant potential to support RETs, these strategies—green competitive set-asides. green pricing, or stockholder incentives---arc too new for any significant conclusions to be drawn as to their effectiveness in practice.

Federal taxes

Current federal tax incentives for RETs, such as accelerated depreciation, investment tax credits, and pduction credits, reduce federal tax burdens on RETs depending on the particular incentives and RET. As discussed above, however, the tax burden per kWh on many RETs remains higher than that for coal- or gas-powered electricity generation. For wind and biomass, which are competitive or near-competitive with fossil systems, tax incentives may have a significant influence on their market viability. However, the REPC of 1.5¢/kWh is limited to facilities in operation by 1999, which does not allow time for most biomass systems. with their 3- to 7-year growth cycles (for woody crops) to get established.

Tax policy has had a significant influence on the development of RETs such as wind (see box 6-2). Government incentives intended to help renewables, however, have also on occasion had the perverse effect of hurting them. For example, un-

[71] Sacramento Muni Aims To Have 50 MW of Photovoltaics on System by 2000," *Electric Utility Week*, June 27, 1994, pp. 16-17.

[72] "PSCO 'Green Pricing' To Fund Renewable Energy Projects," *Wind Energy Weekly*, Dec. 6, 1993, pp. 5.

[73] "Michigan Muni Turns to "Green Pricing" To Finance Wind Turbine," *Wind Energy Weekly*, May 30, 1994.

[74] Daniel Kaplan, "SCE, Kenetech Announce Wind Power Deal, Green Pricing Plan," *The Energy Daily*, vol. 22, Mar. 17, 1994, p. 1.

[75] See, e.g., David Moskovitz, *Renewable Energy: Barriers and Opportunities; Walls and Bridges* (Washington, DC: World Resources Institute, July 1992).

[76] "Minnesota Utility Eligible To Receive Wisconsin Incentive," *Wind Energy Weekly*, Nov. 8, 1993, pp. 4-5.

certainty over incentives raises risks for private developers and makes financing more difficult, as in the bankruptcy of the largest solar thermal company (see box 6-3). Ways to reduce the impact of this uncertainty are to make proposed incentives retroactive and to increase their duration.

Front-loaded capital costs of RETs

High investment costs for RETs can result in a NUG paying as much or more for debt and other costs than it receives from the sale of its power during the first critical years of a project. Ways to mitigate this problem might include: 1) innovative financial mechanisms to redistribute loan repayments over the project lifetime so as to better meet the cash flow constraints of the developer; 2) changes in the schedule for energy and capacity payments (i.e., to front-load payments); 3) interest rate buydowns (in which public entities provide a one-shot upfront payment of interest to reduce this front-loading);[77] and 4) longer contract periods to put NUG financing on a more level basis with the financing utilities implicitly receive from ratepayers.

For example, the senior debt of some recent NUG projects has been divided into two separate components, one with a shorter term and a variable interest rate, the other with a longer term and a fixed interest rate. Such financing structures have arisen because banks have increasingly been unwilling to lend for periods longer than 15 years, while insurance companies and other institutions are sometimes willing to lend for terms of 20 years or more. In addition, banks and other institutions increasingly prefer to diversify their portfolio and prefer to not underwrite an entire project alone.[78] Such mechanisms may allow some restructuring of the front-loaded cost structure of RET projects but also require careful negotiation to properly allocate risk among the participants, particularly for the longer term debtholder. A detailed analysis is needed of mechanisms to assist development of long-term loans for RETs through private capital markets. There may be a federal role in matchmaking and/or leveraging such arrangements.

Changing contract payment schedules to better match the cash flow requirements of RET developers raises the risk of paying in advance for a powerplant that later fails. If, however, payments are structured so that they are always sufficient to cover operating and other costs and also provide a reasonable margin for the operator, it will always be profitable for someone to keep the plant operating. This can reduce the risk of premature failure and abandonment.

Transaction costs

High transaction costs can be a significant barrier for small renewable energy developers. Among the lessons drawn from past experiences (see box 6-1) is the value of standard contracts. Providing standard contracts is usually a state regulatory issue.

Direct and indirect subsidies

To improve the competitiveness of RETs, a more detailed and ongoing accounting of subsidies and related supports such as tax expenditures in the electricity sector might be made for each fuel cycle. Explicitly identifying subsidies and related supports for each fuel cycle on an ongoing basis could provide policymakers with a better sense of federal tax and budget expenditures so they could determine if taxpayers are getting their money's worth, and if any change is warranted.

Risk and environmental costs

Potential fuel price changes and environmental liabilities may not be adequately accounted for in the planning of new electricity-generation capac-

[77] Interest rate buydowns may often be preferable to such public finance instruments as loan guarantees, as buydowns leave the commercial lender at risk and thus maintain market incentives to perform, while minimizing federal exposure. On the other hand, interest rate buydowns do require specific federal outlays.

[78] John H. Kenney, "Financing with a Dual-Tranche," *Independent Energy*, September 1992, pp. 16-22.

ity or in the cost of electricity, Therefore, the potential of RETs to offset these risk pass-throughs may not be adequately valued by planners, reducing the likelihood that these RETs will be chosen when new capacity is planned. More analysis could help understand these risks, determine means of valuing them, and understand how risk pass -throughs influence financial markets and the choice of generation technologies.

The federal government could work with states to examine fuel adjustment clauses in particular and the impact these have on the choice of generation technologies. Mechanisms to adequately account for the risk of future fuel price increases in generation capacity planning could be developed and implemented. Initial work on this is under way in Colorado[79] and elsewhere. Environmental cleanup bonds, trust funds, or other funding mechanisms could be examined to determine their ability to recover long-term environmental cleanup costs from energy industries and companies.[80] Tax benefits that could affect the choice of a fuel cycle could be based on minimizing environmental impact.

State governments could incorporate environmental externality costs in their utility planning efforts or direct] y in electricity y costs, and state regulators could encourage utilities to consider environmental impacts when deciding which generating units to operate.[81] Although these are primarily state issues, the federal government could support such efforts through information programs, the development of appropriate analytical tools, and further analysis of the social costs of energy use. Proposals to base state and/or federal electric sector taxes on emissions. potentially including greenhouse gas emissions, rather than profits or sales could be examined for potential effectiveness, costs and benefits. equity impacts, or other consequences. Some studies have indicated that shifting from corporate income taxes may have positive benefits in the longer term.[82]

Structural change

The potentially negative impact of changes in the electric power sector on RETs, discussed at the beginning of this chapter, might be addressed by the use of sectorwide policy tools, rather than utility-specific regulatory interventions. For example, the valuation of fuel cost risks and environmental costs, and corresponding use of technology-specific set-asides for both utilities and NUGs, may ease some of the conflict inherent in limiting such costs or controls to regulated utilities alone. Such electricity sectorwide policy tools could be considered at both the state and federal levels.

CONCLUSION

This chapter has outlined a variety of challenges—structural, financial, tax, risk, and competitive-–that face commercialization of RETs in the electric sector. These challenges will likely preclude many cost-effective applications of RETs under current policies. A significant RET industry is beginning to develop with a portfolio of maturing as well as immature but promising technologies. The considerable experience that has been gained builds confidence for the industry's future. Policy experience is also developing. More effective commercialization, if done wisely, can lead to increased growth and widespread benefits.

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79 Shimon Awerbuch, "Direct Testimony," *Investigation Into the Development of Rules Concerning Integrated Resource Planning*, Colorado Public Utility Commission Docket 91R-642EG, February 1992.

80 See, e.g., House Committee on Natural Resources, op. cit., footnote 57.

81 Steve Bernow et al., "Full-Cost Dispatch: Incorporating Environmental Externalities in Electric System Operation," The *Electricity Journal*, March 1991, pp. 20-33.

82 Moskovitz, op. cit., footnote 75; Robert Repetto et al., *Green Fees: How a Tax Shift Can Work for the Environment and the Economy* (Washington, DC: World Resources Institute. November 1992); and Dale W. Jorgenson and Kun-Young Hun, "The Excess Burden of Taxation in the United States." *Journal of Accounting, Auditing, and Finance*, vol. 6, No. 6, fall 1991.

Government Supports and International Competition 7

U.S.-owned and U.S-based manufacturers have led the world in the research, development, and commercialization of many renewable energy technologies. Today, these manufacturers are facing strong competitive challenges both at home and abroad. Compared with U.S. firms, foreign competitors are often more strongly supported by public research, development, and demonstration (RD&D) and commercialization programs, protected by tariff or nontariff trade barriers, and assisted in their drive to enter foreign markets. At stake is a potentially large international market and the U.S. jobs and other economic benefits that might come from serving it.

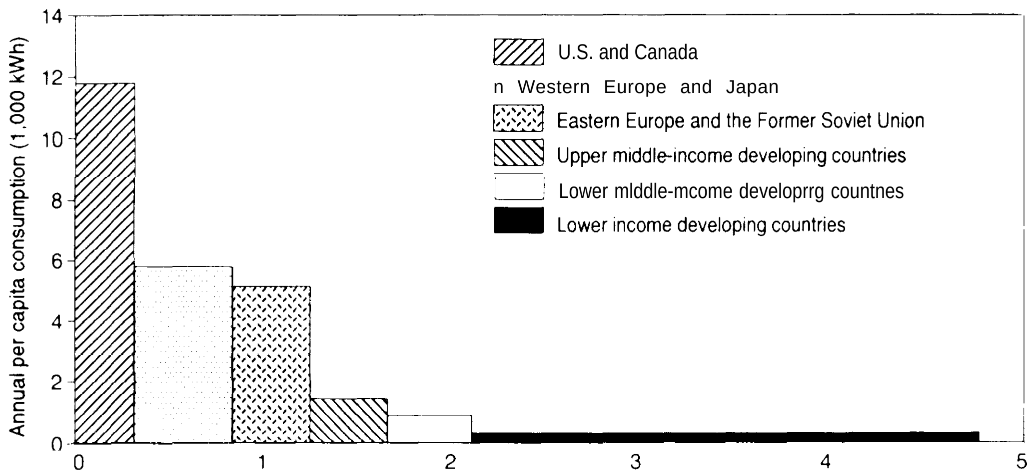
What Has Changed?

International interest in renewable energy technologies (RETs) has increased over the past decade. Environmental concerns-due to acid-rain damage to forests in Europe. the Chernobyl nuclear accident in the former Soviet Union. and possible global warming, as well as ongoing concerns about future fossil fuel prices and supply reliability—have generated a strong push in Europe to find alternatives to nuclear- and fossil-based electricity generation. Recently, the "Declaration of Madrid" called for RETs to provide 15 percent of primary energy demand in the European Union by 2010.[1]

At the same time, many power markets in Europe are going through substantial structural change. Some utilities in Europe (e.g., in the United Kingdom) have undergone large-scale priva-

[1]European Commission, Directorates-General XII, XIII, XVII and European Parliament, STOA Programme et al., "Declaration of Madrid," Conference on an Action Plan for Renewable Energy Sources in Europe, Madrid, Spain, Mar. 16-18, 1994.

FIGURE 7-1: World Electricity Consumption, 1987



The distribution of electricity use among different population groups around the world is shown. Lower income developing countries have very low levels of electricity consumption and are likely to be an important and rapidly growing market for renewable energy technologies over the next several decades.

SOURCE: Adopted from United Nations, *Energy Statistics Yearbook 1990* (New York, NY: 1992).

tization: others arc searching for ways to cooperate across many aspects of their operations. Whatever form European utilities take,[2] there are likely to be additional opportunities for using RETs within them.

In developing countries, current levels of electricity use are very low (figure 7-1) and the demand for electricity is growing rapidly.[3] Estimates of the market for power generation equipment in developing countries are typical] y in the $1 -trillion range over the next 10 years, or an average of $100 billion per year;[4] the market could grow much larger in the longer term. Investment and operational expansion at this level poses great difficulties for many inefficient or heavily subsidized state-owned electric utilities. In response, many developing countries are opening up their electricity sectors and beginning to encourage private investment. Use of RETs in distributed utility applications may offer opportunities to improve power sector performance.

Despite large investments. many people in many rural areas of developing countries are unlikely to be served by conventional electric utility grids for many years; the cost of transmission and distribution grid extension is too great. Similarly,

[2]Andrew Holmes, "E\ olution and De-Evolution of a European Power Grid," *Electricity Journal*, October 1992, pp. 34-47. See also Edward Kahn and Richard Gilbert, "International Comparisons of Electricity Regulation." 17th International Con ference of the International Association o! Energy Economists, Stavanger, Norway, May 1994.

[3]For a detailed review of energy use in developing countries, see U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries*, OTA-E-516 (Washington, DC: U.S. Government Printing Office, April 1992).

[4]The market is likely to be smaller in the near term and grow larger with time. See, e.g., Edwin A. Moore and George Smith, "Capital Expenditures for Electric Power in the Developing Countries in the 1990s," World Bank, Industry and Energy Department Working Paper No. 21 for the Energy Series, February 1990.

transport of fuel for diesel electric systems is expensive and often unreliable. In many cases, the choice is either to purchase remote RET systems or continue to do without electricity. RETs have the potential to cost-effectively provide electricity to people in areas outside the utility grid. The benefits of electricity, such as lights, water pumps, and modern communications, can help transform these traditional societies. This can contribute to political stability as well as provide trade benefits and jobs for the United States.

Both within Europe and in developing countries, RETs are thus increasingly seen as key power technologies in the future, with potentially huge markets. These factors have resulted in much more activist government policies in support of RETs in recent years and pose a significant competitive challenge to U.S. firms.

Potential Roles

Foreign markets offer a promising opportunity for using RETs. Many of these applications are higher value uses, for example, remote applications where RETs such as photovoltaic (PV), small solar thermal, and small wind have strong competitive advantages. These markets thus offer the potential to scale up manufacturing and drive down prices through economies of scale and learning.

The United States is now doing well in some RET export markets. For example, about 70 percent of U.S. photovoltaic production was shipped abroad in 1993; about 37 percent of world production of PVs was in the United States.[5] Nearly two-thirds of U.S.-based PV production, however, is by firms recently purchased by foreign interests. To lose foreign market share could then greatly reduce U.S. firms' economies of scale and learning; ultimately, this could lead to a loss of competitiveness even in our own markets.

As discussed elsewhere in this chapter, several countries appear to have earmarked the PV industry for special support. Such support could threaten U.S. firms in both domestic and export markets, especially since the PV industry is one where economies of scale and rapidly improving technology, along with steep technical and financial barriers to entry, give the first in the field a strong advantage.

Principal Themes

Rather than a broad overview of U.S. and foreign RD&D, commercialization, and trade programs —such reviews and related policy discussions are well covered elsewhere[6]—this chapter makes a detailed comparison of international activities in two specific areas—photovoltaics and wind. Other renewables, such as biomass energy technologies,[7]

[5] "U.S. PV Shipments Climb Sharply as Thermal Collector Numbers Drop," *Solar Letter*, June 10, 1994, p. 134.

[6] Interagency Environmental Exports Working Group, *Environmental Technologies Exports: Strategic Framework for U.S. Leadership* (Washington, DC: U.S. Department of Commerce, U.S. Department of Energy, and Environmental Protection Agency, November 1993); U.S. Department of Energy, *National Energy Strategy, Technical Annex 5: Analysis of Options To Increase Exports of U.S. Energy Technology*, US-DOE/S-0096P (Washington, DC: National Technical Information Service, 1992); Trade Promotion Coordinating Committee, "Toward a National Export Strategy," Report to Congress, September 1993; Office of Technology Assessment, op. cit., footnote 3; U.S. Congress, Office of Technology Assessment, *Industry, Technology, and the Environment: Competitive Challenges and Business Opportunities*, OTA-ITE-586 (Washington, DC: U.S. Government Printing Office, January 1994); U.S. Congress, Office of Technology Assessment, *Development Assistance, Export Promotion, and Environmental Technology—Background Paper*, OTA-BP-ITE-107 (Washington, DC: U.S. Government Printing Office, August 1993); and Andrew Barnett, "The Financing of Electric Power Projects in Developing Countries," *Energy Policy*, vol. 20, April 1992, pp. 326-334.

[7] For a review of biomass energy technology development, financial support, and its relationship to agriculture in Europe, see European Parliament, Scientific and Technological Options Assessment, Directorate General for Research, *Energy and Biomass: Potential for Cultivation and Prospects for Utilization from the European Community's Perspective*, Project Paper No. 1 (Luxembourg: April 1993); *Energy and Biomass: Country Profiles: Agriculture and Forestry Biomass Production—Operations Achieved*, Project Paper No. 2 (Luxembourg: August 1993); and *Energy and Biomass: Liquid Biofuels*, Project Paper No. 3 (Luxembourg: August 1993).

have recently been[8] or are currently being reviewed elsewhere.[9]

This comparison of PV and wind programs shows a wide range of supports among various nations of the Organization for Economic Cooperation and Development (OECD), including government-supported RD&D; direct funding of, or tax credits for, investments in RET equipment; supports for the purchase of generated renewable energy; and a variety of legislative—including environmental—supports for renewables.

The bulk of this chapter is focused on national PV and wind programs in Japan, Europe, and the United States. Following this discussion is a brief crosscutting summary and discussion of possible policy options to respond to this competitive challenge. How U.S. firms do in this international competition will depend on the groundwork that is laid today.

Finally, it should be noted that PV and wind technologies are advancing rapidly and government programs are changing quickly in response to new opportunities and shifting public concerns.

INTERNATIONAL ACTIVITIES IN PV AND WIND TECHNOLOGIES[10]

Competition in RETs is increasing rapidly as industrial countries recognize the growth potential of these environmentally friendly and currently or potentially cost-effective energy technologies. The PV and wind energy technology activities of nine OECD countries are reviewed and compared here.

All of the renewable energy programs reviewed have three complementary strategies: 1) RD&D to increase the cost-effectiveness of the technology and thus broaden its scope of economically attractive market applications: 2) market development to accelerate acceptance of RETs in currently cost-effective or newly emerging applications; and 3) market priming to support the use of RETs where they are not yet cost-effective but could become so with further development and large-scale manufacturing.

The link between increased cost-effectiveness and market development is critical. The potential market relies heavily on price (without considering risk or environmental costs, see chapter 6), particularly compared with the mature energy technologies that RETs compete against. Prices for RETs are determined by technical performance as determined by RD&D, economies of scale and learning realized by mass production, and the requirement to recoup certain fixed RD&D, manufacturing, and marketing costs through sales. Thus, costs can be reduced if sales volumes are increased, but sales volumes may not increase until prices are reduced. This "chicken-and-egg" problem is a central challenge for RETs.

RD&D for Increased Cost-Effectiveness

Photovoltaics

The general routes to improved PV cost-effectiveness are increased energy conversion efficiencies, improved balance of systems, and reduced manufacturing and installation costs. Increasing conversion efficiencies will make each square centimeter of PV surface more productive, increasing the utilization of available solar energy while making the cell less costly on a materials basis per unit output. A reduction in manufacturing costs per unit of cell area makes each square centimeter of cell less costly. The combination of reduced cost and increased efficiency is expected to

[8] For a broad review, see James & James Science Publishers, *European Directory of Renewable Energy Suppliers and Services, 1992* (London, England: 1992).

[9] A detailed competitive assessment of international renewable energy technology, policy, and activities is currently under way at Sandia National Laboratory for the Department of Energy. It covers biomass, geothermal, ocean, photovoltaic, solar thermal, wind, and advanced batteries.

[10] This section is drawn primarily from Ted Kennedy and Christine Egan, Meridian Corp., "International Activities Supporting Wind and Photovoltaic Energy," report prepared for the Office of Technology Assessment, Nov. 8, 1993.

TABLE 7-1: Publicly Funded Photovoltaic R&D, by Country (current U.S. dollars in millions)

Year	United States	Japan	Germany	Italy	France	European Union	Switzerland	United Kingdom
1979	118.8	13						
1980	148.6	35	6	9				
1981	151.6	32	10	9				
1982	61.6	40	33	9				
1983	57.9	41	30	9	6.3			
1984	50.2	41	30	9	5.2			
1935	54.5	46	31	20	6.1	6		
1986	37.8	48	31	20	4.6	6		
1987	40.0	38	32	20	3.8	6		
1988	34.6	37	35	20	3.1	6		
1989	35.1	42	50	20	2.8	4		
1990	34.7	54	65	27	4.4	4	5.2	
i991	46.3	54	65	41	4.5	4	6.0	0.5
1992	60.4	62	65	41	4.5	4	8.6	1.0

SOURCE: Morton Prince, Office of Solar Energy Conversion, U.S. Department of Energy; Paul Maycock, Photovoltaic Energy Systems, Inc.; and Fred J. Sissine, Congressional Research Service, "Renewable Energy: A New National Commitment," IB93063, Feb. 10, 1994.

result in dramatic declines in system capital costs as well as energy costs per kilowatt-hour produced (see chapter 5). Most countries with PV programs include a variety of activities to improve performance and reduce manufacturing costs.

Incorporation of PVs into building structures is a concept that is being pursued by most of the major programs, including those of the United States (PV-Bonus Program), Japan (superhigh-efficiency cell applications), Germany ("1,000 Roof" program), and Great Britain (Study of PV Applications in Buildings).

Improvements in balance of system (BOS) components and system reliability and lifetime are two additional areas addressed by most programs. BOS components include batteries, power conditioning equipment, system interconnections, and support structures. The Japanese, Italian, and Swiss programs specifically target BOS components either as budget line items or as discrete program areas.

System reliability and lifetime research is directed at several critical areas, including subsystem components such as the PV modules, batteries, and inverters; system configurations and interconnections; and operations and maintenance requirements. These concerns are addressed either as specific program areas or as components of broader program initiatives by virtually all countries examined.

Table 7-1 provides data on national annual PV RD&D budgets, and table 7-2 lists production levels by country from 1976 to 1993.

Wind

Improvements in the cost-effectiveness of wind energy technologies (see chapter 5) have been pursued through advanced engineering and manufacturing improvements. For example, improvements in blade design through public-private U.S. efforts are now resulting in rotors that increase energy capture by 10 to 30 percent, while reducing inefficiencies caused by fouling due to insects and airborne particles (see chapter 5). Virtually all of the country programs addressed in this report are investigating such improvements, as well as improvements in power system components—including variable-speed operation with advanced power electronics and expert control systems to

TABLE 7-2: Photovoltaic Production, by Region

	World	United States		Japan		Europe		Rest-of-World	
Year	MW	MW	'?/0	MW	'?!0	MW	'?!0	MW	%0
1976	0.42	0.32	76						
1977	0.45	0.42	93						
1978	0.96	0.84	88						
1979	1.46	1.24	85						
1980	3.30	2.50	76	0.50	15	030	9		
1981	5.40	3.50	65	1.10	20	080	15		
1982	8.40	5.20	62	1.70	20	1.40	17	010	1
1983	21.70	13.10	60	5.00	23	330	15	030	1
1984	25.00	11.50	46	8.90	36	360	14	080	3
1985	22.80	7.70	34	10.60	45	340	15	140	6
1986	26.00	7.10	27.3	12.60	485	400	154	230	9
1987	29.20	8.70	29.8	13.20	45..2	450	154	280	10
1988	33.80	11.30	35.1	12.80	353	670	197	300	9
1989	40.20	14.10	35.1	14.20	353	790	197	400	10
1990	46.50	14.80	31.8	16.80	361	1020	219	470	10
1991	55.30	17.10	30.9	19.90	360	13.40	242	500	9
1992	57.90	18.10	31.3	18.80	325	1640	283	460	8
1993	60.69	22.44	36.9	17.30	285	1655	273	440	72

MW megawatts

NOTE World total for 1976-79 does not add up, because data from those years was not broken out by region.

SOURCE Morton Prince Office of Solar Energy Conversion, U.S. Department of Energy, and Paul Maycock, Photovoltaic Energy Systems, Inc

increase power output, improve power quality, and reduce mechanical loads.

The development of large-scale turbines to reduce unit costs per kilowatt and address siting constraints is being pursued by the European Union (EU), Danish, Italian, and German programs with specific budget line items or discrete program areas. The development of offshore turbines—land-use restrictions such as the location of population centers may prevent wind energy development in some prime areas—is being investigated in many of the country programs, particularly Denmark and the Netherlands, as a mid-term option.

Increases in system reliability and lifetime are addressed in most national programs. In the United States, for example, design improvements and better operations and maintenance regimes have resulted in availabilities of up to 97 percent, compared with 20 percent in 1981 (see chapter 5). Turbines have been simplified and the numnber of moving parts has been reduced. This has cut down on maintenance requirements and has enhanced lifetimes while reducing manufacturing costs.

overall, Europe appears to be gearing up for largc-scale deployment of wind turbines in the war term. Plans for installing some 4,000 MW of wind capacity by the year 2000 have been announced. [11] The large-scale deployment of turbines will permit further economics of scale in manufacturing and operations.

[11] J.C. Chapman, *European Wind Technology*, EPRI TR-101391 (Palo Alto, CA: Electric Power Research Institute, March 1993).

Market Development Initiatives

Various OECD nations have undertaken activities to support the commercialization of RETs. By encouraging commercialization of RETs, larger scale production can be initiated, allowing economies of scale to be realized. In turn, these economies lower the costs of RETs and allow still larger market opportunities to be tapped. This cycle will ultimately allow the creation of a large and cost-effective RET industry. Commercialization strategies now in use for wind and PV technologies include removing regulatory and institutional barriers; information programs to better inform key decisionmakers regarding renewables; demonstrating technically appropriate and cost-effective applications of the technology; and stimulating market demand through market conditioning demonstrations, large-scale government purchases, subsidies, low-interest loans, tax incentives, and other supports.

Photovoltaics

Market conditioning is specifically identified in the U.S. photovoltaic program as a key strategy element. Activities include education; technical assistance and training; market, economic, and financial analyses; technology characterizations; regulatory and value analyses; and codes and standards assessment and development. Efforts to improve the policy and regulatory framework include evaluation of transmission issues affecting PVs, development of integrated resource planning methodologies, and integration of environmental considerations into utility planning. There are similar market conditioning activities in other countries, including efforts by the Photovoltaic Power Generation Technology Research Association in Japan and the Future Energies Forum in Germany.

Demonstrations are intended to encourage market participation through example, proving a new technology application in the critical areas of appropriateness, reliability, cost-effectiveness, ease of maintenance, integration with existing systems, and so forth. The major PV evaluation program in the United States is the PV-USA project. Major demonstration projects in other countries include the "1,000 Roof" PV program in Germany, promoted with the use of subsidies; "model" facilities in Japan, which are supported through subsidies; and the PLUG modular 100-kW grid-connected PV systems in Italy.

Market subsidies[12] are intended to foster market development and growth to the point at which the market can operate without them.[13] In the United States, supports are limited to tax incentives, including five-year accelerated depreciation and a 10-percent investment tax credit for nonutility generators. At the current state of cost and performance in PVs, these provide only modest incentive for additional investment.

Italian subsidies support up to 80 percent of installation costs or provide buyback rates for peak periods of up to 28¢/kWh. In Japan they range up to two-thirds of the cost of residential systems, and buybacks rates for PV-produced electricity are reported to be as high as 24¢/kWh. Japan also offers a 7-percent tax credit for PV systems and low-interest loans with rates as low as 4.1 percent. Germany offers subsidies for system capital costs of up to 70 percent.

Wind

For wind energy development, the U.S. experience in the 1980s was with targeted investment tax credits. In effect, these favored installation of turbines over the production of power. They were phased out in the mid-1980s. The Energy Policy

[12] An important note with regard to subsidies is that they can translate into significant additional government support of PV technology beyond RD&D budgets. Determining the level of this support ranges from difficult to nearly impossible. Since most of the budgets described here include only on-budget line items, subsidy expenditures for hardware installation and power production (whether they take the form of cash support or tax relief) may provide a significantly higher level of support than could be fully described in this report.

[13] Of course, programs may take on a life of their own and live on after their intended purpose has been met.

Act of 1992 provides a 1.5¢/kWh production tax credit for wind-generated electricity, Subsidies have been used by Denmark and Germany in the form of stable power purhase prices, paying 85 and 90 percent of the retail price of electricity, respectively. In England. power purchase rates have been set at very attractive levels for certain periods, which has accelerated installations dramatically.

| Country Programs and Market Share

Photovoltaics

The market for PV modules has been rapidly increasing and is expected to continue to do so for the foreseeable future (see table 7-2). Global market share trends indicate that U.S.-based production, after experiencing a decline through the mid-1980s, remained at 30 to 32 percent during 1990-92 and then jumped to nearly 37 percent in 1993.[14] Japan, which had 15 percent of the market in 1980, rose to 49 percent in 1986, and declined to 28.5 percent in 1993. The gains during 1980-86 were largely related to expanded sales of amorphous silicon technologies introduced through a number of consumer products. After 1986, the PV market began to shift from consumer product opportunities to power sector applications. European producers gained more of the market between 1986 and 1992, largely at the expense of Japanese firms. The combined market share of producers in the rest of the world has remained relatively constant since 1986.

Some of these PV firms have an international presence, with RD&D, manufacturing, sales, and other activities taking place in many countries. A number of foreign firms have also recently purchased U.S. PV producers. In March 1990, for example, Siemens A.G. of Munich purchased Atlantic Richfield Company's ARCO Solar.[15] This gave Siemens nearly 50 percent of U.S. photovoltaic shipments in 1992. In March 1994, Ebara Corporation of Japan purchased majority control of Blue Ridge Industrial Development Group, a spinoff from Westinghouse Electric that was commercializing dendritic web silicon PV.[16] In July 1994, Mobil Solar Energy Corporation, a Massachusetts-based producer of ribbon silicon PV cells, was sold to Angewandte Solarenergie GmbH of Germany, a joint venture whose parent companies include Daimler-Benz A.G. and the largest electric utility in Germany,[17] In November 1994, Solec International] was purchased by Sumitomo and Sanyo of Japan.[8] Together, these companies accounted for about 63 percent of the PVs manufactured in the United States in 1993 (see table 7-3).

The issue of "who is us" has appeared repeatedly in discussions of international competitiveness. Closely related is the question of the extent to which benefits-jobs, earnings, training, intellectual property-of federal assistance go abroad. whether transferred by a U.S. firm operating or sourcing offshore or by a foreign firm operating in and receiving benefits from the United States.[19] Maintaining U.S.-based production of PVs will likely require significant RD&D and investments in *advancd* automated production facilities, particularly as PV-production increasingly becomes a commodity production process.

[14] Paul D. Maycock, Photovoltaic Energy Systems, Inc., "International Photovoltaic Markets, Developments, Trends: Forecast to 2010," 1994.

[15] The agreement was announced In mid1989. See Richard McCormack, "Siemens Snare\ Arco Solar," *New Technology Week*. Aug. 7. 1989.

[16] "Japanese Firm, Westinghouse, Investors To Commercialize Dendritic Web PV," *Solar Letter*, vol. 4, No. 7, Apr. 1, 1994, pp. 76-77.

[17] "Mobil Announces Sale to ASE Americas, Venture of Deutsche Aerospace Nukem," *Solar Letter*, vol. 4, No. 17, Aug. 5, 1994, p. 186.

[18] "Sumitomo, Sanyo Acquire Solec: Financing and Marketing Aid Set," *Solar Letter*, vol. 4, No. 25, Nov. 11, 1994, p. 284.

[19] For a detailed discussion of these issues, see U.S. Congress, Office of Technology Assessment, *Multinationals and the National Interest: Playing by Different Rules*, OTA-ITE-569 (Washington, DC: U.S. Government Printing Office, September 1993).

TABLE 7-3: Photovoltaic Cell and Module Shipments, by Company (megawatts)

Company	1987	1988	1989	1990	1991	1992	1993
United States							
Siemens Solar	4 2	5 5	6 5	7 0	9 0	9 0	125
Solarex	2 9	3 2	5 0	5 4	5 6	5 7	6 5
Solec International	0 3	0 6	0 9	0 9	1 2	1 3	1 3
Advanced PV Systems					0 2	0 8	0 5
Astropower		01	0 2	0 4	045	0 6	0.9
Ussc	0 3	0 4	0 5	0 6	0 2	0 3	0 5
Mobil Solar/ASE GmbH	005	01	005	005	0 2	0 3	0 2
Entech			0 3	003	003	005	001
Other (Chronar)	0 9	1 2	065	042	0 2	01	
Total	865	11.3	141	148	171	182	22-1
Japan							
Sanyo	4 8	4 8	4 8	4 9	6 0	6 5	6 2
Kaneka	165	2 2	2 4	2 5	31	3 0	2 2
Kyocera	1 3	1 7	2 5	4.5	5 8	51	4 8
Talyo Yuden	12	1 3	1 5	1 6	1 6	1 6	1 6
Sharp	1 5	0 8	1 0	1 0	1 0	1 0	1 0
Hoxan	1 5	0 8	1 0	0 8	0 8	0 6	0 4
Fuji	0 5	0 5	01	01	01		
Matsushita				0 6	0 8	1 0	1 0
Other	0 7	0 7	0 9	0 8	0 6	oil	0 0
Total	132	128	142	168	198	188	173
Europe							
Deutsche Aerospace	0 8	1.3	1 2	1 7	21	2 6	2 6
BP Solar Systems	13	1 3	14	1 4	2 2	3 5	4 5
Naps France		1 0	0 7	0 6	1 0	0 6	0.5
Cnronar Wales		0 9	0 7	0 6	0 2	0 0	01
Photowatt (France)	1 0	0 8	0 8	1 5	1 8	2 0	1 7
Eurosolaire (Italy)	0 4	0 4	0 8	1 0	1 5	2 6	3 2
Helios (Italy)	0 3	0 3	0 8	12	1 5	2 0	1 0
Isophoton (Spain)	0 2	0 2	0 3	0 5	0 5	0 6	0 5
Siemens (Germany)	0 2	0 2	0 4	0 6	0 8	0 6	0 5
RES (Netherlands)			0 4	0 5	0 5	0.8	0 5
Other	0 3	0 4	0 4	0 6	1 3	11	12
Total	4 5	6 7	7 9	102	134	164	166
Rest-of-World							
CEL (Indua)	1 2	1 3	1 3	1 4	1.4	1 5	1 8
Sinonar (Taiwan)				0 6	0.4	0 4	NA
Heliodinamica (Brazil)	0 5	0 5	0 6	0 6	1 0	0 5	0 5
Reil (India)			0 5	0 5	0 5	0 5	NA
Bharat (India)	0 4	0 4	0 4	0 4	0 4	0 8	1 0
UDTS/HCR Algiers	—		0 3	0.3	0 3	0 3	NA
Venergia (Venezuela)			0 3	0 3	0 3		NA
Other	0 7	0 8	0 8	0 8	1 0	1 0	NA
Total	2 8	3 0	4 0	4 7	5 0	4 6	4.4

NA not avaiable

SOURCE: Paul Maycock, Photovoltaic Energy Systems, Inc., *Photovoltaic News*, vol. 12, No. 2, February 1993, and Paul Maycock, Photovoltaic Energy Systems, Inc., "International Photovoltaic Markets, Developments and Trends Forecast to 2010," 1994.

BERGEY WINDPOWER CO.

Six 10-kW wind turbines from Bergey Windpower, an 11.2-kW photovoltaic array from Siemens Solar, and a diesel power backup provide power for 150 homes in the village of Xcalac in Quintana Roo province, Mexico.

In general, the major PV RD& D programs have similar goals. all of which are aimed at producing PV modules and equipment that are cost-effective in the broadest array of' applications. In addition, activitits that facilitatc PV tcchnology and market developmcnt have been adopted. many of which arc not included in a country RD&D budget. These include demonstrations. government purchases, market subsidies. low-interest loans, and tax incentives. Such facilitating support activities differ widely among countries and are examined below. Japan, Germany, Italy, and others offer more aggtrddivr supports than does the United States in many respects.

Wind

In 1992, European utilities and developers installed some 225 MW of wind capacity, while only 5 MW was instulled in the United States.[20] Europeans, either privately or through electric utilities, are investing $300 million to $500 million per year in wind cquipment and associated services, not including research and development (R&D).[21] More recently. several U.S. utilities have shown increased interest in wind energy.

In general, the goals of the wind RD&D programs are similarly focused on cost-efective wind turbine development and deployment, but emphases vary. Japan, Sweden, Canada, Italy, and Belgium have financially supported exploitation of the wind resource primarily as an R&D activity. In contrast, the United Kingdom, Dcnrnark, the Netherlands. and Germany have attcmpted to stimulate the market by subsidizing turbine installations and paying a premium price for power produced. The U.S. program is balanced between both approaches. Wind energy RD&D budgets arc listed in tuble 7-4.

It is now useful to examine country-specific programs in more dctail. U.S. programs arc discussed in chapter 5.

JAPAN[22]

Japanese R&D of new and altermative sources of energy has taken place under the framework of the Sunshine Project initiated in response to the first oil crisis. In 1993, the Sunshine Project was combined with, among others, the Moonlight Project. which focused on energy conservation technologies, and the Research and Development Project on Environmcntal Technology, which focused on reduction of carbon dioxide (CO_2) and other emissions, to form the New Sunshine Project.

The New Sunshine Project includes three initifatives[23]:

[20] American Wind Energy Association, *1993 Wind Technology Status Report: Wind Energy on Verge of Expansion in U.S.* (Washington, DC: 1994).

[21] "European Wind Generation To Top Billion kWp Mark in 1993," *Wind Energy Weekly*, Sept. 28, 1992, p. 5.

[22] This section is primarily drawn from Kennedy and Egan, op. cit., footnote 10.

[23] Environment Agency, Government of Japan, *Establishing a Basic Law on the Environment* (Tokyo, Japan: Oct. 20, 1992); and Jacob M. Schlesinger, "In Japan, Environment Means an Opportunity for New Technologies," *Wall Street Journal*, June 3, 1992, p. A1.

TABLE 7-4: International Government-Funded Wind Energy RD&D[a]

Year	United States	Japan	Germany	Italy	CEC[b]	Denmark	Netherlands	United Kingdom
1983	31.4	15	18.0	1.5	62	1,0	3.3	5.3
1984	265	1.5	160	19	8.5	4.5	76	7.1
1985	316	1.5	129	23	96	8.0	12,0	90
1986	25.8	20	12,9	53	97	8.0	177	95
1987	167	32	12,9	96	13,0	80	236	95
1988	85	20	135	155	13.0	80	236	10.0
1989	8.8	20	250	245	155	8.0	236	100
1990	91	29	29.5	304	200	80	258	195
1991	111	31	295	30.4	20,0	76	27.3	255
1992	21.4	65	168	33 0[c]	19,6	6.0	289	15.8
1993	240	7.7	222	330	19.6	6.0	326	15,8

[a]Including test stations for Germany the Netherlands the United States, Italy, and Denmark

[b]CEC . Commission of the European Communities Includes budgets for both the Directorate General for Science, Research and Development and the Directorate General for Energy

[c]According to Dan Ancona o! the U S Department of Energy, these figures may include some double counting of funds due to projects falling behind schedule Thus, the actual budget may be overstated for 1992 and 1993

SOURCE Ted Kennedy and Christine Egan International Activities Supporting Wind and Photovoltaic Energy, " report prepared for the Office of Technology Assessment Nov 8 1993

1. the Action Plan for the Prevention of Global Warming-focused on CO_2 reduction and an increase in the pace of development and application of alternative energy technologies;[24]
2. research under the New Earth 21 Program—focused on technological development and international cooperation on energy and environmental issues;[25] and
3. the Applications in Neighboring Developing Countries Program—focused on collaborative research and application, including support for feasibility studies, design, installation, operation, and evaluation of renewable energy and environmental technologies in less developed countries.[26]

The total budget for the New Sunshine Project through 2020 is $11.5 billion.[27]

Photovoltaics have been a major focus of Japanese efforts. Although, the budget for PVS under the New Sunshine Project declined from $53.5 million in 1991 to $51.8 million[28] in 1992, the

[24]New Sunshine Program Headquarters, Agency of Industrial Science and Technology, "Comprehensive Approach to the New Sunshine Program Which Supports the 21 st Century—Sustainable Growth Through a Simultaneous Solution of Energy and Env ironmental Constraints," *Sunshine Journal, No. 4, 1993;* and Hisao Kobiyashi, "PV Status and Trends in Japan," paper presented at Soltech 1992, Albuquerque, NM, Feb. 10-12, 1992.

[25]New Sunshine Program Headquarters, op. cit., footnote 24.

[26]Nobuaki Mori, "Collaborative R&D Program on Appropriate Technologies—Contribution To Reducing Constraints on Energy and Environmental Technologies in Developing Countries," *Sunshine Journal. No. 4, 1993,*

[27]Yoshihiro Hamakawa, "New Sunshine Project and Recent Progress *in* Photovoltaic Technology in Japan, " UNESCO Solar Energy Summit, Paris, France, July 1993; and Ichiro Tansawa, "Broad Area Energy Utilization Network System Project—Eco Energy City Concept," *Sunshine Journal, No. 4,* 1993.

[28]One reviewer reports a separate estimate of $48.1 million, based on a budget of 6.1 billion yen for "solar power" quoted in Joint publications Research Service, Foreign Broadcast Information Service, JPRS-EST-92-037-L, May 7, 1992, p. 46, and a conversion rate of $0.007888 per yen in 1992. Linda Branstetter, Sandia National Laboratory, personal communication, April 1994.

overall PV budget will increase as a result of new spending by the Agency of Natural Resources and Energy of $9.7 million on initiatives to facilitate "public use." In recognition of the importance of reducing balance of system costs, roughly 16 percent of the 1992 budget is aimed at systems-level development, including BOS components such as inverters, batteries, and mounting systems. The world's most comprehensive dedicated testing facility for grid interconnection of distributed systems-consisting of at least 100 small (2-kW) arrays-is at a site on Rokko Island.[29]

The New Energy and Industrial Technology Development Organization (NEDO),[30] funded by the New Sunshine Project, established a Photovoltaic Power Generation Technology Research Association (PVTEC) in November 1991. This semigovernmental agency has 26 members representing a broad range of Japanese industries. PVTEC encourages collaborative R&D among member companies as well as with other private sector, government, and academic institutions. PVTEC's programs focus on production technology of advanced PV cells; production technology of amorphous PV cells; superhigh-efficiency PV cells; research and analysis on commercialization; and investigation of the trends of industry and technology in photovoltaic power generation, supporting research, and other activities. PVTEC also seeks to be a major base of effective R&D overseas, working in close cooperation with foreign organizations.[31]

Japan has implemented major financial subsidies for photovoltaics. A 7-percent tax credit has been established for enterprises installing PV systems.[32] MITI had a fund of $3.7 million in FY 1993 for individuals installing home PV systems to obtain loans at a rate of 4.55 percent for 5- or 10-year terms.[33] An installer of a "model plant" (interpreted to mean power installations, not manufacturing facilities) may receive a subsidy of up to 50 percent of the installation cost. In 1992, the government set up an institution to finance PV installations at public facilities such as schools at two-thirds of the total project cost. A budget of approximately $6.5 million was reported for FY 1992[34] and $3 million for FY 1993.[35] Japan has also announced a plan to install four model plants in developing countries.[36]

MITI is also planning to support up to two-thirds of the cost of residential systems. The program goal is 1,000 homes the first year and up to 70,000 by the year 2000.[37] Some $39 million of the MITI FY 1994 budget was requested for this program. The 3-kW systems will be grid con-

[29] Dan Shugar, Pacific Gas and Electric Co., personal communication, 1993.

[30] NEDO was initiated in 1980 in response to the second oil crisis. It is responsible for intensive and effective promotion of, and is subsidized by, the Sunshine Project. In 1991, NEDO'S responsibilities were expanded from a strict energy security focus to include environmental security. See Takashi Goto, "Photovoltaic R&D Program in Japan (Sunshine Project)," paper presented at the Sixth International Photovoltaic Science and Engineering Conference Proceedings, New Delhi, India, Feb. 10-14, 1992, p. 521.

[31] Photovoltaic power Generation Technology Research Association, "Aiming at a Major Base of Research and Development of Solar Cells," Summary Sheet, n.d.; Seiji Wakamatsu, Photovoltaic Power Generation Technology Research Association, slide presentation, n.d.

32. "NEDO Supports Field Test program," *NEDO Newsletter*, August 1992.

[33] Kiyoko Matsuyama, New Energy and Industrial Technology Development organization, personal Communication to Ted Kennedy and Christine Egan, Meridian Corp., June 1993.

[34] NEDO Supports Field Test Program, Op. cit., footnote 32.

35 Matsuyama, op. cit., footnote 33.

[36] Paul Maycock, "Japanese Plan for Global Warming Stimulates Major PV Initiatives," *PV News, vol.* 11, *No.* 5, May 1992.

[37] Foreign Broadcast Information Service, "MITI To Subsidize Household Solar Power Generation Systems," *Pacific Rim Economic Review, vol. 2, No. 18,* Sept. 8, 1993, p. 7, citing *Nihon Keizai Shimbun*, Aug. 22, 1993.

nected, with excess energy sold back to the utilities.[38] If the 70,000-home goal is achieved, it would represent four times current worldwide annual production. Firms with access to this market would benefit hugely from economies of scale and learning.

Beginning in April 1992, utility companies were directed by the Japanese government to allow grid interconnection[39] of systems such as photovoltaics, wind turbines, and fuel cells and to purchase their excess power. Privately generated renewable energy is purchased by the utility at the highest marginal price paid by the user for power. This ranges from approximately 16¢ to 24¢/kWh.[40] Utility companies have set a goal of 2.4 MW and 150 sites, including rooftops, offices, and technical centers, by 1995.

Japanese development of wind systems has not been as aggressive as that for PV. About 23 wind turbines, totaling 3.2 MW, were designed and installed from 1982 through 1991 in Japan. Total capacity additions for the country are expected to be about 3 MW by 1995, and another 7 MW between 1996 and the year 2000, for a total of 10 MW. Practical R&D is conducted by NEDO and more theoretical research is performed by the Mechanical Engineering Laboratory. Resource assessment work has identified more than 20 prime wind resource sites within the country. Mitsubishi has, however, exported about 700 of its 250-kW machines to the United States, most of which were installed in California.

EUROPEAN UNION[41]

The European Commission (EC) programs for RD&D in renewable energy are conducted by the Directorate General for Science, Research, and Development (DG XII) and the Directorate General for Energy (DG XVII). The major programs arc JOULE II (focused on R&D and emphasizing photovoltaics, wind, and biomass with a total allocation of $70.8 million[42] for 1991 -94) and THERMIE (focused on demonstration and with a budget allocation of $424 million from 1990 to 1992 and a proposed budget of $181.8 million from 1993 to 1994). The Commission provides direct financial support on a cost-shared basis of up to 50 percent of project costs for R&D and up to 40 percent for demonstration.[43] ALTENER is a recently proposed program under the direction of DG XVII intended to focus on barriers to the development of renewable energy .44

U.S. industry competition within the European Union has in the past been constrained by EU directives that allow public purchasers in four sectors (water, energy, transport, and telecommunicate ions) to reject bids that have less than half EU content by value. Furthermore. if purchasers consider non-EU bids. they are required to give a

[38] Paul Maycock, "Japan Mount\ 27 Year Conservation and Energy Plan," *PV News*, vol. 1 I, No. 10, October 1992.

[39] Kobiyashi, op. cit., footnote 24.

[40] Matsuyama, op. cit., footnote 33.

[41] Formerly the European Economic Community, the name was changed in November 1993. This section is primarily drawn from Kennedy and Egan, op. cit., footnote 10.

[42] Commission of the European Communities, Directorate General XII for Science, Research and Development, "Non-Nuclear Energy (JOULE 11) 1991- 1994," Information Package, pp. 10-11; and Wolfgang Palz, "The European Community R&D program on Photovoltaics," paper presented at the 10th European Photovoltaic Solar Energy Conference, Lisbon, Portugal. Apr. 8-12, 1991, p. 1369.

[43] "The European Community and Wind Energy," *Wind Directions*, vol. 1 I, No. 3, winter 1991-92.

[44] "Renewables Could Benefit from EC Tax on CO_2 Output," *Wind Energy Weekly*, Aug. 24, 1992; "European Carbon Dioxide Target Needs To Triple Renewables Use," *Solar Letter*, vol. 2. No. 18, Sept. 4, 1992: and "Europe Gets Clean Away," *Wind Power Monthly*, vol. 8, No. 9, September 1992.

SAM BALDWIN, OTA STAFF

A photovoltaic pumping system near Ziniare, Burkina Faso. This system provides clean drinking water, reduces the labor of lifting and hauling water, and can help break waterborne disease cycles.

3-percent price advantage to goods and services of EU origin.[45] The latest round of the General Agreement on Tariffs and Trade (GATT) addresses some of these issues and commits signatories to follow a set of rules specifying open, nondiscriminatory procurement practices. It should be noted that EU directives do allow for equal treatment to be negotiated bilaterally or multilaterally.[46]

DG VIII (Development Fund) implements an international development program with activities in developing countries. The projects have included photovoltaic water pumping and electrification with $1.7 million in funding from the EC.[47] Donor country contributions, primarily from Germany and France, have increased the value of this program to U.S. $10 million to $20 million. In 1989, a project was initiated within the THERMIE framework to install PV pumping systems and other small-scale applications for use in the Sahel region of Africa. More than 1,300 pumps powered by 600-W to 3.5-kW PV arrays with a total PV capacity of nearly 2 MW were to be installed beginning in 1992. The EC contributed $39 million for this program.[48]

The EC RD&D objectives with regard to wind energy are to identify the Union's resources and to develop design and testing methods with a focus on large machines. Current expenditures are about $4.85 million per year.

The EU is considering a Europe-wide carbon tax on fossil fuels in order to reduce CO_2 emissions. Thus far, only Denmark has passed legislation enacting this type of tax, although several other countries such as Germany, the Netherlands, and Italy have considered similar measures. The renewable energy industry in Europe could benefit from a tax on CO_2 emissions. It should be noted, however, that European prices for electricity are often substantially higher than those in the United States without any carbon tax. For example, the price for electricity in the industrial sector in 1991 was 8.8¢/kWh in Germany compared with 4.9¢/kWh in the United States.[49] This allows RETs to be fully competitive at a somewhat earlier point in their development path.

To preserve competition within the European Union, implementation of a carbon tax is contingent on the introduction of similar tax measures by other OECD member countries.[50] Oil export-

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[45] U.S. International Trade Commission, *The Effects of Greater Economic Integration Within the European Community on the United States,* USITC Publication 2204 (Washington DC: July 1989).

[46] U.S. International Trade Commission, *The Effects of Greater Economic Integration Within the United States: Second Follow-up Report,* USITC Publication 2318 (Washington DC: September 1990); U.S. International Trade Commission, *The Effects of Greater Economic Integration Within the European Community on the United States: Fifth Follow-Up Report,* USITC Publication 2628 (Washington DC: April 1993).

[47] Palz, op. cit., footnote 42.

[48] M.S. Imamura et al., *Photovoltaic System Technology: A European Handbook* (Brussels, Belgium: Commission of the European Communities, 1992).

[49] U.S. Congress, Office of Technology Assessment, *Industrial Energy Efficiency, OTA-E-560* (Washington, DC: U.S. Government Printing Office, August 1993).

[50] "Renewables Could Benefit from EC Tax on CO_2 Output," op. cit., footnote 44.

ers to the EU have threatened retaliatory trade action if the community pushes ahead with this proposal.[51]

DENMARK[52]

In 1973, Denmark was 99-percent dependent on imported energy supplies, mainly oil. As a result of new energy policies, Denmark's annual gross energy consumption is lower now than in 1972, and its dependence on imported oil is less than 50 percent of the energy supply.[53] The Energy 2000: Plan of Action for Sustainable Development now serves as the foundation of Denmark's energy policy.[54] Its goal is to reduce energy use and atmospheric emissions by 2005 by reducing energy consumption by 15 percent, $C0_2$ emissions by at least 20 percent, sulfur dioxide ($S0_2$) emissions by 60 percent, and nitrogen oxide (NO_x) emissions by 50 percent. Use of renewable energy is expected to double. As part of this goal, the government has committed to further promotion of wind power. The plan estimates an installed capacity of 1,500 MW in 2005, corresponding to 10 percent of the expected electricity consumption .55

Installed wind power capacity in Denmark is currently between 670 and 730 MW; wind power supplies approximately 2.3 to 2.6 percent of its total electricity.[56] Wind energy development ‘n Denmark has followed two paths: the development of small wind turbines through private initiatives on an individual or collective basis, and the development of large wind turbines and windfarms by Danish utilities.[57] PV is not a major focus of the Danish renewable energy program.

The Danish wind energy program was initiated in 1977. Government support for R&D has been limited. The RD&D program is funded by both the Ministry of Energy at $1.6 million/year and the Ministry of Industry at $2.4 million/year. Most of the support has gone to the Riso Test Station, with a small portion allocated to universities and miscellaneous RD&D projects. The overall Danish wind program during the 1980s cost about $95 million.[58] The Danish government has opted to pursue direct market stimulation in the form of subsidies rather than implement an extensive R&D program.

The private sector has contributed significantly to the development of wind technology, and rough estimates suggest that total private contributions toward wind development are of the same order of magnitude as government programs .59 Additional support is provided by the utilities.[60] In December 1985, Danish utilities entered an agreement with the government to develop 100 MW of wind power capacity by the end of 1990; the 100-MW goal

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51 "European Official Raps U.S. Stance on Carbon Dioxide," W/rid *Energy Weekly, vol. 11, No. 493,* Apr. 13, 1992, p. 4.

52 This section is primarily drawn from Kennedy and Egan, op. cit., footnote 10.

53 Finn Godtfredsen, "Wind Energy Planning in Denmark, " paper presented at the European Wind Energy Association (EWEA) Special Topic Conference on [he Potential of Wind Farms in Denmark, Denmark, Sept. 8-11, 1992.

54 Danish Ministry of Energy, "Energy 2000--A Plan of Action for Sustainable Development," April 1990; and ibid.

55 Jens Kr. Vesterdal, "Experience with Windfarms in Denmark," paper presented at the EWEA Special Topic Conference on the Potential of Wind Farms in Denmark, Denmark, Sept. 8-11, 1992.

56 Birger T, Madsen, "The Danish Wind power Industry, " paper presented at the Wind Power 199 l Conference, 1991, p. 82; Godtfredsen, op. cit., footnote 53; and ibid.

57 Vilhem Morup-Pedersen and Soren Pedersen, "Windfarm Projects Joint Ventures Between a Danish Utility and Private Cooperatives," paper presented at the EWEA Special Topic Conference on the Potential of Wind Farms in Denmark, Denmark, 1992.

58 "Renewable Energy is Key Part of Global policy, Danes Say," *Wind Energy Weekly, vol. I* 1, No. 480, Jan. 13, 1992, pp. 3-4.

59 Danish Ministry of Energy *Wind Energy in Denmark: Research and Technological Development* (Copenhagen, Denmark: 1990).

60 Ibid.; Danish Ministry of Energy, "Development of Wind Energy in Denmark," paper presented at the World Renewable Energy Congress 11, Reading, England, Sept. 13-18, 1992.

was achieved by the end of 1992.[61] In March 1990, the Danish Parliament asked the utilities to develop an additional 100 MW of installed capacity by the end of 1993.

Until the end of 1990, Danish utilities bore 30 percent of the cost of grid connection for private wind turbines with a ceiling of $54.50/kW installed.[62] A new approach requires that the sometimes substantial costs of reinforcing the grid due to connection of new windmills be paid by the electric utility companies, while the cost of connecting to the grid be covered by the wind powerplant owner.[63] This has been controversial. For a time it appeared that the utilities would be successful in shifting more of the cost of grid connection back onto wind turbine owners, and requiring them to pay 65 percent of the costs of strengthening the grid, if necessary. It appears that the owners' association has prevailed in this battle since reports indicate that the cost of grid connection has been made the responsibility of the utilities.[64]

Danish wind energy incentives were introduced approximately 10 years ago. Initially each wind turbine erected by private companies received a government payment of 30 percent of capital costs. This subsidy was reduced gradually as the costs of wind energy declined, and it was discontinued in 1989. Under this payment program, approximately 2,500 wind turbines with a total capacity of 205 MW were installed.[65] In late 1992, a new subsidy program to stimulate investment in wind power was initiated. The program guarantees private turbine owners a buyback rate equivalent to 85 percent of the pre-tax price at which local electricity companies sell power to customers, and it obligates utilities to purchase the power.[66] The wind power purchase price 'ill average 6¢/kWh.[67]

Denmark has an energy tax levied at 4.9¢/kWh. Until May 1992, this tax was refunded to renewable energy power producers in the private sector at a level of 4¢/kWh. The tax relief was structured so as to reflect avoided costs.[68] The value of the electricity tax was added to the payment that owners of wind turbines received for supplying wind-generated electricity to the grid.[69] Electricity produced by wind turbines owned by electric utilities was not exempted from taxation.

A private individual or group of individuals pays taxes only on income from the sale of those wind power kilowatt-hours generated in excess of domestic consumption of electricity with a 10-percent margin.[70] Private turbines receive a grant amounting to 4.3¢/kWh as part of a CO_2 tax package, replacing the refund of a standard electricity tax described above. According to a press release of the EC, the combined guaranteed buyback rate and the grant "will give windmill operators an average subsidy of around 55 percent of building and operating turbines." Altogether, $19.7 million was channeled to turbine operators by the program in 1992.[71]

61 International *Energy Agency, Wind Energy Annual Report* (Paris, France: 1992).

62 Andrew Garrad, European Wind Energy Association, "Time for Action: Wind Energy in Europe," October 1991.

63 European Commission, "Commission Approves Price Support for Wind Power," press release, Sept. 30, 1992.

64 "Minister Rules Against Single Turbines and for Grid connection Charges," *Wind Power Monthly, vol. 8, No. 3,* March 1992.

65 American Wind Energy Association, "European Wind Energy Incentives," Feb. 19, 1992.

66 European Commission, op. cit., footnote 63.

67 "Developers Wait Anxiously for Brussels Approval Of New Regulations," *Wind Power Monthly,* vol. *8, No. 8,* August 1992.

68 Garrad, op. cit., footnote 6*.

69 Danish Ministry of Energy, Op. Cit., footnote 54.

70 Ibid.; and Garrad, op. cit., footnote 62.

71 European Commission, op. cit., footnote 63.

Shareholders in wind plants also reclaimed the value-added tax (VAT) paid on their power of 22 to 25 percent in 1992. Private owners of turbines supplying power directly to their properties could not reclaim the VAT.[72]

In 1990, the Danish government, in cooperation with Danish wind turbine manufacturers and two Danish financing companies, created a private company called Danish Wind Turbine Guarantee to offer long-term financing of large projects using Danish wind turbines. Financing periods depend on project value and run from 8.5 to 12 years. The Danish program will guarantee repayment of loans on Danish wind turbine projects for a 2.5-percent premium added to the interest on the debt, for up to 20 percent of the financed amount. The price of the guarantee is built into the cost of the wind project. The guarantees are underwritten partially by the government and partially by the limited-risk shareholder company set up to administer them. The company's share of the capital is $6.38 million, and is supported by a guarantee of U.S. $110 million from the Danish government and income from sale of the guarantees and interest earned on investment of the shareholder capital.[73]

This loan guarantee program significantly reduces the risk in selecting Danish units for a wind plant. If the units should become uneconomical to operate in the future, a company could shed the added debt service burden. It is an attractive tool to boost export sales and has been used by the American company Zond on a recently completed project in California.[74] This financing is not available within the EU, however, due to the EU decision that it was a form of unfair competition.[75]

In the early 1980s. wind turbine sales were based primarily on a subsidized home market. During this time, the Danish wind industry was characterized by more than 20 small companies producing 55-kW wind turbines. As of 1989, there were six significant manufacturers of wind turbines (see table 7-5). In the mid-1980s, exports became important. Danish wind turbines have been installed in 30 countries around the world. The market distribution of Danish wind turbine exports in 1990 was California, 64 percent; Germany, 19 percent; Spain, 5 percent; India, 4 percent; Netherlands, 3 percent; Sweden, 2 percent; and others, 3 percent.[76] By the end of 1991> 'ore than 8,300 Danish wind turbines with a total capacity of approximately 840 MW had been installed abroad.[77] Development assistance for wind energy projects, usually tied to Danish equipment, has been offered by DAN IDA (Danish International Development Agency) to various developing countries including India, Egypt, China, and Somalia.

FRANCE[78]

RD&D in renewable energy is the responsibility of the Agency for Energy and Environment Management (ADEME), which funds and coordinates R&D with programs undertaken by industrial partners and other public organizations. For example, in collaboration with the state-owned utility, Electricity de France (EdF), ADEME is sponsoring a program for 20 isolated homes to generate electricity from photovoltaic panels and/or wind turbines. The FY 1993 renewable energy

72 "Danes Use Carbon Tax To Pay for Wind," *Wind Power Monthly*, vol. 8, No. 6, June 1992.

73 Madsen, op. cit., footnote 56.

74 Ibid.

75 See ibid; and "If You Can't Beat Them Join Them," *Wind Power Monthly*, vol. 8, No. 1, January 1992.

76 Madsen, op. cit., footnote 56: Danish Ministry of Energy, Op. cit., footnote 59.

77 Godtfredsen, op. cit., footnote 53.

78 This section is primarily drawn from Kennedy and Egan, op. cit., footnote 10.

TABLE 7-5: Principal Manufacturers of Grid-Connected Wind Turbines

Manufacturer	Country	Turbines produced through end of 1989
US Windpower	United States	**3,500**
Mitsubishi	Japan	**500**
Vestas/DWT	Denmark	**2,800**
Micon	Denmark	**1,600**
Bonus	Denmark	**1,250**
Nordtank	Denmark	**1,100**
Danwin	Denmark	**300**
Windworld	Denmark	**102**
HMZ/Windmaster	Belgium/NL	**269**
Nedwind-Bouma	Netherlands	**58**
Nedwind-Newinco	Netherlands	**68**
Lagerwey	Netherlands	**125**
Holec	Netherlands	**19**
MAN	Germany	**321**
Enercon	Germany	**35**
MBB	Germany	**29**
Elektromat	Germany	**15**
HSW	Germany	**9**
WEG	United Kingdom	**27**
WEST	Italy	**35** (end of 1991)
Riva Calzoni	Italy	50 (end of 1991)
Ecotecnia	Spare	NA
Voest	Austria	NA

NA = not available

SOURCE A J M van Wik et al , *W/rid Energy Status, Constraits and Opportunities (L0ndon,England* World Energy Council, Study Group on Wind Energy, July 1992), sitxth draft

budget was $18.7 million, a 15-percent increase over the 1992 level of funding.

In France, PV is considered among the more promising of the renewable energy alternatives for rural electrification and remote offgrid applications. The year 1991 was a turning point for the French photovoltaic R&D program with the start of "PV20," a new R&D program that has the following goals for the year 2000: a 20-percent conversion efficiency for crystalline silicon solar cells; $3.50/W (20 francs) as the installed price of a 100-kW grid-connected plant that is assembled and installed by the utility; a system lifetime of 20 years given basic maintenance; and 20 MW per year manufactured in France. Under the framework of PV20, an R&D program was initiated for the 1992-96 period.

France has some excellent wind resources, but its program is small. France expected to reach 5 MW of wind generation capacity by the end of 1993 and 12 MW by the end of 1994, and has set a target of 500 MW by the year 2005.[79] France has approved construction of the country's first commercial wind powerplant. Electricity de France has agreed to buy wind-generated electricity from

[79] Paul Gipe, "The Race for Wind," *Independent Energy*, July/August 1993, pp. 60-66

independently owned turbines. EdF will now pay an average of 6¢/kWh. EdF will also assist ADEME in mapping the country's wind resource as well as identifying sites for future plants.

GERMANY[80]

Germany spends more on renewable energy than any other country in Europe. In 1992, its federal budget for renewable energy was approximately $216 million; this does not i include spending by the states, which is substantial for some technologies such as wind energy, The national renewable program is focused on solar, wind, and biomass energy technologies, with a strong bias toward PV. In 1992, the government spent $65.4 million on RD&D in PVs[81] compared with $17.6 million on wind. The government program is supplemented by substantial state (up to 30 percent of a project's total cost in Bavaria[82]) and utility support, as well as other financial support. This financial support includes credits/loans through the Energy Savings Program and the Credit Program To Promote Community Investment: and the "Law on Supplying Electricity to the Public from Renewable Energy Sources," which requires public purchase and compensation for electricity generated by small wind or solar systems at a rate of at least 90 percent of the consumer price.[83]

The Law on Supplying Electricity has had the effect of raising the national tariff for wind and PV paid by the utilities, from 7¢~ to 11 ¢kWh.[84] Compensation at these rates is not required if it can be proven to cause ".. . undue hardship or prevent the electric companies from meeting their federally mandated obligations. Undue hardship exists if the electric company must raise its prices significantly above the market rate."[85]

In November 1990, the federal government established a goal of decreasing CO_2 emissions by 25 to 30 percent from the 1987 level by the year 2000, which couId stimulate the use of renewables.[86] A proposal has been introduced to initiate a CO_2 tax on conventional energy sources; this has been postponed pending development of related initiatives by the EU.[87]

The German PV program is strongly R&D-oriented but has begun to focus more on demonstration projects, which increased from 5 percent of the PV budget in 1989 to 16 percent in 1991. The " 1,000 Roof' program, initiated in 1990, is a demonstration project that is expected to result in 2,250 systems of 1 to 5 kW capacity on roofs of

80 This section is drawn primarily from Kennedy and Egan, op. cit., footnote 10.

81 A. Rauber and K. Wollin, "Photovoltaic R&D in the Federal Republic of Germany," paper presented at the 6th International Photovoltaic Science and Engineering Conference. New Delhi, India, Feb. 10- 12, 1992, p. 529.

82 "Bavaria Takes Up the Challenge," W/rid *Power Monthly*, vol. 8, No. 7, July 1992.

83 Compensation for hydropower, municipal solid waste, and agricultural and forestry residues must be at least 75 percent of the average rate per kilowatt-hour paid by consumers.

84 German Federal Ministry of Research and Technology, "Law on Supplying Electricity to the Public from Renewable Energy Sources (Electricity Supply Law)," translation in summary of German Government Document No. 66090, Oct. 5, 1990; American Wind Energy Association, op. cit., footnote 65; and P. Mann et al., "The 250 MW Wind Energy Program in Germany," paper presented at the Wind Energy Technology and Implementation European Wind Energy Conference, Amsterdam, The Netherlands, 1991.

85 German Federal Ministry of Research and Technology, op. cit., footnote 84.

86 The citizens group Germanwatch (established to monitor German\'s action on environment and development issues) released a study on April 7, 1992. that stated that the country would fall short of stated goals for reduction of CO_2 emissions and predicting that Germany will achieve CO_2 emission cuts of only 10 percent by the year 2005. See "Germany Won't Achieve Goal Environmental Group Says," *Wind Energy Weekly*, vol. 1 I. No. 494, Apr. 20, 1992, pp. 5-6.

X7 Armin Rauber, Fraunhofer Institute of Solar Energy, personal communication to Ted Kennedy and Christine Egan, Aug. 18, 1992.

private homes. Participants receive a direct federal subsidy of 50 percent in the western states and 60 percent in the new eastern states. Approximately 20 percent of the cost of the system is subsidized by state govemments.[88] A limit has been set to a total subsidy of 70 percent of the system cost. This grid-connected application also allows owners to sell unused power to the utility at 12¢/kWh. The program is accompanied by a comprehensive measurement and evaluation program. The budget for the "1,000 Roof' program from 1990 to 1995 is approximately $55 million. This figure is incorporated in the Federal Ministry of Research and Technology (BMFT) annual budget figures. As of January 31, 1992, this program was opened to non-German manufacturers within the EU with the appropriate business permits.[89] Interest in the program was very high, but reportedly moderated in 1993.

The development of wind power has been supported by BMFT since 1975 through cost-shared wind-related RD&D. Germany has a national goal of 1,000 MW of installed wind power capacity by 2000. The installed wind power capacity at the end of 1991 was 110 MW, which had increased to 333 MW by January 1994.[90] BMFT provides approximately 50 percent of the total cost of all wind-related RD&D projects, with additional funding provided by the states and the EU.[91] These figures exclude the 250-MW demonstration program, which was reportedly allocated a total budget of$215 million.[92] Wind also receives a 10¢/kWh incentive for grid-connected machines and additional subsidies from several states. Other initiatives are expected.[93]

Under the "250-MW" demonstration program, wind installations are subsidized either through a price incentive of 3.7@ to 5¢/kWh[94] or a one-time capital investment grant of up to 60 percent of the facility cost.[95] By May 1991, more than 2,300 applications for 4,200 systems with a total capacity of 520 MW had been submitted.[9G] By the end of July 1992, 545 turbines representing an installed capacity of 89 MW were operating under the government program. Some 690 turbines had been installed as of December 1992 under the program, with a capacity of approximately 110 MW.[97] As of March 1993, expenditures for the 250-MW program totaled $24.6 million.[98]

Special low-rate bank loans from two central pools contribute significantly to wind power's fi-

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88German Federal Ministry for Research and Technology, "Extension of Deadline for Applicants from the New German States for the 1000-Roofs Photovoltaics Program," press release, Jan. 31, 1991; and Rauber and Wollin, op. cit., footnote 81.

89Ibid.

90 Randy Swisher, American Wind Energy Association, personal communication, May 1994.

91International Energy Agency, *Wind Energy Annual Report* (Paris, France: 1991).

92International Energy Agency, op. cit., footnote 61; "Guidelines for the Promotion of Wind Turbines Under the 250 MW Program and Within the Framework of the Third Program for Energy Research and Technology," translation in summary of the German Government document, Feb. 22, 1991.

93"New Program in the Pipeline," *Wind Power Monthly, vol. 8. No. 7,* July 1992.

94An operator of a stand-alone machine receives 5¢/kWh for power consumed by the operator, and operators of grid-connected turbines receive 3.7¢/kWh, as well as the compensation paid by the utility equal to 10¢/kWh. Payment of this incentive ceases when the sum of the avoided electricity costs, electricity sales, and public subsidies (including those of the EC) reaches double what it cost to build the wind energy facility.

95Mann et al., op. cit., footnote 84.

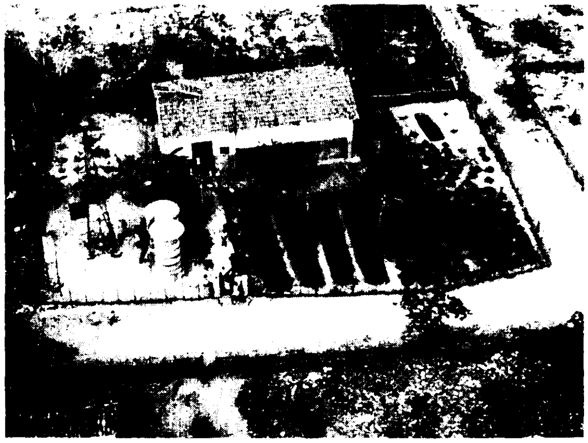
96Ibid.

97German Federal Ministry of Research and Technology, "Promotion of Wind Energy by the Federal Ministry of Research and Technology," translation in summary of the German Government document, March 1993.

98Ibid.

nancial support. Kredistanstalt fur Wiederaufbau and Deutsche Ausgleichsbank operate behind the scenes to offer credit schemes for wind power development, resulting in interest rates as low as 8 percent[99] compared with standard rates of around 15 percent (as of July 1992; assumed to be the nominal rate) or a rate subsidy of nearly half. Borrowing procedures are simple, and loans often come through faster than planning permission. The bank assumes the risk in exchange for the 1 percent interest rate it levies.[100]

International development is supported under the five-year Eldorado Program initiated in October 1991, which provides for wind and PV energy projects in developing countries through investment subsidies with a maximum of 70 percent of the equipment price. German-based manufacturers and suppliers of plants and systems are eligible.[101] The subsidies are granted directly to the manufacturer of the equipment rather than the project operator, with the hope that the manufacturer will be more likely to protect its reputation, and the reputation of the technology, by making sure the project succeeds.[102] Transportation from Germany to the site is subsidized 70 percent, and a scientific measuring and evaluation program is supported.[103] As of February 1993, six Eldorado Wind projects with a total capacity of 4.5 MW had been contracted with Chinese, Brazilian, Russian, and Egyptian counterparts and one Eldorado Sun project was supported in the Peoples Republic of China, including four PV pump systems of 4.8 kW, four battery chargers without inverters (1.1 kW), and 16 battery chargers with inverters (43.8 kW)



NATIONAL RENEWABLE ENERGY LABORATORY

In the state of Ceara in northeast Brazil, the village of Cardeiros has been the site of early PV deployments. The photo shows the village school with individual PV power systems for lighting and TV, refrigeration, street lighting, and water pumping.

ITALY[104]

In 1988, all the existing nuclear powerplants in Italy were shut down and all plans for the construction of new nuclear facilities were halted.[105] Renewable energy is viewed as the most plausible option for decreasing dependence on imported fossil fuels and protecting the environment. The Italian National Energy Strategy (PEN) sets national goals for the installed capacity of renewable energy. For PVs, goals of 25-MW installed capacity by 1995 and 50- to 75-MW

99 Rates are typically 7 to 7.5 percent, with a 1-percent loan origination fee.

100 "Financial Packaging," *Wind Power Monthly, vol.* 8, *No. 7,* July 1992.

101 German Federal Ministry of Research and Technology, "Guideline for the Promotion of Piloting Wind Power Plants Under Various Climactic Conditions, " translation in summary of the German Government document, Oct. 23, 1991.

102 "Seeking New Horizons," *Windpower Monthly*, vol. 8, No. i, January 1992.

103 German Federal Ministry of Research and Technology, "The Eldorado Test and Demonstration of Wind and Photovoltaic Systems Under Different Climactic Condition\," n.d.; "Staying Power Needed To Reach El Dorado," *Wind Power Monthly*, vol. 8, No. 9, September 1992; and "German Wind Power in Brazil," *Solar Energy Intelligence Report, vol. 19, No.* 3, February 1993.

104 This section is drawn primarily from Kennedy and Egan, op. cit., footnote 10.

105 The moratorium ended in December 1992, but it is unclear whether the industry will be revived. Branstetter, op. cit., footnote 28.

installed capacity by 2000 have been outlined. When the goals were established in 1991, the installed capacity was 3 MW. For wind power, PEN has established a target of 300 to 600 MW by the year 2000,[106] with an interim goal of 60 MW of installed capacity by 1995. [107] In December 1992, Italy's wind generating capacity was approximately 6 MW, another 14 MW were under construction, and nearly 20 MW were expected to be in operation by the end of 1993. [108]

The Italian renewable energy program is a joint effort of the Agency for Research and Development on Nuclear and Alternative Energies (ENEA) and the National Electricity Board (ENEL). In 1989, ENEL launched a demonstration program including two major initiatives: testing of Italian turbines and foreign turbines side by side in a marine environment at the Alta Nurra test site and in mountainous terrain at the Acqua Spruzza test site; and development of two full-scale windfarms (each equipped with 40 machines supplied by Italian manufacturers), one in Monte Arci in Sardinia and another at Acqua Spruzza. ENEA carries out the bulk of the PV R&D activities, with a focus on research into innovative materials and devices. ENEL works with ENEA on systems development and demonstration programs.

RD&D initiatives are supplemented by Law No. 10 passed on January 9, 1991, which determined the use of renewable energy to be in the "public interest" and provides for grants to public authorities, private companies, and state organizations. For wind turbines or windfarms with a capacity of 3 MW, investment subsidies of up to 30 percent of the capital expenditure are available. For PVs, subsidies of up to 80 percent of the capital expenditure are available for isolated houses. Demonstration plants in both technologies are eligible for a 50-percent subsidy. [109] A similar subsidy, limited to rural residences inhabited by those engaged in agriculture, was contained in a previous law instituted in 1982. Significant results came of this support, including the electrification of 4,100 rural dwellings and a total installed capacity of 1,850 kW of PV systems.

In June 1992, the Interministerial Committee on Prices passed a new law on the price paid by ENEL for electricity produced by renewable energy. New PV equipment can now receive 20@ to 28¢/kWh, and new wind equipment can receive 14@ to 17¢/kWh. Payment is determined by whether the power is dedicated to the grid or whether only excess capacity is provided, and is adjusted further for peak or offpeak production and capacity factors.

NETHERLANDS[110]

The wind energy program in the Netherlands includes RD&D supported by the Ministry of Economic Affairs through the Netherlands Agency for Energy and the Environment. It also includes direct funding of research institutions such as the Netherlands Energy Research Foundation.

The Integral Wind Energy Plan (IPW), which was in existence from 1986 to 1990, was the first government program to engage in direct market stimulation in the form of capital cost incentives based on installed kilowatts. In 1989, the investment subsidy was between 37 and 45 percent of the project cost, with a maximum of $600 to $740/kW installed. In 1990, the subsidy was reduced to 35 to 40 percent, with a maximum of $545 to $600/kW. In both cases, the percentage depended on the nonprofit or for-profit status of

[106] American Wind Energy Association, op. cit., footnote 65.

[107] "Italian Federal Wind Program Begins To Gather Momentum," *Wind Energy Weekly,* vol. 11, *No.* 525, Dec. 7, 1992, pp. 2-4.

[108] Ibid.

[109] G. Ambrosini et a]., "Programs for Wind Energy Exploitation in Italy: A Progress Report," paper presented at the Windpower 1991 Conference, Palm Springs, CA, Sept. 24-27, 1991; "Renewable Energy Incentive Gets Approval," *Wind Directions,* winter 1991.

[110] This section is drawn primarily from Kennedy and Egan, op. cit., footnote 10.

the company. An environmental/low-noise-pollution subsidy was offered in the amount of $55/kW installed in 1989 and $27/kW installed in 1990. In 1990,$25 million was available through the IPW program.[111] A total of 127 MW of wind power capacity was installed under this program: 58 percent by utilities, 24 percent in commercial applications (including farming), 14 percent by private investors, and 4 percent by family cooperatives.[112] Total wind capacity in 1992 was expected to be 130 MW.

In January 1991, the Application of Wind Energy in the Netherlands (TWIN) program was initiated. TWIN is based on the official government position developed in the Energy Conservation Policy Paper and the National Environmental Policy Plan, which together set ambitious goals for energy conservation and supply diversification. These include the development of 1,000 MW of wind power by the year 2000, with $300 million allocated to the first 400 MW, to be followed by additional support for the remaining 600 MW. A goal of 2,000 MW of installed wind power capacity by 2010 is outlined. Most of the funds for wind power development are provided by the Ministry of Economic Affairs ($22.29 million in 1992), and the Ministry of Housing, Physical Planning and the Environment ($820,000 in 1992).

Technological development is conducted under TWIN to ensure continuing product development, with a goal of a 30-percent improvement in the price performance ratio and an electricity cost of 14¢/kWh. Wind turbine owners in the TWIN program receive a capital cost subsidy of up to 40 percent as determined by the rotor swept area. A bonus payment from the Environment Ministry is offered for low-noise wind turbines[113] and for turbines sited in specially approved, less environmentally sensitive areas. Additionally, 50 percent of the cost of feasibility y studies can be covered, up to $31,250. Information dissemination, outreach/ education, assessment of the existing program against international and market developments, and promotion of international cooperation are also conducted under TWIN.

The utility sector has developed an Environmental Action Plan to install 250 MW of wind power in the Netherlands in 1991-95. The eight power distribution companies combined to form an organization called the Windplan Foundation with plans to construct most of the 1,000-MW goal of the TWIN program. The objectives of Windplan are the coordination of a combined investment program of 250 MW of windfarms within the next five years, coordination of a purchasing program for wind turbines, and support of the development of wind turbine technology.[114] In addition, the utilities pay tariffs to turbine owners ranging approximately from 6.8@ to 10.6¢/kWh depending on the province.[115]

The power distribution company for the Netherlands provinces of Gelderland and Flevoland, PGEM, has more than doubled the tariff it pays for wind power to private owners of turbines up to 3 MW. Beginning in 1993 for a period of 10 years the utility will pay new installations 8.8¢/kWh. The new policy of PGEM apparently offers support to the Association of Private Wind Turbine Owners (PAWEX). PAWEX is in the midst of a drawn-out conflict with the Association of Distribution Companies (VEEN) over the tariffs paid for wind power in the Netherlands. VEEN claims that 3.5@ to 3.7¢/kWh, the equivalent of the cost of fuel saved by the use of wind power, is a fair rate.

[111] Joe Beurskens, "Wind Energy in the Netherlands," compiled for the 1990 Annual Report of the International Energy Agency, Large-Scale Wind Energy Conversion Systems Executive Committee, 1990.

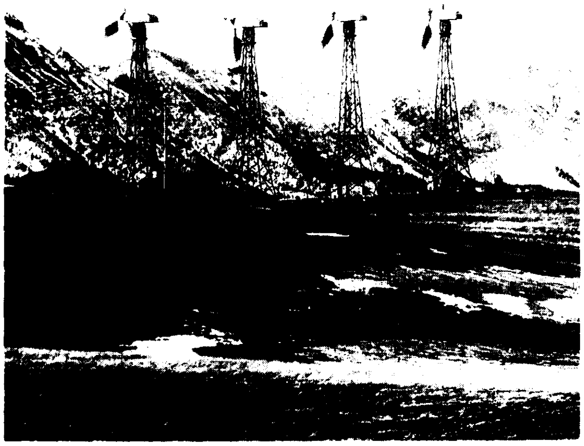
[112] American Wind Energy Association, op. cit., footnote 65.

[113] "Private Developers Granted Larger Share of Subsidy Cake," *Wind Power Monthly, vol. 8, No. 2,* February 1992.

[114] OTA has received word that the Windplan program had been substantially cut back, but details are not available.

[115] "One Thousand Extra Turbines in Four Years," *Wind Directions*, winter 1991.

KENETECH WINDPOWER INC



Kenetech Windpower, Inc., 33M-VS wind turbines on Cowley Ridge in Alberta, Canada.

PAWEX wants the utilities to also pay for the avoided cost of environmental damage and claims that a tariff of 10.6¢/kWh would be more reasonable. The conflict is now in arbitration. Until December 1991, PGEM followed the VEEN guidelines, but it has changed its policy to "express its appreciation for the environmental advantages of wind power." Members of VEEN in Friesland and PEN in Noors pay 6¢ and 8¢/kWh, respectively.[116]

An estimated 25 MW will also be installed by private investors in 1991-95.[117] Opportunities for wind turbine installation by private individuals were significantly improved in 1992, following changes in the regulations governing wind power subsidies.

Of the 250 MW of wind capacity Windplan intends to install, it invited non-Dutch manufacturers to bid for only 80 MW, providing Dutch companies a significant advantage. It is not clear how this action—with more than 2,600 turbines installed in the Netherlands, none imported as of 1991—fits within the framework of EU regulations.[118]

Kenetech-U.S. Wind Power, a privately held American company, has signed a contract to build and operate 25 MW of wind energy turbines for a utility in the Netherlands. U.S. Wind Power will finance, install, and operate the turbines and, under a power purchase agreement, will sell its output of 60 million kWh of electricity a year to NV Energiebedrijf, which serves the provinces of Gronigen and Drenthe. The machines are scheduled to be online by the end of 1994. Actual construction may be performed by a Dutch company rather than Kenetech's construction subsidiary, but no transfer of technology is presently planned.[119]

SWITZERLAND[120]

In September 1990, Switzerland's citizens voted for a three-pronged energy policy: a moratorium was declared on the construction of new nuclear plants for 10 years; existing nuclear plants were to continue to operate; and the Federal Ministry of Energy and the states (cantons) were given a mandate to pursue a more intensive energy policy promoting conservation and renewable. As a result, an action plan, "Energy 2000," was initiated. As of early 1993, funds had not been allocated specifically to the Energy 2000 program, and it is not yet clear what initiatives will be developed for PV or

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116 "Utility Doubles Rate of Pay," *Wind Power Monthly*, vol. 8, No, 1, February 1992.

117 E Luke and R. de Bruijne, Netherlands Agency for Energy and the Environment, "The Netherlands Wind Energy Stimulation Program: The Success of a Continuous Effort," paper presented at the Wind Energy Technology and Implementation European Wind Energy Conference, Amsterdam, 1991.

118 "One Thousand Extra Turbines in Four Years," op. cit., footnote 115.

119 "USW T. Supply Windpower to Netherlands Utility," *Solar Energy Intelligence Report*, vol. 18, No. 14, July 13, 1992.

120 This section is drawn primarily from Kennedy and Egan, op. cit., footnote 10.

wind power. The budget will be allocated annually by Parliament, and the necessary funding is estimated to be approximately $777 million. This is expected to be covered by the federal government in the form of incentives, as well as by the private owner. Subsidies of 30 to 50 percent of the capital cost of systems would appear to be necessary.

Switzerland stated goal is for renewable energy to provide 3 percent of the thermal energy and 0.5 percent of the electric energy the country needs by the year 2000. A complementary goal of 50 MW of installed PV capacity by the year 2000 has also been set. Photovoltaic R&D expenditures have risen from $5.2 million in 1990 to $8.64 million in 1992, but were expected to decrease to $5.05 million in 1993.

As a result of the energy utilization resolution passed by the Swiss Parliament in December 1990, public power companies are obliged to purchase the electrical energy produced by independent power producers using PV, wind, cogeneration. and micro-hydroelectric power stations and to reimburse them at an "appropriate rate. " For renewable energy power generation, the purchase price is based on the marginal cost of new domestic installations. Remuneration of between 21@ and 29¢/kWh "is possible. ''121 Scattered canton support in the form of attractive buyback rates and installation incentives has been reported, although there does not appear to be a uniform policy,

The government parties have reached a verbal agreement to impose a resource or energy tax to encourage the use of renewable. However, the rapid introduction of a $C0_2$-energy tax is restricted by the need to find a consensus with the EU. Consequently, it is unlikely to be introduced soon.

A fund exists for PV installations in government-owned buildings, such as military camps, railway stations, and post oftices. Since September 1992, the Swiss government has supported PV grid-connected installations for schools with a payment of $4,000/kW.[122]

UNITED KINGDOM[123]

The British Department of Trade and Industry has a series of regional planning studies under way to assist local authorities in identifying the renewable energy potential. Although the United Kingdom is considered to have the best wind resource in Europe, relatively few wind turbines had been installed until recently. High taxation on independent power production and low buyback rates throughout the 1980s hindered large-scale wind power development.[124] The completion of England's first commercial wind powerplant, a 2-MW installation at Delabole in the southeastern county of Cornwall, brought total wind capacity in the United Kingdom to 12 MW.[125] Proposals for 16 large-scale windfarms amounting to 130 MW were granted power purchase contracts and planning permission in mid-1992.126 By the end of 1992, 30 MW of wind power capacity were expected to be in operation,[127] and an additional 100 MW were under development, to be operational in

121 T. Nordman, "Photo\ voltaics Applications in Switzerland, " paper presented at the 11 th European Photovoltaic Solar Energy Conference, Montreux, Switzerland, Oct. 16, 1992.

122 Ibid.

123 This section is primarily drawn from Kennedy and Egan, *op.* cit., footnote 10.

124 Peter Musgrove and David Lindley, "Wind Farm Developments in [he U.K.," paper presented at the European Wind Energy Conference. Amsterdam, The Netherlands\, 1991,

125 "British Renewables Budget Frozen," *Wind Power Monthly, vol. 8, No. 3,* March 1992.

126 "Great Oaks from NFFO Acorns," *Wind Power Monthly,* vol. *8,* No. *5,* May 1992.

127 Andrew Garrard of Garrad Hassan, persona] communication with Ted Kennedy and Christine Egan, Meridian Corp., 1993.

1993,[128] making the British market the largest in the world in 1992.[129]

Photovoltaic efforts have not fared as well. A budget of about $4 million is dedicated to solar energy overall, but there is no official budget for PV. In 1989-90, an assessment of the prospects for PV power generation in the United Kingdom was undertaken by the Energy Technology Support Unit (ETSU). In response to this action, a number of leading authorities on PVs have setup the British Photovoltaic Association.

In 1990, the British power industry was privatized, and the government developed the Non-Fossil Fuel Obligation (NFFO), which required the purchase of specified amounts of power from nonfossil sources. This was done in part to ensure that the industry continued to buy output from the nuclear stations (despite their higher costs compared with fossil fuels), but it has also provided an impetus to the development of some renewable energy technologies such as wind.[130] At present costs, PV projects are not considered supportable under the obligation. The additional costs incurred by the regional distribution companies to satisfy the nonfossil fuel obligation are met by a tax on the electricity supplier (which is passed on to the consumer) of 10 to 11 percent on all revenue from coal-, oil-, and gas-generated power sales.[131]

Since NFFO was introduced, three calls for proposals have been made. The first phase of project solicitations took place in 1990 and resulted in 75 contracts totaling 152 MW of installed renewable energy capacity.[132] The 1991 call resulted in 122 contracts for 472 MW. By far the largest portion of the proposals were based on waste burning to generate power. Wind projects totaling more than 400 MW were submitted, and nine projects (a total of 28.4 MW) were selected.[133] Of these, four were existing prototype projects, and the remaining five were windfarm proposals each of greater than 1 -MW rated capacity.[134] The most recent call requires the purchase of an additional 300 to 400 MW of renewable power in contracts that run 15 to 20 years.[135]

Originally, power was to be purchased at 11 ¢/kWh, but by 1991 the price for wind was 21¢/kWh.[136] After 1998, payment will fluctuate and be based on a "pool price" of approximately 4.6¢kWh. This expiration date has been reflected in the availability of financing for this truncated period. Because of the planning, permitting, and construction time of 1 ½ to 2 years, the preferred rate will be available for only 6 to 7 years, and lenders have insisted on recovering their investment during the fixed price period.[137] British wind powerplants cost $2,300/kW installed capacity to build, with power costing about 18¢/kWh, as of 1992.

Throughout the 1990s, NFFO orders are expected to total about 1,000 MW, expanded from an original obligation of 600 MW. Wind is expected

[128] "United Kingdom To Pass U.S. in the New Wind Installations," *Wind Energy Weekly,* vol. 11, No. 500, June 1, 1992, pp. 4-5.

[129] "Great Oaks from NFFO Acorns," op. cit., footnote 126.

[130] Musgrove and Lindley, op. cit., footnote 124.

[131] "United Kingdom Moving To. Slowly on Renewables Government panel Says," *Solar Letter,* vol. 3, No. 2, Jan. 22, 1993; D.I. Page and H.G. Parkinson, Energy Technology Support Unit, Harwell Laboratory, Didcot, U. K., "The Development of Wind Farms in England and Wales," n.d.

[132] Page and Parkinson, op. cit., footnote 131.

[133] Musgrove and Lindley, op. cit., footnote 124.

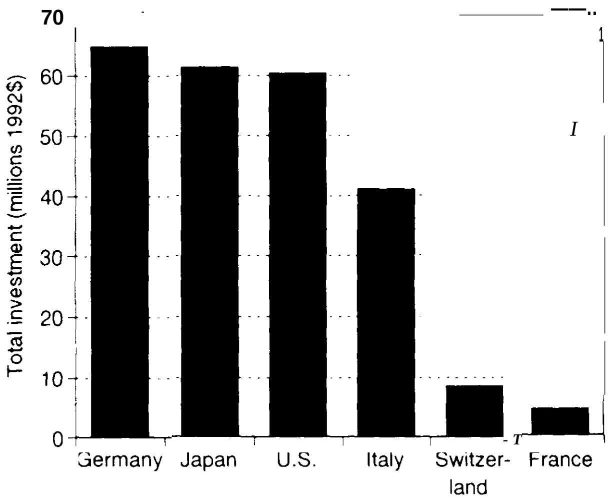
[134] Page and Parkinson, op. cit., footnote 131.

[135] Branstetter, op. cit., footnote 28.

[136] Page and Parkinson, Op. Cit., footnote 131.

[137] "UK Expected T. Expand Renewable Energy Program," *Wind Energy Weekly,* vol. 1, No. 499, May 18, 1992, p. 1.

FIGURE 7-2A: Total Federal RD&D in Photovoltaic Technologies, 1992



7otal RD&D investment m PV techno/ogles is gwen for var/ous OECD counfnes By this measure the Umted States ranked a close third m investment beh{nd Germany and Japan

SOURCE Otice of Technology Assessment, 1995 based on table 7-1

to comprise about half of this amount.[138] By Sep. (ember 1992, f"lnal permission had been acquired for 49 percent of the NFF0.1[39] Monitoring of these projects will be carried out by ETSU. A few projects will be singled out for more detailed mon - itoring by independent consultants, including two windfarrns under a three-year, $4.4-million, co-funded R&D program between National Wind Power and the Department of Trade and Industry. ""

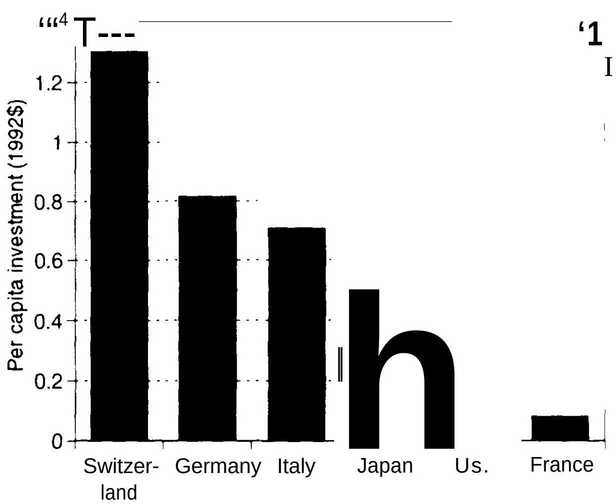
According to the American Wind Energy Association, several U,S. companies have placed bids through the NFFO program, including the Wind Harvest Company and a 4-MW project of Carter Wind Turbines. SeaWest Power Systems is the most active U.S. firm in the United Kingdom and is developing 40 MW of capacity there.

COMPARISONS

The preceding descriptions of national programs, and those of the United States as discussed in chapter 5, offer a snapshot of the wide array of supports that PV and wind technologies are receiving. It is useful here to briefly compare these supports.

Federal RD&D support for PVS is shown in total current dollars and in dollars per capita in figure 7-2. As noted in chapter 1, U.S. support for PVS has risen considerably since 1992, but that

FIGURE 7-2B: Per Capita Federal RD&D in Photovoltaic Technologies, 1992



Per capita RD&D investment In PV technologies IS gwen for various OECD counfrles By this measure, the Un/fed Slates ranks a dManf fifth behind Swli'edand, Germany /fa/y, and Japan

SOURCE Off Ice o! Tectmology Assessment 1995

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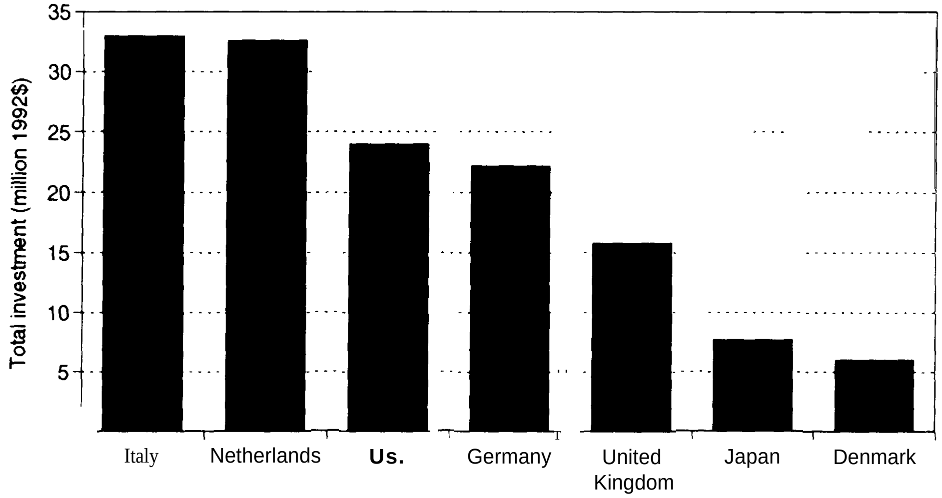
i ~x. 'P l Replrt Re~orllnlcnd~ Long-Term Market Incentl Ve$," *Wind Po\~er Monthl), vol. 8, No. 3,* March 1992.

1 l')p ~n~ parklns{>n, op. cit., footnote I ~ ~

'Ibld,

FIGURE 7-3A: Total Federal RD&D in Wind Energy Technologies, 1992



Total RD&D investment in wind energy technologies is shown for various OECD countries. By this measure, the United States ranked third in investment, well behind Italy and the Netherlands.

SOURCE: Office of Technology Assessment, 1995, based on table 7-4.

year was chosen for comparison because more recent data for several countries were not available on a consistent basis. The United States has a program roughly comparable in terms of total investment to those of Japan and Germany, and somewhat larger than that of Italy. In terms of per capita investment, however, the United States ranks far behind the leading countries.

Total and per capita federal RD&D support for wind technology is shown in figure 7-3. In terms of total investment, the United States ranks well behind Italy and Holland, and is roughly comparable to Germany. In terms of per capita investment, the United States ranks near the bottom of the list, for example, spending less than one-twentieth per capita of the amount spent by the Netherlands.

To encourage PV commercialization, the United States supports several major initiatives including the PV Manufacturing Technology Project and the PV for Utility Scale Applications, which are discussed in chapter 6. In addition, the United States provides five-year accelerated depreciation for PV systems as well as 10-percent investment tax credits for PV investments by nonutility generators. PV power must be purchased at the utility's avoided costs, but these are typically in the neighborhood of 3@ to 7¢/kWh, well below current PV costs.

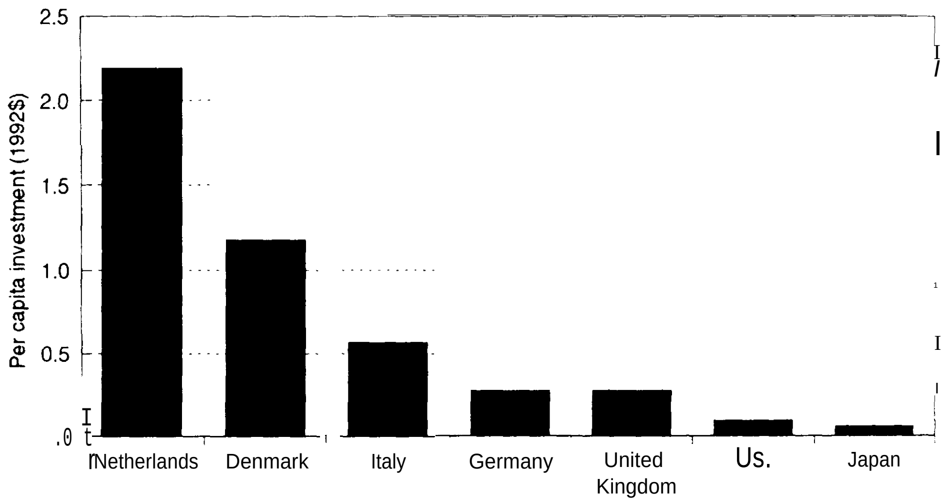
In comparison, Japan variously provides 7-percent investment tax credits, loans at interest rates of 4.55 percent, and subsidies of up to 50 percent on model plants, and it plans to subsidize up to two-thirds of the cost of residential systems. Further, the purchase price for privately generated power in Japan is 16@ to 24¢/kWh.

Germany provides 50 to 60 percent federal subsidies and roughly 20-percent state subsidies, with a limit of 70 percent, for PVs installed under its "1,000 Roof" program. Utilities purchase PV power at 12¢/kWh.

In Italy, remote houses can receive a PV subsidy of up to 80 percent of capital costs; grid-integrated PV systems receive 20@ to 28¢/kWh for power sold to the grid.

RD&D and commercialization strategies might rely on "deep-pocket" firms that can carry PV programs over the long term. ARCO and Mobil are large oil companies that were expected

FIGURE 7-3B: Per Capita Federal RD&D in Wind Energy Technologies, 1992



Per capita RD&D investment in wind energy technologies is shown for various OECD countries. By this measure, the United States ranks a distant sixth behind the Netherlands, Denmark, Italy, Germany, and the United Kingdom.

SOURCE Office of Technology Assessment 1995

to fill such a role in U.S. photovoltaic development. but both sold their PV division to German companies.

U.S. PV producers themselves, though technically strong, tend to be small firms. Other than U.S.-based production by Siemens (Germany) and Solec International (Japan), the United States has only one firm that produced 1 MW or more of PV power in 1992, compared with six Japanese firms,[141] five European firms,[142] and one firm in India.

The difficulties faced by small U.S. firms in accessing long-term financial resources are leading to arrangements with foreign producers in some cases. A recent example is the Energy Conversion Devices agreement with Canon (Japan) to build a production facility in Virginia (box 6-2).

This leads naturally to the question of the extent to which PV manufacturing might move offshore as it becomes more like a commodity production process. As discussed above. maintaining U. S.-based production of PVs will require maintaining a lead in RD&D as well as developing and investing in advanced automated production facilities.

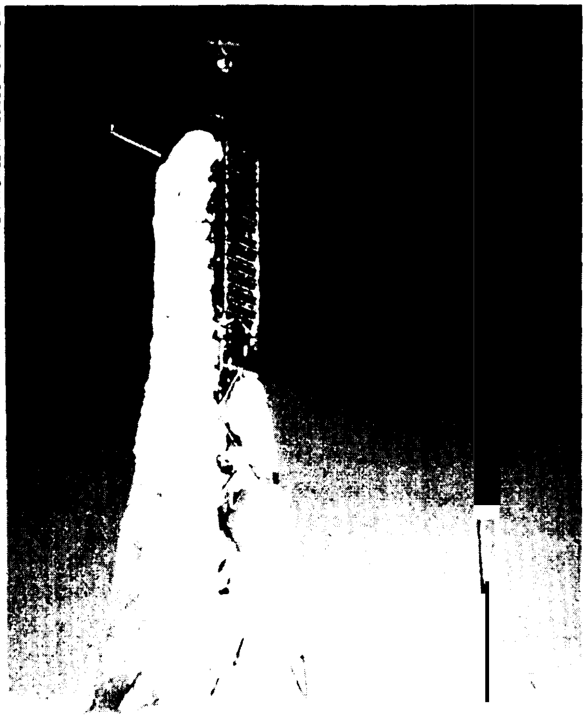
POLICY OPTIONS

Given the rapid change in technologies and government programs, more current data and anal ysis are needed for effective decisionrnaking. Thus, Congress could direct both the Departments of Energy and of Commerce to expand recent work examining competitiveness.[143] Such work migh include a more detailed examination of the sup-

[141] Not including U. S.-based production by Solec International, now owned by Sumitomo and Sanyo.

[142] Not including U.S.-based production by Siemens-Solar.

[143] Work is currently being done at Sandia National Laboratory at the request of the Office of Intelligence. Office of Foreign Intelligence, U.S. Department of Energy.



NEW WORLD WIRELESS POWER CO

Above the arctic circle on Spitsbergen Island, Norway, this

port provided by foreign governments to their industries, including RD&D, tax. financial, and export assistance. This analysis could compare the effective level of subsidy provided to different technologies and firms within each country's accounting framework. It could also examine the firm-or industry-specific impact of these supports in terms of profitability, access to capital, ability to expand and capture market share, and other measures of vitality. Such analysis would seem particularly important in terms of small entrepreneurial U.S. firms, which may have difficulty adequately accessing capital even to match cost-shared R&D programs. Finally, the effectiveness of these supports could be compared on the basis of their long-term impacts on competitiveness; particularly important may be support for early scaleup of manufacturing that captures significant economies of scale and learning.

Correspondingly, specific strengths and weaknesses of the U.S. system could be examined to determine where it might be improved with respect to the international challenge. This analysis might include an examination of:

- RD&D and commercialization to develop adomestic industry (see chapters 5 and 6);
- the effectiveness and means of improving industry consortia and public-private partnerships for RD&D and market development;
- how RD&D can support U.S. exports;
- the access of small entrepreneurial firms to capital markets; [144] and
- gaps in support for developing export markets—particularly the lack of technology-specific knowledge or support, and weak market development support (especially public-private export project finance)-on the part of trade agencies.[145]

CONCLUSION

Renewable energy technologies could become a major growth industry in the 21st century. Competition in global renewable energy markets is likely to become increasingly intense, and the winners stand to dominate a lucrative international market. Several countries are vying for the lead in the world PV and wind markets with very aggressive programs. The U.S. is still a major player in the international marketplace and, given the opportunity, U.S. firms can continue to be competitive in international markets for renewable energy technologies. This may provide substantial long-term economic and environmental benefits at home and abroad.

[144] Michael E. Porter, "Capital Disadvantage: America's Failing Capital Investment System," *Harvard Business Review*, September-October 1992, pp. 65-82.

[145] For an analysis and discussion of U.S. export programs, see the references in footnote 6.

Appendix A: Units, Scales, and Conversion Factors

A

CONVERSION FACTORS

Area

1 *square kilometer (km²) =*
0.386 square mile
247 acres
100 hectares

1 square mile=
2.59 square kilometers (km^2)
640 acres
259 hectares

| *hectare* = 2.47 acres

Length

| meter= *39.37* inches

| *kilometer=* 0.6214 miles

Weight

1 *kilogram (kg)=* 2.2046 pounds (lb)

1 *pound (16)= 0.454* kilogram (kg)

1 metric tonne (ml) (or "long ton") =
1,000 kilograms or 2,204 lbs

1 short ton = 2,000 pounds or 907 kg

Energy

1 Exajoule = 0.9478 quads

1 Gigajoule (GJ) = *0.9478* million Btu

1 MegaJoule (MJ) = 0.9478 thousand Btu

1 quad (quadrillion Btu) =
1.05x 10^{18} Joules (J)
1.05 exajoules (EJ)
4.20x 107 metric tonnes, coal
1.72x 10^8 barrels, oil
2,34x10^7 metric tonnes, oil
2.56x10^{10} cubic meters, gas
5.8x10^7 metric tonnes dry wood
2.92x 10^{11} kilowatthours

1 kilowatthour =
3410 British thermal units (Btu)
3.6x10^6 Joules (J)

1 Joule=
9.48x10-^{4} British thermal unit (Btu)
2.78x10_^{7} kilowatthours (kWh)

1 British thermal unit (Btu) =
2.93x10-^{4} kilowatthours (kWh)
1.05x 103 Joules (J)

Volume

1 l *liter (1)=*
0.264 gallons (liquid, U. S.)
6.29x 1 0-^{3} barrels (petroleum, U s.)
1x 10-^{3} cubic meters (m^3)
3.53x1 0-^{2} cubic feet (ft^3)

1 *gallon (liquid, U.S.)=*
3.78 liters (1)
2.38x 10-^{2} barrels (petroleum, U s.)
3.78x 10-^{3} cubic meter (m^3)
1.33x10_^{1} cubic feet (ft^3)

1 barrel (bbl) (petroleum, U. S.) =
1 .59x 102 liters (1)
42 gallons (liquid, U. S.)

1 *cord wood=*
128 cubic feet (ft^3) stacked wood
3.62 cubic meters (m^3) stacked wood

Temperature

From Celsius to Fahrenheit:
((9/5) x ("C))+ 32 =°F

From Fahrenheit to Celsius:
(5/9) x (°F - 32) = °C

Temperature changes:

- To convert a Celsius change to a Fahrenheit change:
  9/5 x (change in °C) = change in °F
- To convert a Fahrenheit change to a Celsius change:
  5/9 x (change in °F) = change in °C

Example: a 3.0°C rise in temperature = a 5.4 °F rise in temperature

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