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Outlook for Renewable Energy Technologies: Assessment of International Programs and Policies

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**OUTLOOK FOR RENEWABLE ENERGY TECHNOLOGIES:
ASSESSMENT OF INTERNATIONAL PROGRAMS
AND POLICIES**

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ABSTRACT

The report presents an evaluation of worldwide research efforts in three specific renewable energy technologies, with a view towards future United States (US) energy security, environmental factors, and industrial competitiveness. The overall energy technology priorities of foreign governments and industry leaders, as well as the motivating factors for these priorities, are identified and evaluated from both technological and policy perspectives. The specific technologies of interest are wind, solar thermal, and solar photovoltaics (PV). These program areas, as well as the overall energy policies of Denmark, France, Germany, Italy, the United Kingdom (UK), Japan, Russia, and the European Community as a whole are described. The present and likely future picture for worldwide technological leadership in these technologies is portrayed. The report is meant to help in forecasting challenges to US preeminence in the various technology areas, particularly over the next ten years, and to help guide US policy-makers as they try to identify specific actions which would help to retain and/or expand the US leadership position.

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EXECUTIVE SUMMARY

Significant worldwide trends influencing the future outlook for renewable energy research, development, and demonstration (RD&D) include: decentralization and privatization of electricity generation capacity; environmentally-driven movements away from nuclear and fossil fuel generation options; and, the emergence of significant energy markets in lesser developed countries (LDCs). European dependence on oil, coupled with expected growth in the transportation sector, and the need to restructure the Common Agricultural Policy of the European Community (EC), will invigorate efforts to strengthen political and economic ties to potential fossil fuel suppliers such as Russia, as well as to develop biofuels (an area not covered in this report). In the short term, Russian energy concerns will remain centered on its fossil fuel and nuclear energy sectors, however, the current crisis situation in that complex (resulting in a deteriorating infrastructure) and defense industry conversion will continue to drive a level of interest in renewables. Future leadership in basic research and development (R&D) will be required for dominance of emerging worldwide markets in some renewable technologies, particularly solar photovoltaics (PV). Japan is unlikely to achieve this dominance, given their relatively poor track record in basic R&D and a domestic environment of reduced R&D expenditures in a struggling economy.

The United States (US), although a technological leader in most renewable technologies, stands to lose out on many emerging worldwide market opportunities because of a concerted focus by US renewable energy policy-makers on domestic market development. Tied aid programs employed by many European manufacturers have also effectively shut the US out of many developing renewable energy markets around the world.

The consolidation of European energy policy is tied to EC goals of economic and technology integration. Environmental concerns and energy

supply security will remain significant drivers in EC policy for the foreseeable future, as EC member states work to develop a Single Energy Market (SEM).

Denmark's energy policies can be described as environmentally progressive, investment-oriented, and geared toward a goal of independent power production. Of the renewable energy technologies considered in this study, Denmark is most strongly positioned in wind.

The French energy picture is most strongly influenced by the dominance (and overcapacity) of its nuclear power industry, and the monopolistic position of its main national power producer and distributor. France's low level of support for renewable energy technologies reflects these factors, but remains alive primarily because of France's interest in biofuels (agricultural subsidies hold a vital position in French energy policy), and because of France's recognition of the commercial potential of renewable energy technologies in developing countries. Again, biofuels are not covered in this report.

The primary challenges facing German energy policy over the near term are the integration of the new federal states (Länder) of the former East Germany and the reconciliation of the roles that domestic coal and nuclear power will play in the country as a whole in the future. Tied to these challenges is the question of what new technologies and resources can be utilized to address these supply concerns in light of Germany's powerful environmental movement. Although budget constraints due to reunification will most likely lead to spending reductions in the near term, environmental damage in the former East Germany, coupled with Germany's import dependence, powerful domestic environmental opinion, and the potential for the development of a new, job-creating export industry will ensure its continued commitment to renewable energies.

Italy is faced with restricted options with which to devise its energy policy. Constraints include: its limited domestic sources of energy; a referendum on nuclear power generation which, although officially over, has made a revival of Italy's nuclear industry uncertain; and, public opposition to the siting of new coal-fired thermal power plants. Such constraints have led Italy to spend more for energy R&D in the past than most European countries, but the immediate future of renewable energy in Italy is being jeopardized by an ongoing governmental preoccupation with scandals, political upheaval, and fiscal austerity. Privatization of the electricity supply industry has also caused a short term disruption in support for renewables.

Energy policy objectives in the United Kingdom (UK) have focused in the near term primarily on the privatization of its national energy industries (most notably, its coal industry), diversification of supply, and most recently, the reduction in the environmental impact of its energy sector. UK renewable energy technology investments have been more along the lines of the pragmatic Danes than the export-minded Germans. In order to meet environmental commitments, Britain will be forced to impose further stringent energy efficiency measures, increase taxation on domestic fossil fuel and power, or greatly increase the use of renewables.

Japanese energy import dependence has caused security of supply and conservation to be the primary bases of Japanese energy policy. Growing international concern over the environmental damage caused by fossil fuels, however, has begun to play an increasingly pivotal role. This is especially pertinent to Japan, which would have much of its coastline inundated by the rising sea levels thought to accompany global warming. The Japanese government has taken a turn toward integrating strategy planning in the energy and environmental fields with that of economic growth, placing much more emphasis on international cooperation and technology transfer to developing countries than ever before. The US would likely benefit by partnering with Japan in one or more large scale renewable energy developments in Southeast Asia, where Japan sees a tremendous

opportunity to lead the region with green technologies.

Pertinent developments in Russia related to the breakup of the Soviet Union include: the expected near term emphasis on a revitalization of Russia's fossil fuel energy complex; political instability; a lack of capital, both domestic and foreign; defense industry conversion; expected progress toward energy efficiency; and, newly created geographic and political separation between various scientific research and development centers.

Wind, solar thermal, and solar PV technologies will play a very large role in the renewable energy contribution to large-scale electricity generation for the foreseeable future. Other renewable technologies such as geothermal, ocean, or biomass will also contribute to electricity generation, and can produce significant spinoff benefits to other industries. These other technologies are either more site-specific in nature (geothermal and ocean), however, than the three technologies studied in this report, or they are so diverse (biomass) that an adequate treatment would require more resources than were available to perform this study.

The worldwide trend toward decentralization of electrical power generating capacity favors modular applications of renewable energy technologies. For this reason, as well as others including the difficulty of achieving manufacturing economies of scale, financing difficulties, regulatory impediments, and a limited window of economic opportunity, lead the authors to conclude that proponents of large scale solar thermal central receiver technology are likely overly optimistic in their projections of commercial implementation by the year 2000. More favored in the short term is parabolic trough power generation, and in the short to medium term, parabolic dish applications, such as dishes coupled to efficient Stirling engines. In the long term, the success of solar PV technologies will depend on the expected attainment of manufacturing economies of scale in PV products. Emerging thin film technology will likely pave the way for such economies in solar PV power generation.

In the short term, no one PV program is likely to achieve the degree of dominance enjoyed by Japan for most of the 1980s. Nor is Japan likely to regain its leadership position, as future dominance depends on high quality basic research leading to commercial applications, the largest and fastest growing PV sector. Japan's traditional leadership in the PV area was built upon a foundation of niche-oriented consumer products using low-grade low-efficiency cells impractical for primary electricity generation. In recent years, intensive PV programs have provided the Europeans with the momentum to draw even with the US and Japan in PV technology quality and market share, and the potential to overtake them in market leadership as soon as 1994.

The center of gravity of world research and market development in wind energy is shifting to Europe, which is expected to possess nearly two thirds of worldwide installed wind energy generating capacity by the year 2000, a near reversal of the current situation. This shift is symptomatic of likely European strength in international wind energy markets through the year 2010.

Operating efficiency, in a battle for the lowest possible electricity generation rates, is the single most vital factor which will determine future leadership in wind energy markets. The current US lead in efficiency is the result of a substantial market dislocation caused by "feast or famine" RD&D support for the industry by

US policy-makers, in which only the strongest competitors have survived. In contrast, consistent European support for wind energy technology has given Europe the advantage of numbers when it comes to manufacturing capability, albeit with generally less efficient technology. This is especially true of Germany and Italy, whose wind energy industries have been heavily subsidized with little exposure to a truly competitive marketplace.

An early US RD&D emphasis on very large turbine development (of the multi-megawatt size) was out of sync with market demand, and has produced little domestic benefit while providing European developers valuable information as they pursue (without US competition) designs for turbines of the single megawatt range, which will be advantageous for use in offshore applications and in areas of high population density, both keys to success in the European marketplace.

The current worldwide leaders in the three technology areas considered in detail in this report are judged to be: 1) wind (US, Denmark, Germany, Italy); 2) solar thermal (US, Germany, Israel, Japan); and, 3) solar PV (US, Germany, Japan, UK). Technological leadership will not necessarily translate into future leadership in developing world markets. The current US advantage is threatened in many technology areas, and many international competitors are more adept than the US at establishing market footholds.

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CHAPTER 1: INTRODUCTION

The overall goals of this report are to evaluate worldwide energy technology policies and trends, as well as the research efforts of several leading countries in three specific renewable energy technologies. These technologies (wind, solar thermal, and solar PV) are of potential importance in future large-scale electricity generation. Issues of concern include: future United States (US) energy security; environmental factors; and, industrial competitiveness. Of interest is the identification of the energy technology priorities of foreign governments and industry leaders, as well as the motivating factors for these priorities. Also of importance is an identification of worldwide technological leadership, not only at present but the likely future picture. The report is meant to help in forecasting challenges to US preeminence in the various technology areas, particularly over the next ten years, and to help guide US policy-makers as they try to identify specific actions which would help to retain and/or expand the US leadership position.

Chapter 2 of this report is devoted to a discussion of international trends and the future outlook for the three renewable energy technologies of interest¹. Underlying factors which provide the foundation for the authors' projections are highlighted.

Chapter 3 is in many ways the heart and soul of the report. This chapter covers two very important topical areas for each of the seven study countries (Denmark, France, Germany, Italy, the United Kingdom (UK), Japan, and Russia²): 1) energy policy; and, 2) technology

program descriptions for wind, solar thermal, and solar PV. Chapter 4 provides a similar treatment for European Community (EC) renewable energy policies and programs. Both of these areas must be well understood in order to objectively evaluate future worldwide trends. The policy perspective is vital to an understanding of the driving forces behind current and expected energy technology research, development and demonstration (RD&D) decisions by the various nations (or the EC). An understanding of technology program content and level of sophistication is indispensable in predicting future market leadership, and opportunities for collaborative research. The authors recognize that not all readers will be equally interested in the policy and technology areas. Therefore, Chapters 3 and 4 are subdivided into policy and technology sections to allow selective reading.

Chapter 5 presents some thoughts about renewable energy technology areas in which international collaboration could be either beneficial to, or a detriment to, US interests, and why. These thoughts rely on the entirety of information contained within the remainder of the report, along with considerable judgement on the part of the authors. Many of the suggestions are drawn from the opinions of the numerous technical experts in the various fields who were interviewed in the course of the research.

Appendix A may be a useful place to begin reading for those basically unfamiliar with the various technology areas. An introduction to the language and terminology would be very helpful in reading the remainder of the report.

Appendix B provides funding information for six renewable energy technologies (converted to millions of US dollars) by each of the countries (except Russia) for the years 1990-1993. In addition to actual budgets, funding levels are

¹In order to provide a balanced perspective and a better understanding of available policy options, background research was also conducted for geothermal, ocean, and biomass energy technologies. References to these technologies, however, are confined to the policy-related sections of this report.

²The seven study countries were chosen by the DOE agency which funded this study. In addition, the emphasis on foreign, as opposed to US, programs in

the report is the direct result of DOE customer requirements.

given as percentages of total "New Energy" spending, and also as percentages of Gross Domestic Product (GDP). Information sources are noted. When multiple sources were available, each source has been listed, and the source chosen for use by the authors is highlighted. In some instances, funding levels are estimated. Estimation rationales are described. This appendix should be very useful in the identification of trends and funding priorities.

Appendix B also contains a table of currency conversion factors for the years 1990-1993. These factors were used throughout the report when expenditures were converted to U.S. dollar equivalents.

Hybrid wind energy systems are for the most part not covered in this report. (Hybrid systems include wind turbines used in tandem with other power generation alternatives, such as diesel fuel, for example). Both horizontal axis and vertical axis wind turbines are included in the scope.

Of the wide array of different solar thermal concepts and applications, the report focuses attention most heavily on solar thermal technologies for electric power generation (parabolic troughs, parabolic dishes, and central receivers). These are thought to most directly determine the worldwide leadership picture in the short to medium term. Activities in other areas of solar thermal technology (such as, for example, low temperature applications, solar detoxification, water desalination, and materials processing) are not covered as thoroughly, and are factored into the overall assessments not so much in light of their relative level of current technical sophistication by the various countries, but more in light of the overall scope and breadth of the countries' programs.

Solar photovoltaic (PV) information included in this report, as well as overall assessments about PV technology trends, are based on terrestrial technology only. PV technologies for use in space are not considered.

None of the opinions presented in this report are meant to be a consensus of all those who provided input. The report is an entirely *independent* evaluation which is almost

guaranteed to generate some level of disagreement and debate (this is unavoidable given the complexity of the subject area), and is not always complimentary of past program strategies or current directions.

CHAPTER 2: INTERNATIONAL TECHNOLOGY OUTLOOK

International trends, market potential, and overall outlooks are provided for each of the three renewable energy technologies of interest in this study. Emphasis is placed on explanations of underlying factors which the authors feel will determine the future picture.

2.1 WIND

Consistent governmental support, substantial incentive and subsidy programs, and effective marketing tactics should enable the Europeans to maintain a strong (if not a dominant) position in the emerging international market for wind energy through the year 2010. The Europeans have benefited from an early US emphasis on RD&D for very large machines that was out of sync with evolving markets. Now that the European market is beginning to develop in the large machine area, US industry is showing little interest.

The worldwide center of gravity for wind energy RD&D has shifted from the US to Europe. The strength of the future European position depends upon an improved level of collaboration in research and development (R&D) and market development activities among EC nations, and could be weakened by an acceleration of recent legislative and policy trends in the US, such as the enactment of a production tax credit for wind generated electricity in the US Energy Policy Act of 1992 (EPAct) [1], and in the expanded use of innovative US government-industry partnerships.

Japan is currently not technologically competitive in the wind energy field, but could become a major market player in lesser developed countries (LDCs) if wind energy technology were to be identified as a high priority by government or business. A significant Russian market in stand-alone wind turbines could be penetrated during the next decade by Western developers able to find innovative solutions to Russia's foreign currency problems.

A viable worldwide market now exists for wind generated electricity, driven by the following

factors: 1) competitive cost per kilowatt hour (kWh) at many sites [2]; 2) substantial incentives and an improving regulatory environment; 3) modularity; and, 5) environmental advantages. Worldwide sales of wind turbines and wind generated electricity will exceed \$1 billion in 1993 [3], and the market stands to grow significantly. However, compared with some other renewable energy options, a fairly short window of economic opportunity (roughly three to five decades) exists for wind technology. If potential wind markets are not developed during this time, other renewable energy sources (particularly solar PV) may become sufficiently inexpensive to displace wind as the most attractive renewable energy option at many sites.

The potential for wind generated electricity is unquestionable. According to one recent study, up to 20 percent of US electricity needs could be met by capturing the wind resources available in its most windy regions [4]. In Denmark, the government plans to increase the contribution of wind generated electricity to 10 percent of the country's needs by the end of the century [5]. The European Wind Energy Association has suggested as a goal that 10 percent of the ECs electricity needs be met by wind power by the year 2030 (based on 1990 demand) [6]. The United Kingdom's (UKs) Department of Energy has estimated that at least two thirds of its 1989 total electricity consumption could, in principle, be generated from the wind, and that three quarters of this could come from shallow, offshore locations [5]. (The UK estimate is unsuitable for actual market penetration at the current level of wind technology, since the sustained power needed in an electricity grid cannot be guaranteed if wind turbines supply more than about 15 percent of the total [7]. The potential for wind generated electricity in the UK is nevertheless impressive).

The government of India estimates a potential for 20,000 megawatts (MW) of wind energy capacity in that country [8]. It has been suggested that 100 percent of the world's electricity needs could be met by exploiting 10 percent of total world wind resources (the maximum feasible utilization taking into account technical and human constraints). This means that if only one percent of available wind resources were harnessed worldwide, then 10 percent of the world's electricity needs (1991 levels) could be met [6]. Russian researchers are even more optimistic. They claim that if only one percent of the land area suitable for wind energy development (i.e., having an average annual wind speed in excess of ten meters per second) within the territory of the former Soviet Union were utilized, then the total installed wind capacity would be commensurate with the total installed capacity of all power plants in the world today [9].

Developing worldwide markets exist for both standalone and grid-connected wind turbines. By far the largest markets (in terms of dollar return) will be in the grid-connected arena. Europe has been identified as the largest developing wind power market in the near term [4], with grid-connected systems being the most viable in that region because of the high population density and lack of potential remote application sites. According to a European Commission study, the European market for wind generated electricity could exceed 4000 MW by the year 2000 [10]. Although many US wind-power firms are establishing European offices [11], US firms have a difficult challenge in capturing an appreciable portion of that market. During 1991 and 1992, more than 90 percent of grid-connected turbines installed in Europe were made by European manufacturers [12]. A significant component of the future European wind energy market will likely be its potential for offshore applications.

Other significant grid-connected markets show promise. Following a several-year lull, the US market appears poised for a major influx of new grid-connected systems in the mid- to late-1990s. A combination of factors, including demand growth and the retirement of existing utility plants will contribute to the influx [11]. Large-scale electric utility involvement in the

actual ownership and operation of these new systems is expected due to the technological maturation of the industry, as well as environmental considerations. The expected involvement of electric utilities is a breakthrough for the wind industry, because utilities' ability to obtain lower financing rates than smaller independent developers contributes greatly to an overall 30-40 percent reduction in the real cost of producing wind power [4].

In the long term, LDCs such as India represent the largest potential market for wind energy technologies, although lack of capital in the LDCs is a significant obstacle. Market opportunities for small standalone wind turbines are vast and largely untapped, and represent an area where the US holds both a technological and market share lead. Most of these opportunities are in LDCs. Eastern Siberia is also recognized for its enormous standalone potential [13].

Consistent government support, substantial incentive and subsidy programs, and effective marketing tactics have allowed the Europeans to challenge the initial leadership position held by the US in wind energy technology. European subsidies exceed current US levels for wind technology by a factor of up to ten in absolute terms. Because of existing US advantages in certain technology areas and efficiency of design, European dominance of emerging wind markets would be seriously challenged by a "level playing field" for US companies in terms of subsidies, incentives, and marketing tactics.

European utilities have been given generous tax credits and other financial incentives for the development of wind energy technology for many years [4]. However, government assistance in some European countries has been so generous that their commercial turbine manufacturers have not had their products exposed to the demands of a truly competitive marketplace. This is true particularly for the newer or emerging European players such as Germany and Italy. As a result, commercial turbines manufactured in those countries are generally much more expensive per kilowatt (kW) of electricity produced (i.e., they are less optimized) than the best US wind turbines [14]. On the other hand, manufacturers in Denmark (and to a lesser extent in the UK and the

Netherlands) *have* had exposure to a competitive marketplace and so have better efficiencies. Superiority in operating efficiency will be of crucial importance in the determination of future worldwide leadership in the wind energy industry.

The initial US domestic wind energy market was given an enormous boost by federal and (in the case of California) state incentives such as investment tax credits, as well as by the 1978 Public Utility Regulatory Policies Act (PURPA), which required public utilities to purchase the power of independent power producers. However, under the rules, there was no economic penalty if a wind power facility, once built, failed to produce any electricity. This led to a large number of poorly conceived turbine designs being manufactured and installed quickly and in very large numbers. When the turbines proved economic failures, the reputation of wind as a viable source of alternative energy was tarnished. The investment tax credits also produced a limited partnership environment, which, because of the large number of stockholders, made the resulting companies inefficient and unmanageable in terms of day-to-day operations. This contributed to many of the ultimate failures.

In the mid-1980s, just as the industry was beginning to develop more advanced technology which would prove more economically competitive, US RD&D funding for wind was drastically cut. This resulted in a substantial dislocation of the US wind industry; only a few companies remained. The remaining US companies had the most efficient, highly developed technology best suited to the marketplace. However, the Europeans were given an opportunity to learn from US mistakes and began to equal or surpass US industry in many areas.

Recent legislative and policy trends in the US are encouraging, but must be fully funded and expanded if they are to be competitive with current European incentives for wind energy development. EPAct [1], which became law in October 1992, allows a \$0.015/kWh production tax credit (quite small by European standards) for privately-produced wind generated electricity (with some restrictions). EPAct is the

first new national program for wind energy to go into effect in fourteen years in the US [15]. Because of the intensive up-front capital costs of wind projects, the impact of the EPAct tax credit could be severely limited unless independent power producers are also granted relief from current Alternative Minimum Tax (AMT) rules [16]. The current administration has opposed this idea.

Tied bilateral aid represents the single biggest advantage that foreign competitors have over US industry in the pursuit of foreign wind energy markets. The Danes have essentially claimed the emerging market in India by providing \$50 million in attractively packaged additional funding (tied to the purchase of Danish turbines) to an 85 MW wind energy project partially funded by the United Nations' (UN) and World Bank's Global Environment Facility (GEF) [17,18]. During 1991 and 1992, *all* grid-connected turbines installed in India and Egypt (another large developing market) were produced by European manufacturers [12]. Tied bilateral aid is a direct contributor to this fact.

The US has recently begun to address the bilateral aid problem. Existing US legislation was amended by EPAct to expand commercialization opportunities for domestic wind energy producers. The US Department of Energy (DOE) will oversee joint venture projects which focus on demonstration and commercialization of renewable energy, including wind. In addition, the DOE may now enter into agreements with private lenders to pay a portion of the interest on loans for renewable projects. Thus far, funds for these programs have been authorized but not appropriated. In principle, these provisions of EPAct could begin to alleviate the tied bilateral aid problem.

An important part of the worldwide technology picture is concerned with optimum turbine size. To begin, it must be noted that there has never been a large standalone wind turbine (i.e., one having a rated power of approximately 1 MW or more) built that approaches economic viability [15]. Nor is there any guarantee that this will ever occur, although recent technological advances provide hope that viability might be achieved within a decade for machines in the single megawatt range [19]. Despite negative historical experience with large turbine

performance and cost, many national wind energy RD&D programs have devoted (and still devote) significant resources to the development and demonstration of large standalone turbines [20].

Early US multi-MW turbines were developed when the practicality of large-turbine technology, as well as its economics, was highly suspect. Now that US industry does not seem interested in developing commercial turbines even as large as the 1 MW range, further successful European development of large turbines would give them an advantage over the US in the offshore market, where increased costs for firmly anchoring turbine structures tend to make fewer, larger machines more economically attractive [21], and in the European market where limited space is a concern. Knowledge gained from the early US multi-MW experience is now available to the Europeans, who can refine the technology for application to potential markets worldwide. The current European strategy for large turbine development involves risk-reduction through the partial underwriting of development costs (in the UK and Italy), or market stimulation (in Germany, Denmark, and the UK) [7].

Early US emphasis on multi-MW technology arose partly from a perception that electric utility companies, accustomed to building power plants in the 100-1000 MW range, would never be interested in smaller turbines. It was felt that electric utilities had to take the lead if wind energy was to ever achieve a substantial position in the commercial marketplace. In addition, early DOE-sponsored studies indicated an optimum turbine size in excess of one megawatt. Multi-MW technology development was therefore encouraged, despite the fact that many of the early studies were performed by potential contractors with a bias favoring large machine development, and the existence of countering evidence that large machines were neither practical nor economical. In the end, utilities were unwilling to commit resources to such an unpromising new technology. As a result, the early worldwide market for wind energy demanded small-to-medium-sized turbines (in roughly the 50 kW to 400 kW range) which could be afforded by independent entrepreneurs. These developers received only indirect US government support in the form of

tax incentives that were in place until the mid-1980s. Benefits of the early US multi-MW approach can be argued, but the majority of experts support the view that the time and investment could have been much more profitably spent.

Pursuit of multi-MW turbine development by the EC is declining, while more promising large turbines on the order of a 1 MW capacity remain a priority. This turbine size is approaching capacities already commercially available in the private sector [15], as the marketplace is beginning to define an optimal turbine as one in the range of 500 kW to 1 MW. It may be that the Europeans have, in several of their recent programs, repeated a mistake made by the US when its own RD&D budget for wind technology was large: the development of very large (multi-MW) turbines is an appealing and glamorous way to spend available dollars, but is not necessarily the most effective path toward market success. Sweden, for example, had until very recently focused its wind program almost exclusively on the development of multi-MW turbines [15]. This focus has been loudly criticized and blamed for Sweden's lack of commercial success, as well as its lack of a well-developed domestic market. Sweden has now begun to stimulate a domestic market for smaller commercial turbines [22].

One country not explicitly included in this study, yet worth mentioning in regards to the wind energy picture, is Israel. Israel is highly motivated to develop renewable energy sources by its desire for energy security and its abundant resources in solar and wind (if the Golan Heights area is included, Israel's total wind energy potential is roughly 600 MW [23]). Israel is also concerned about its diminishing air quality. Israeli researchers have demonstrated the technical expertise and innovative thinking required for a leadership role in the technology. In addition, the Israeli government has actively supported and encouraged the use of renewables.

The Technion, Israel Institute of Technology, seems particularly innovative. Although not their original concept, the Technion is pursuing the idea of a giant downdraft wind generator known as SNAP (*sneh* aero-electric power) [24]. Other Israeli players include: Terem Advanced

Wind Technologies, a company formed recently with money from Italian investors, which has received an advance order from a German company for 40 highly efficient wind turbines worth \$1 million apiece [25]; Israeli Electric Corp. (IEC), which is planning a large wind farm on the Golan Heights, a smaller wind farm in the Galilee region, and up to ten additional stations in northern Israel [26]; and, Ormat Turbines, which has sold several million dollars worth of turbines to Mexico and Iceland [27].

2.2 SOLAR THERMAL

Solar thermal technologies with the strongest economic staying power over the very long term will be in the areas of building heat, solar hot water, materials processing, and certain other low temperature applications. A worldwide trend toward decentralization of electrical power generating capacity favors modular applications such as remote dish receivers and small parabolic trough facilities over central receiver plants. Commercialization of large-scale solar thermal electricity generation plants is also hampered by regulatory and tax barriers which favor fossil fuel generation options. Commercial central receiver plants, although technically viable by the year 2000, will likely not enjoy the commercial success touted by their supporters. In the short to medium term, it is unlikely that established suppliers and manufacturing economies of scale can be achieved for the essential components of such large plants. In the long term, even if such economies occur, trends toward decentralization and improved economies for solar PV power generation could push central receivers largely out of the worldwide marketplace.

Parabolic trough power plants are positioned to fill a worldwide niche market (particularly in developing nations such as India) for increased power generation in the short to medium term. The US, Israel, and to a lesser extent Germany are best positioned to take advantage of these opportunities. The US has the advantage of ongoing operating experience with trough plants originally built by the then-US corporation LUZ International, Ltd. (LUZ) in southern California. Israel and Germany have the advantage of active collaborative research in improved trough

technology, and seem more adept than the US at establishing footholds in foreign markets. Therefore, the US cannot claim a distinct advantage in this area. Harsh environmental conditions in India (and some other emerging market areas) may be a further advantage for troughs over more sophisticated central receiver and dish applications in these areas.

The US and Germany share leadership in parabolic dish technology, with Japan positioned for strong contributions in Stirling engine applications. The prognosis for dish applications is seen to be midway between troughs and central receivers. Dishes have the distinct advantage of modularity, which is consistent with trends toward decentralization, and fills a need for power generation in remote areas. Hybridization (i.e. the optional ability to generate electricity using fossil fuel, or a combination of fossil fuel and solar energy during non-optimal solar conditions) of dish applications reduces the advantage of thermal storage touted by proponents of central receivers. Even dish technology may be displaced by PV at many sites in the long term.

Overall, the US is positioned to be the world leader in solar thermal technology for the foreseeable future, but only slightly ahead of Germany. This prognosis is the result of a healthy level of competitiveness between US industry participants in important subareas of solar thermal R&D, as well as established cooperative working relationships between US industry and government research laboratories in this country. In lieu of a shift in focus by US policy-makers to a more global perspective, overall US leadership in the solar thermal arena is crucially dependent on successful domestic commercialization of large-scale solar thermal power generation technology. Given the inherent obstacles to such commercialization, the US might be wise to pursue a more secure track toward continued leadership by accounting more seriously for overseas market opportunities, and by developing more aggressive strategies to take advantage of them.

EC programs and policies have done less to move member nations to the forefront of solar thermal technology than in, for example, wind energy technology. However, dividends have been realized. Germany and Israel are the major

competitors to the US in solar thermal technology. Germany is the European leader, not only in the number and variety of ongoing programs, but in the quality of its research and development activities. Germany is particularly interested in the solar production of hydrogen (one of their visions is that of a hydrogen-based economy). Since the German domestic solar resource is too poor to allow the economic operation of a domestic central receiver power plant, German interest in the technology is strictly from an energy export standpoint. Therefore, as opposed to the US, the Germans are by definition concerned with tailoring technology to overseas market needs. Germany is a world leader in volumetric air central receiver technology, and is a direct competitor to the US in nearly all aspects of dish technology. Israel is well positioned in both the central receiver and parabolic trough areas, with many cooperative research programs in place with other leading nations. Israeli researchers seem to have a superior understanding of the optical characteristics of heliostats, and are quite strong in other aspects of their basic research and development. Japan is among the world leaders in Stirling engine development (though not in solarization of their engines). Japan clearly trails the US and Germany in both trough technology and central receivers. The Japanese could catch up in trough technology fairly easily because of the large amount of information available in the open literature. Little evidence is seen, however, of Japanese interest in this area. Their trailing position in central receiver technology is likely to remain, even if central receivers become a national priority.

Negative pressure from the French government and utility industry, as well as a largely unfavorable public perception of solar thermal technology, has caused France to fail to capitalize on its quick start in the area beginning in the early 1970s. Today there are dim prospects for the successful advancement of either significant research or commercialization of solar thermal technology in France. Because of their pragmatic strategies and poor domestic solar resources, Denmark and the United Kingdom (UK) are also not expected to become major players in solar thermal technology (particularly for power generation). The same is true of Russia, where many major scientific

solar thermal research centers have become geographically separated from the new Russian republic by the dissolution of the former Soviet Union, and where the major economic emphasis in the short to medium term is expected to be in the further development of the domestic fossil fuel energy complex. Italian activities in solar thermal technology are largely small scale, and Italy is not expected to assume a leadership position in the foreseeable future.

Emerging markets in developing nations will play a large role in determining future worldwide leadership in solar thermal R&D. Several countries, including Israel, are positioning themselves advantageously to pursue these opportunities.

Israel's involvement with solar thermal technology is most strongly identified by its relationship to LUZ. LUZ was founded in 1979 by two men who later emigrated to Israel, starting with US-developed technology readily accessible in the open literature. It became a US corporation based in Los Angeles, but with a subsidiary (LUZ Industries Israel, or LII) in Israel. Much of the private financing obtained by LUZ came from Jewish investors in the US who were anxious to support an Israeli enterprise. This important religious factor meant that private sector financing came more easily to LUZ than it would have come to most companies. The government of Israel also provided some financing. LUZ declared bankruptcy in November 1991, and the rights to the LUZ technology were purchased by the Belgian company Belgo Instruments, which established Soleil Solar Systems Ltd. in Israel as the successor to LUZ. Several of the original SEGS plants (the nine parabolic trough power plants built by LUZ in southern California from 1985 to 1991) are now being operated by KJC Operating Company of the US (a wholly owned subsidiary of Kramer Junction Company). Many current Israeli activities in solar thermal technology (including both advanced research and commercialization) are described later in this report.

Israel is contemplating building large process heat plants (on the order of 100 MW) in the Dead Sea area before the year 2000. These plants represent a potential market for US manufacturers needing to "ramp-up" in the

production of certain high-volume components for large central receiver power plants. Such a ramp-up is necessary in order for sustained large-scale production (i.e., manufacturing economies of scale) to become a reality.

The US Office of Solar Energy Conversion has established the following goals for total solar thermal electric generating capacity by the year 2000: 750 MW in the US; and, 500 MW overseas [28]. At present, the 355 MW total capacity of the LUZ SEGS plants in California represent roughly 95 percent of the world's solar generated electricity [29]. Parabolic trough systems are currently the only viable large-scale solar thermal technology option for electricity generation. As such, most additional capacity by the year 2000 will result from the application of trough technology. Central receiver and dish/Stirling systems should begin to be technologically viable by about the year 2000 to 2005. The proportion of solar thermal electric generating capacity provided by these technologies (particularly dish/Stirling) will increase after that time.

From a technological standpoint, commercial central receiver plants in the 100 to 200 MW range will be viable by the year 2000. According to some current studies, central receiver technology has progressed to the point where commercial plants sized in this range could supply electricity at a cost competitive with other sources, if environmental externalities are considered [30]. Optimistic proponents of the technology believe that the first commercial central receiver plants will be built within a decade in the US desert Southwest. These projections are based on recent indications of increased utility interest in central receiver technology in localized areas, and on increased awareness of and sensitivity to the environmental drawbacks of fossil fuel generation options. Increasing pressure to shut down existing nuclear plants is also a factor. For various reasons, the authors do not share this viewpoint.

For one thing, some Southwest utilities have excess capacity today, and will need no capacity additions before the year 2000. In addition, perceived economic risk is a large barrier affecting prospects for the successful commercialization of central receiver

technology. This perception will certainly be reduced with the completion and operation of Solar Two, a retrofit of the 10 MW Solar One water/steam central receiver in Barstow, California with second-generation molten salt technology incorporated into both the receiver and thermal storage systems. However, other important considerations related to commercialization involve current inequities in the tax treatment afforded solar energy facilities as compared to conventional fossil fuel facilities. The establishment of manufacturing economies of scale for certain critical components of such plants (such as cost effective reflective surface materials) is also considered unlikely, as the required sustainable markets would be substantial. Despite estimates that by the year 2000, US electric utilities will need to add 20,000 MW of new capacity nationwide [28], significant utility scale commercialization of solar energy electricity generation will likely not occur in the US before major tax law changes are enacted.

Current barriers to US domestic commercialization of large-scale solar electricity generation include [29]: 1) low fossil energy prices; 2) lack of methods for evaluating the cost of environmental externalities for various power generation options; 3) energy pricing policies which force the developers of solar thermal generating plants to bear the full risk of future energy price fluctuations; 4) plant size limitations resulting from PURPA, which prevent manufacturing economies of scale from being achieved; 5) property tax inequities, which arise from the fact that by forcing solar thermal plant operators to pay property tax on that part of their facility which collects the suns energy, they are in reality having to pay property tax on their "fuel," a burden not shared by the operators of fossil fuel plants; 6) inequities in other taxes, which arise mainly from the capital-intensive nature of solar thermal plants; 7) changes to PURPA which force solar thermal developers to enter into all-source bidding, and which alter the concept of avoided cost; 8) lack of renewable energy incentives to utilities; 9) a regulatory structure which inhibits solar investment; and 10) difficulties in obtaining insurance.

It has been estimated that between 2 and 4 QUADs (a quadrillion BTUs) of industrial

process heat energy may be displaced by solar thermal technology by the year 2030 in the US. Although this sounds like a large number, it is actually fairly small when compared to the roughly 80 QUADs consumed by all energy sectors in the US today.

Germany's Federal Ministry of Research and Technology (BMFT) commissioned a study which concluded that 16 Mediterranean countries could substitute with solar plant capacity (viable and economically) four to 15 percent of the additional oil- and gas-powered plants which should be needed in that area by the year 2005 (with the actual percentage dependent on energy policy decisions). This result meshes nicely with Germany's interest in pursuing solar thermal power generation in the region. The increased utilization of solar thermal energy for domestic consumption in Germany is, however, a long-term proposition brought about by reunification (and its associated drag on the growth of primary energy demand) and the lack of a viable domestic solar resource.

By far the largest opportunities for future expansion of solar thermal markets lie in developing nations. India represents the largest potential market in the world for solar thermal technology, driven by environmental stresses (including population growth) and India's abundant solar resource. The Indian market is attractive for both power generation (India plans to double its 70,000 MW of installed capacity by the year 2000) and low temperature solar thermal devices. The developing Indian market does possess some interesting features, which include: 1) the desire on the part of the Indian government to build future solar thermal facilities using Indian resources as much as possible (the driver here is the need to expand domestic employment); 2) harsh regional atmospheric conditions which could dictate suitable technologies; and, 3) the need for relatively inexpensive and easily repaired installations.

There is an enormous market for remote applications of low temperature solar thermal energy technology in other undeveloped areas around the world. It has been said that the three most important applications of solar energy in the Third World will be for the drying of

produce, distillation of salt water and brackish water, and cooking [31]. Water distillation will increase in importance as the world population continues to grow and supplies of potable water are depleted. Another low temperature application is in the provision of low cost, reliable refrigeration, essential for vaccine storage and food preservation. Tens of thousands of remote Mexican villages, plus innumerable others in the roughly forty similar sunbelt countries around the world, would benefit from solar refrigeration systems such as are now being marketed.

2.3 SOLAR PV

Solar PV technologies have two major advantages which position them well in the long-term renewable energy picture: 1) modularity; and, 2) diversity of applications which suit some form of PV to nearly every geographic market. Geography, climate, infrastructure, and local energy requirements dictate the role that PV will play within national energy strategies. In the long run, given continued technological progress and cost reduction, certain parts of the world will eventually be host to wide-scale production of "utility-scale" PV electricity, while other parts will most likely utilize PV more as a method of energy conservation. Either way, PV will play an integral role in national energy strategies.

In 1992, PV modules with a generation capacity of 57.9 MW and worth an estimated \$347 million dollars (based on 1990 prices) were shipped worldwide [32, 33]. This represents an increase of over 100 percent since 1986, and over 1650 percent since 1980. Module shipment trends since 1980 are illustrated in terms of Megawatts (MW) in Table 2.1. Japan has been the leading shipper since 1985. However, since 1987, the momentum in growth of shipments has been driven by Europe, which had a five-year growth rate of over 250 percent and an average annual growth rate of 29 percent. This is followed by the US, whose shipments grew over 100 percent between 1987 and 1992, and whose average annual growth rate during this period was 16 percent. This compares with Japan's five-year growth rate of 42 percent and average annual growth rate of seven percent. If

current growth rates continue, Europe could draw practically even with the US and Japan by as early as this year, and surpass them both slightly by 1994 (Table 2.2). This would leave the world PV market divided into relatively even thirds and could intensify efforts to further decrease costs and develop market opportunities in industrialized and developing countries alike.

The statistics of Tables 2.1 and 2.2 do not take into account that Siemens Solar, an American-based company, is owned by a German company and can be effectively considered a European asset in terms of technological advantage. If Siemens Solar were considered a European company, the US would presently be in third place, behind both Japan and Europe.

The end-use applications for PV modules and systems are divided into three primary sectors: 1) *Niche-oriented consumer products* (watches, calculators, patio lights, small electronic appliances, ventilation fans, etc.); 2)

Commercial applications (stand-alone, remote power systems for limited (0.2-25 kW) residential, commercial and agricultural applications; grid-connected supplemental power sources; PV-integrated building products such as PV glass, roofing tiles, and building facades); and, 3) *Government procurement for demonstration projects*.

Consumer Sector. Though the sale of consumer products will continue to play an important role in sustaining the PV industry and expanding public awareness and appreciation of the merits of PV, this market sector will not serve as a significant technology driver in the pursuit of competitive PV electric power production. Nor will consumer products provide the level of demand required to develop the mass-scale production of PV modules and support systems that is the requisite for the development of competitively priced PV-generated electricity.

Table 2.1 PV Module Shipments Since 1980 (MW).

	U.S.	JAPAN	EUROPE	R.O.W.*	TOTAL
1980	2.5	0.5	0.3	0	3.3
1981	3.5	1.1	0.8	0	5.4
1982	5.2	1.7	1.4	0.1	8.4
1983	13.1	5.0	3.3	0.3	20.8
1984	11.5	6.2	3.3	0.6	21.6
1985	7.6	8.1	3.5	1.4	23.7
1986	7.1	12.6	4.0	2.3	26.0
1987	8.7	13.2	4.6	2.8	29.2
1988	11.3	12.8	6.7	3.0	33.8
1989	14.1	14.2	7.9	4.0	40.2
1990	14.8	16.8	10.2	4.7	46.5
1991	17.1	19.9	13.4	5.0	55.3
1992	18.1	18.8	16.4	4.6	57.9

* Rest of World

Table 2.2 Projected PV Module Shipments (MW).

	U.S.	JAPAN	EUROPE	R.O.W.*	TOTAL
1993	21.0	20.1	21.2	5.1	67.4
1994	24.4 ^a	21.5 ^b	27.3 ^c	5.7 ^d	78.9

^a— continuing at 16% average 5-year growth rate

^b— continuing at 7% average 5-year growth rate

^c— continuing at 29% average 5-year growth rate

^d— continuing at 11.2% average 5-year growth rate

Consumer products use low-grade/low-efficiency cells that are impractical in the production of electricity for primary use. They often use single cells or very small modules of cells, thus do not provide the opportunity for the development of expertise and experience in the manufacture of the larger modules and arrays needed for primary power production. Consumer products do not require a support system or "Balance Of System" (BOS) upon which primary PV power generation depends, thus there is no opportunity to further develop these components and reduce their costs.

Commercial Sector. The commercial market is the largest and fastest growing PV sector. It is this sector that is the driving force behind the development of PV as a potential wide-scale source of power generation. Current commercial applications, coupled with trends toward decentralization in utility planning world-wide, focus on PV as a modular, primary power source off-grid, and a modular, supplemental power source within a decentralized grid.

It is specifically the off-grid application that is so promising at present and which has the potential to produce the short-term scale of demand that the PV industry has been anticipating for so long. Remote installation of PV has been - and will remain - the primary power generation application of PV in the short to medium term, and is currently the only PV

application which can be shown commercially viable, albeit only in certain markets.

In the medium term, other commercial applications that will become wide-spread include: 1) grid-connected PV arrays, producing power for direct use on-site during peak demand periods and releasing excess power to the grid during off-peak periods; and 2) "dual-use" PV-based building products (roof tiles, glass, building facades) that will produce power on-site with no need for a structural BOS (thus reducing space and cost restrictions), and that will "shave" grid electricity demand by consumers.

In the medium to long term, small-scale, grid-connected PV power plants will be used by utilities as part of a decentralized electric power grid, bringing electricity production to demand centers rather than distributing power from a few, large central power plants. This is a strategy that is now being considered by utilities in several different countries and is the one in which PV will first be utilized by utilities as a grid-connected source of commercial power generation [34].

Government Sector. Government-funded demonstration programs in Europe, Japan, and the US have been re-invigorated during the last few years after languishing during the oil glut of the 1980s. These programs support domestic PV industries by providing for large-scale projects that require manufactured PV technologies and their direct application in the

field. Accordingly, they provide the PV industry with publicity, financial support and experience in power production, as well as an incentive for utilities to become involved in the use and assessment of PV.

As of 1992, silicon is still the principal material used in PV cell technology, representing almost 99 percent of the total market. Within the silicon technology category, crystalline silicon modules account for almost three-quarters of all modules shipped. Less expensive and more easily engineered (but less efficient) amorphous silicon, though making up about 25 percent of total module shipments, represents only about ten percent of modules shipped for power production - the remainder are for the consumer sector. This is expected to change soon as thin-film technology allows the production of amorphous silicon PV modules in large sheets, rather than as individual cells as crystalline silicon cells are now produced. Future advances in amorphous silicon efficiency, combined with improved thin-film technology, may make amorphous thin-film technology economically viable for the commercial power market [35].

New materials are not expected to pose any threat to the supremacy of silicon in PV manufacturing for at least the next five years [35]. As of 1992, of the new PV materials currently being developed, only cadmium telluride had entered the consumer market (in calculators). New materials technologies and manufacturing techniques have not yet matured to the point that they are commercially viable; and silicon, being the oldest and best understood PV material, continues to be engineered into different cell forms (thin film, spheres), and to achieve improving efficiencies. However, based upon the minimalization of materials required, the ease with which modules will purportedly be manufactured and the deflationary effect this will have on PV costs, thin-film technology is the vehicle upon which PV is ultimately expected to be brought into mainstream energy markets.

Success in the developing country PV market will depend on three important elements: 1) financing; 2) planning; and, 3) access. Financing options include bilateral aid from individual donor countries, multilateral aid from the World Bank, aid from non-governmental

organizations (NGOs) or the United Nations, or a combination of these. International environmental concerns have also led to the establishment of the World Bank's Global Environment Facility (GEF) and Japan's "Green Aid" program, each of which are potential funding sources for solar PV projects.

Solar PV generally suffers from a bad reputation based upon past projects that were poorly designed, inappropriate for local power requirements and conditions, or lacking a strategy for the establishment of local sustainability (establishment of service/supply centers and training programs for locals on how to maintain PV systems). Proper feasibility studies, joint research projects, personnel exchange and training, and local participation in project planning will be crucial in gaining PV sales contracts from governments and aid agencies.

The third element of success in the developing world PV market is access. Access is based on a mixture of different factors, including: 1) existing market presence in other products or technologies; 2) the existence of an on-going or long-standing political, economic and/or aid relationship; 3) geographic proximity to the market; and, 4) provision of the first two elements: financing and planning. The initial stages of PV dissemination to developing countries will most likely be carried out "vertically." Essentially, specific countries will provide financing and planning for demonstration projects that are carried-out by their own PV manufacturers. This will introduce the companies into the local PV market, where they will then establish local relationships and "presence" in PV technology. This will most likely occur in parallel with multilateral aid projects requiring international bids for renewables contracts. Once specific companies have established market presence, it is highly likely that they will be favored in the bidding process.

Geography and population density pose serious limitations to economically practical, large-scale, grid-connected PV installations in most European countries in the short, medium, and even the long-term future. The primary role of PV in these countries will most likely be in the realm of conservation, rather than base load

power production. Other countries, especially those in the southern Mediterranean, are much more likely to have grid-connected PV as a contributor to the base load.

PV technology programs exist in several countries in Europe. However, there are only a few national efforts that have significance in the international arena. These programs are found in Germany, Italy, and the Netherlands - and to a lesser extent in France. European companies are poised for international expansion into the markets of industrial as well as developing countries. Combined with the aggressive domestic market development occurring in Germany and Italy, the potential for market expansion by European companies is exceptional.

However, renewed efforts in support of PV development in Japan and the US ensure that, in the short term, no one PV program is likely to achieve the degree of dominance enjoyed by Japan for most of the 1980s. As was shown in Tables 2.1 and 2.2, Japan is about to lose its position at the top of the list of world PV module shippers. This fact may be due to Japan's focus on consumer sector applications of PV products, whereas the future picture lies with commercial applications. Japan is unlikely to regain its market share lead anytime soon, since success in commercial applications is more dependent on strength in basic R&D than is success in the PV consumer products marketplace. Japan has never been particularly successful in basic R&D, and is unlikely to improve on this deficiency in an environment of reduced R&D expenditures in a struggling economy.

The activities of three countries not explicitly included in this report deserve consideration in any discussion of the worldwide outlook for solar PV. These are: the Netherlands; Australia; and, India.

The Netherlands. The R&D program in the Netherlands is relatively insignificant in comparison with those in Germany, Japan and the US (with a 1990 PV budget of only about \$3.5 million [36]). Nevertheless, the Netherlands is active in PV promotion abroad, specifically in its former colony of Indonesia. Its Indonesian ties make the Netherlands an

important world player. With an installed grid that reaches only about 32 percent of a population that is already the fourth largest in the world and spread out among 13,000 islands, Indonesia is a perfect model of the benefits of PV remote power. A joint effort by the governments of Indonesia and the Netherlands, the World Bank (GEF), and R&S Renewable Energy Systems (of the Netherlands) has resulted in the successful installation of over 15,000 residential arrays in Indonesia since 1988 [37]. As a follow-up, the Indonesian government has established a plan to install one million more rural residential arrays over the next six years [38]. R&S recently organized a joint venture with Phillips, called the Solar Electric Light and Power Co., which recently won a contract to work on an additional \$20 million PV project funded by the World Bank through its Asian Alternative Energy Unit [39, 40].

Australia. Australia is becoming one of the global centers of PV R&D and marketing activity. It is home to one of the world's premier PV research centers, and is also host to a number of subsidiaries of international PV companies: BP Solar, Siemens Solar, Helios, Solarex, and Kyocera. Given its wide-open spaces and considerable amount of annual incident sunlight, Australia is an ideal potential market for PV applications of all sizes. The Australian government has recognized this, and has begun to promote domestic use of PV as a peak power source. The government estimates that at least two-thirds of all Australian homes can effectively use PV roof arrays [41].

The Center for PV Devices and Systems at the University of New South Wales (UNSW) is responsible for some of the highest crystalline silicon cell efficiencies on record. The center's technologies have been licensed to BP Solar for commercial application. Australia could potentially become a world leader in PV, given its technical and scientific infrastructure, sunlight, and space to support large-scale PV applications. Some claim that Australia is already the world leader in per-capita PV manufacturing and installation of small PV arrays for remote sites, telecommunications, navigational aids and water pumps [42].

Murdoch University in Australia was selected by the United Nations International Development Organization (UNIDO) to be the site of the first UN Center for Applications of Solar Energy. The center will be the first of several similar facilities set-up by the UN to study high solar radiation. It will be completely financed by UNIDO, and will also receive R&D support from the Australian state and federal governments as well as from various international sources. In its initial stage, the center will concentrate on a detailed assessment of the energy needs of the Asian-Pacific region and how best to satisfy them with solar (and PV) applications [37].

India. India is the largest PV manufacturer outside of Europe, Japan and the US, with three indigenous companies that manufacture PV cells and modules. It is also the site of very vigorous PV dissemination and demonstration projects established and financed by its own government and industry in association with international aid organizations and joint ventures with foreign PV manufacturers.

India's potential for PV application is almost boundless, as it is the world's second most populous country, and has an estimated 75 million homes without electricity. Its geographic location, though not ideal due to tropical conditions, ensures that India receives a significant amount of incident sunlight annually.

The domestic Indian PV industry ships up to 2 MW of modules per year. Although the majority of silicon wafers that comprise the cells within these modules is imported, all of the cells themselves are produced by two government-owned public companies, Central Electronics Ltd. (CEL) and Bharat Heavy Electricals Ltd.

(BHEL). CEL and BHEL also manufacture modules, joined by a third public company, Rajasthan Electric and Instruments Ltd. (REIL), and three private companies, Renewable Energy Systems Private Ltd. (RES), Udhaya Semiconductors Private Ltd., and Tata/BP Solar Private Ltd. (a joint venture between Tata, which is one of India's largest industrial companies, and BP Solar). Virtually all of the modules produced are sold to various Indian government agencies for applications in remote sites and demonstration projects. The rest are sold in the commercial sector, which is dominated by Tata/BP Solar [43].

The Indian government PV program is led by the Indian Renewable Energy Development Agency (IREDA). It is through IREDA that money from the Indian government and international aid agencies is distributed.

The potential of India as a market for solar PV applications is apparent by the high level of investment currently being undertaken in the country. The World Bank has provided India with a \$55 million PV market development loan. The loan is the first installment of an over-all package of \$175 million in aid put together by the Global Environmental Fund (GEF) of the Bank and administered by its Asia Alternative Energy Unit (AAEU). In addition, India has applied for a credit of \$115 million from the International Development Association (IDA) and a loan of \$26 million from the GEF itself, both of which are to aid in the deployment of up to 2.5 MW of PV systems (lighting, water pumps and village power) targeted for installation by 1997 [43]. The government is also reported to have purchased up to 6 MW of PV equipment from the US.

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CHAPTER 3: INDIVIDUAL COUNTRY REPORTS

Reports are given on the activities of the following seven nations: Denmark, France, Germany, Italy, Japan, Russia, and the United Kingdom (UK). These countries play a dominant role in the worldwide R&D picture for the technologies of interest here. R&D activities in these technologies which are underway in other countries are mentioned within the discussion when the activities are pertinent to an understanding of the worldwide technology picture.

3.1 DENMARK

3.1.1 Policy Overview

Like most of its fellow EC members, the oil crisis of the late 1970s caused Denmark to recognize its dependence on oil as a primary energy source and thus redirect its energy policies toward greater diversification. Independent power production has been a national objective ever since [6]. In 1979, Denmark was 96 percent import dependent with regard to its total energy supply. Net imported oil accounted for 95 percent of Denmark's total oil consumption, with oil representing 77 percent of total energy supply and 36.8 percent of electricity generation. As of 1991, import dependence had decreased to 39 percent, with net oil imports dropping to 17 percent of total Danish oil consumption. Oil currently represents 44 percent of total energy supply and just 3.7 percent of electricity generation [44].

This transition was as much a result of providence (in the discovery and exploitation of North Sea oil fields) as it was a product of a directed energy policy. However, while Denmark's newly developed indigenous energy supplies and its policy of diversification of supply has reduced the role of oil (and of oil imports) in the Danish economy, it has correspondingly increased the role of coal (and of coal imports) in the national energy portfolio. Coal now represents 90.9 percent of electricity generation and 41 percent of total Danish energy supply (versus 63.1 percent and 21 percent, respectively, in 1979). Imports account for 94 percent of total coal supply [44].

It was therefore in the interest of energy security, as well as the desire to reduce greenhouse and ozone

depleting gas emissions, that the Danish government instituted its "Energy 2000" plan [45] in 1990. The primary goal of the program is to aid in reducing CO₂, SO₂, and NO_x emissions while simultaneously securing the availability of economical energy resources³. Given the 1985 parliamentary decision against the use of nuclear power in Denmark, this goal is to be achieved primarily by reducing coal's contribution to Denmark's electricity generation and by promoting the use of "clean" indigenous energies such as wind, biomass, and natural gas⁴. Measures taken to accomplish this change in consumption patterns include: 1) the introduction of "carbon taxes" on energy consumption; 2) subsidy programs for energy efficiency, conservation, and promotion of renewable energy sources; 3) investment in RD&D for the development of energy efficient technologies and the advancement of "near market" renewable energy technologies.

Denmark is, thus far, the first EC member country to approve of the "CO₂ Tax," which is to be implemented over a two year period (1992-1993). The tax will favor natural gas and "carbon neutral" energy sources over coal, and will most likely lead to an increased use of natural gas over electricity for heating. Off-setting reductions are to be made in existing energy taxes in order to minimize the negative economic effects of the CO₂ tax. However, a net addition to government revenues is

³ CO₂ emissions from energy use are to be reduced by 20 percent from 1988 levels by the year 2005.

⁴ Patricia K. Falcone, foreign travel report, Technology Transfer and Government Relations Office, Sandia National Laboratories, Livermore, CA, May 25, 1993.

expected, the bulk of which is to be used for subsidizing energy efficiency measures, combined heat and power co-generation, and renewables use. Tax exemptions for renewable energy sources provides an additional form of subsidy. Altogether, Denmark's Value Added Tax (VAT), the CO₂ tax, and other energy taxes will account for a little more than half the price of electricity in Denmark (see Footnote 4, and [46]).

The Danish Energy Agency (DEA) is responsible for implementing and administering programs for promoting renewable energy technologies. The DEA subsidizes certain renewable technologies according to their economic viability (the subsidy is reduced as the commercial viability increases). The maximum subsidy is 30 percent of the eligible cost of new plant or equipment. Subsidies for wind turbines, which were originally set at 30 percent and then reduced to 10 percent, have recently been eliminated because of their commercial success. Subsidies of up to 30 percent are presently offered for solar heating systems and biogas. Additionally, a new law instituted in May of 1992 entitles independent power producers to a subsidy of Dkr.27/kWh (approximately \$.04/kWh) for electricity produced from biogas, wind, or hydropower which is then sold to the grid. Biomass is entitled to this subsidy for demonstration projects [44].

Denmark's strong support for renewable energy R&D has remained relatively constant since 1982, and is expected to remain so for the foreseeable future. Danish energy R&D spending reached Dkr 310 million in 1992 (approximately \$45 million), up 11.5 percent from 1991. Renewables represented an impressive 39 percent of this total, with conservation and fossil fuels taking up 19 percent and 18 percent, respectively [44]. The focus of renewables spending was placed on capital investment, plant construction, and demonstration projects for biomass (including co-generation plants powered by the combustion of straw, straw and waste, municipal solid waste, and wood chips), wind, and solar thermal energy sources. Thus far, preference has been given to the development of small-scale co-generation power plants (250 MW), with a total capacity of 1000 MW planned for the year 2000. Wind, biogas and solar thermal follow co-generation in diminishing order of priority, respectively. This prioritized order reflects an investment-oriented perspective, in which

renewable energy utilization is based on estimated reductions in atmospheric pollutants to be achieved by additional use of the various renewable options [46].

Overall, Denmark is well poised to push through its national goals for the implementation of renewable energy resources, most of which will be in the form of biomass and wind. Denmark's CO₂ tax and domestic energy resources provide its policy-makers a certain measure of leverage in making a transition from coal to natural gas and renewables.

3.1.2 Energy Programs

3.1.2.1 Wind

Denmark's current position at the center of the European wind energy market is not expected to change in the near term because of its strong and long-established political will for wind technology, strong manufacturing base in this technology, and marketing prowess. Denmark should not only maintain its current leadership position, but should further expand its presence in international markets. Denmark will continue to cultivate larger, stronger cooperative ventures in order to foster the technical and financial strength of its manufacturing companies. A strong manufacturing base will encourage utility involvement, which is the key to further major developments in the European market [6]. Denmark has followed the strongest market led wind technology strategy of all other EC nations. Political support for the wind energy industry, both from the government *and* from opposition parties, has resulted from Denmark's national recognition of excessive dependence on imported oil. A temporary downturn in the political climate for wind energy has been reversed with a change in government at the beginning of 1993. The new governing coalition is expected to actively work to solve current administrative and planning hurdles which have caused a recent downturn in the Danish domestic wind energy market [47]. The recent downturn is considered an aberration that will not adversely impact Denmark's long-term leadership position.

When the US wind market surged in the late 1970s, Danish manufacturers (mostly small companies which grew out of the boat building and agricultural machinery industries) were able to immediately supply turbines having higher reliability than their US competitors. This firmly established the Danes as a market leader. The relatively small Danish turbines suited a market-led technology development approach⁵ (as opposed to a capital investment RD&D approach which tends toward the development of larger turbines) [6], and were ideally sized for the early US market. Over time, Danish turbines have gradually increased in size, as has the turbine size best suited to today's markets.

Denmark's goal of producing 10 percent of its electricity needs with wind power by the year 2000 is the most ambitious of any EC nation [2]. It has been estimated that as much as 1500 MW of wind generated electrical capacity may be on line in Denmark by that time [7]. For the first nine months of 1992, grid-connected, small-scale turbines provided 2.5 percent of Denmark's electricity [20]. Denmark's electric utilities were committed to install 100 MW in non-subsidized domestic wind farms under a 1985 agreement with the government. This is now complete. Under a 1990 follow-up agreement, an additional 100 MW is to be installed. Local opposition has delayed siting decisions related to the 1990 agreement [20], but the utility sector is being told that it must honor its commitment [48]. The main economic incentives currently in place are electricity taxation exemptions⁶ and reasonable pay-back rates. New wind turbines are exempt from Denmark's VAT, and receive a 75 percent reduction in energy taxes on new renewable energy projects, among other favorable tax treatments. Grid interconnect costs are also subsidized by the electric utilities [7].

Danish investment subsidies for private, domestic small-scale wind turbines, introduced in 1982 as a 30 percent payment of the capital cost incurred for the erection of each new turbine [20], were successful in encouraging many new manufacturers to enter the wind energy industry. The payments were gradually reduced as the cost of wind energy declined, until they were eliminated in August 1989. This payment program was responsible for the construction of roughly 2500 turbines⁷. The future of the subsidy program was in doubt from year to year. Under conditions of such uncertainty, credit for its success must be given to the large amount of Danish political goodwill for wind energy development [6]. Denmark's large-scale turbine development program is jointly sponsored by the national government, the Commission of the European Communities (CEC), and the Danish electric utilities [20].

Denmark's loan guarantee program boosts export sales by significantly reducing the purchaser's risk of selecting Danish units for wind plants. The Danish government cooperated with domestic turbine manufacturers in 1990 to form a private company which guarantees the repayment of long-term loans on Danish wind turbine projects (see Footnote 7). Denmark is also involved in a demonstration wind farm in Egypt, in which the Danes are providing an initial 1.8 MW of capacity, and the Egyptians have an option to add another 1 MW later [49]. The Danish company Nordtank has two joint ventures in progress with China. The ventures are partially supported by the CECs DG XVII (refer to Chapter 4). Initially, Nordtank is sending to China both completed turbines as well as components for local assembly. Eventually, China will manufacture Nordtank turbines domestically [50, 51].

Denmark is active in offshore applications, has been moving toward the manufacture of larger turbines overall, and has been working to improve turbine quality. Denmark commissioned its first offshore wind farm near the island of Vindeby in 1991. It consists of eleven turbines rated at 450

⁵ By early 1990 Denmark had roughly 80 percent of Europe's grid-connected wind energy capacity [7].

⁶ Wind turbine owners who produce more than their average electricity needs may sell their extra production to Danish utilities. This excess electricity is not subject to Denmark's substantial energy tax [7].

⁷ Information from an article by the American Wind Energy Association titled "European Wind Energy Incentives," 1992.

kW each. Its specific energy output is expected to be about 60 percent higher than for average onshore sites, but the cost of energy it produces will exceed that from onshore sites by about 50 percent [20]. Danish utilities have begun to express interest in machines of the 1 MW range. ELKRAFT, the large Danish utility consortium behind the Vindeby offshore project, has begun designing a 1 MW turbine⁸. ELKRAFT also operates a wind farm at Masnedø, which consists of five 750 kW machines installed in late 1986. This wind farm is partially supported by the CEC. Denmark's ELSAM (the country's other utility consortium⁹) commissioned the 2 MW Tjæreborg turbine, partially funded by Directorate-General (DG) XII of the CEC, in 1988. In January 1989, ELSAM also assumed ownership from the Danish government of the 630 kW Nibe A and Nibe B horizontal axis turbines, first commissioned around 1980. These development machines have all suffered from a variety of operational problems during their lifetimes, most notably in their gear boxes [52]. Nordtank and Vestas (the dominant Danish manufacturer) will participate in the ECs WEGA II (FUTURE) program, which has the goal of producing competitive machines of the 1 MW range [15]. In an effort to improve the quality of Danish turbines, a new approval and certification system was introduced in May 1991. It applies to all turbines installed in Denmark after July 1, 1992. It also is a condition for obtaining certain export guarantees [20].

The US market is still of interest to the Danes. The Danish companies Vestas-DWT¹⁰ and Difko (an investment group) are actively seeking contracts, hopeful for the expected turnaround in the US market. Vestas has formed a US subsidiary with an office in California. Difko financed and now manages nearly ten percent of California's wind turbines [11]. Nordtank has recently opened an

office in the US and is pursuing several projects [53]. The Danish manufacturer Nordex has signed a deal with the American company Windway Technologies Inc. to manufacture Nordex turbines in the US Midwest [54]. One other important private Danish institution in wind energy is Bonus. Important Danish national labs involved in wind energy technology include Risø National Lab (which operates the Test Center for Windmills, responsible for turbine certification). The Danish companies Vestas-DWT, Micon, Nordtank, and Bonus each offer for commercial sale turbines in the 200-400 kW range, as well as turbines with capacities greater than 400 kW. None of these companies receive government RD&D funding. LM Glasfiber is an important independent Danish blade manufacturer. Other Danish manufacturers include Wind World, DWP, and Wincon [7].

3.1.2.2 Solar Thermal

Denmark is not a significant player in either solar thermal technology development, or in the penetration of international solar thermal markets. Of the countries included in this assessment, Denmark joins the UK at the bottom of the rankings. This situation will not change in the foreseeable future. Denmark has acknowledged its poor solar resource in its investment-oriented view of renewable energy development. Accordingly, Danish activities are focused on low temperature applications and passive solar design.

As of 1990, solar heating accounted for only 0.2 percent of Denmark's total renewable energy use. Despite this record, Denmark expects solar heating technology to undergo rapid development in the near future [46]. Solar heating systems are currently subsidized for private developers for up to 30 percent of the eligible cost of new plants or new equipment. This subsidy was until recently also available for passive solar energy systems [46]. The Test Station for Solar Energy is the Danish Technological Institute, established in 1981 and financed by the Danish Energy Agency. Its primary responsibility is for solar heating system efficiency, durability, and reliability. As of January 1, 1991, solar energy was identified by a new Danish renewable energy development program as one of three renewable energy focus areas. An advisory subcommittee has developed a plan which can form the basis for future Danish solar energy activities [46].

⁸ Dan Ancona, CE-121, report on International Energy Agency Meeting and European Wind Energy Conference, 13-23 October 1991.

⁹ ELKRAFT has three members which serve eastern Denmark, while ELSAM has seven members serving the western part of the country [7].

¹⁰ DWT stands for Danish Wind Technology.

The Danish Government has invested two dollars in Danish solar energy for every dollar invested by the European Economic Community (EEC) since 1977. The two main Danish institutions involved in solar energy R&D are the Danish Technological Institute and the Laboratory of Thermal Insulation, Technical University of Denmark. Main areas of research include: improved solar collector durability; improved quality of solar energy installations; improved cost-effectiveness of solar systems; seasonal storage systems; utilization of silica aerogels in collectors and windows; and, passive solar design. Increases in the performance and cost-effectiveness of solar hot water systems has been a research priority. Low flow hot water systems, which, according to laboratory experiments and model simulations, can outperform traditional solar heating systems by 10-20 percent, have been introduced into the Danish market. Denmark also plans to construct up to 100 solar powered district heating plants, containing up to seven million square meters of collector area. Three have been built to date [46].

3.1.2.3 Solar PV

(No information is available on Danish activity in this area).

3.2 FRANCE

3.2.1 Policy Overview

French energy strategy is dominated by their extensive nuclear power industry, which provides about three quarters of France's total electricity supply and is at such a level of overcapacity that France exports surplus electricity to Switzerland, Italy and the UK. The large-scale development of nuclear power was France's response to the energy crises of the 1970s. France is poorly endowed with fossil fuels and therefore vulnerable with regard to its fossil fuel supply, requiring the import of up to 98 percent of its oil, 92 percent of its gas and 66 percent of its coal up to the present day [44]. Since 1973, France has successfully reduced its dependence on imported fossil fuels by 50 percent through a policy stressing diversity of supply, intensive development of indigenous resources

(hydro and nuclear) and improvement in end-use efficiency.

Surprisingly, given the degree of its energy dependence, France does not have an especially strong program in new energy technology development. The bulk of its research efforts have been (and remain) devoted primarily toward nuclear fission (an estimated 88 percent in 1992) [44]. One factor may be that EdF/GdF, France's monopolistic national power producer and distributor¹¹, controls the French nuclear power industry (almost 70 percent of the country's electrical power). Because of its lack of domestic competition, the utility has little incentive to encourage the development of renewables [55].

French researchers and energy visionaries have long been frustrated by the government's lack of interest in renewable energy sources [56]. A promising level of French governmental interest in renewable energy technologies did occur in the late 1970s, with the underlying objective being the eventual export of French-developed alternative energy equipment to former French colonies and overseas departments. However, initial successes lost momentum in the 1980s when low fossil fuel prices eliminated any perceived urgency for renewable energy technology development [56], resulting in the reduction of French renewables expenditures from 147 million francs (Ffr) for solar thermal and wind energy in 1983, to a total of only Ffr 30 million by 1987 [68] (Ffr 30.5 million in 1993 [57]). Today, the bulk of France's small funding allocation for renewable technology development goes to biomass, biofuels and wind energy [56].

Biofuels is an especially important potential energy resource in France, primarily as a consequence of the intense political and social pressures in France concerning the current round of GATT world trade negotiations over, among other things, agricultural subsidies. French farmers are among the primary

¹¹ EdF is Electricity of France, while GdF is Gas of France (Gaz de France). EdF and GdF are actually separate entities, but they combine their marketing activities under the name EdF/GdF, which is the reason for their treatment as a single entity in this discussion.

beneficiaries of EC agricultural subsidies, and being a powerful political force in France, they have succeeded in stalling the GATT negotiations for fear of losing their subsidies and being forced to compete openly on world agricultural markets, where high-cost European agricultural goods are less competitive. The concept of replacing current food crops with biomass crops such as rapeseed is very attractive to French and EC authorities alike, from a political as well as an energy policy standpoint. As a result, in 1992, the French parliament adopted a number of measures to encourage production and use of biofuels in the transport sector - primarily in blends of gas and diesel fuel. Among these measures are the exemption of biofuels from all excise duties and the establishment of a national agency to specifically promote the use of a range of biofuels [44].

There remains some recognition by the French government of the commercial potential that other renewable energy technologies hold for application in developing countries, and therefore it does not wish to completely cede this potentially lucrative market to its competitors, namely Germany, the US, and Japan [58]. Therefore, renewables overall are beginning to receive more official attention, (albeit in a comparatively limited way). Official French efforts with regard to eliminating greenhouse and ozone depleting emissions has resulted in the establishment of the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), a government agency supervised by three ministries: Ministry of the Environment, Ministry of Industry, and Ministry of Research. ADEME's priorities lie in addressing air pollution, transportation, toxic waste and renewables development. Funding for renewables, although modest, has been rising in recent years. ADEME's fiscal 1993 budget for renewables is Ffr 100 million (approximately \$18 million), a 15 percent increase from 1992. This budget is devoted to passive and active solar thermal applications, solar PV, wind technology, small hydropower, biofuels, wood energy, and geothermal [57]. ADEME's goal is to double renewable energy contributions to France's national energy supply by the year 2005 [57].

Nuclear fission will remain the primary focus of French energy policy and research for some time to come. Renewables in general are not expected to

assume a major role in French R&D programs, with the possible exception of biofuels. To the extent that they are successfully developed for transportation use, biofuels could become vital to the future of French agriculture and energy security, as well as that of the EC as a whole. Because of the French predominance in the agricultural sector of the EC, it is likely that much of EC-funded research efforts in this area will take place in France.

3.2.2 Energy Programs

3.2.2.1 Wind

Of the EC nations considered in this report, France clearly lags behind the others in the wind arena. The French energy strategy is so dominated by nuclear power that France is not expected to be a major player in wind energy technology or markets before the year 2010. Despite excellent wind resources, France's wind energy program is extremely small, with only 3 MW of installed domestic capacity expected by the end of 1993 [15]. Little evidence of any developing market is seen there [2]. Centralization has stifled any chance for domestic utilization. French abandonment of wind energy demonstration projects supported by the CEC far exceeds that of any other participating country¹².

ADEME is currently involved in a small regional promotion program (in cooperation with EdF) to equip a few isolated homes with wind turbines. Up to a total of 12 MW of additional wind generated electricity is contemplated for three grid extension projects, the largest of which (a 6 MW extension to an existing wind farm in Dunkerque) will be partially funded by the European THERMIE project. The Dutch company HMZ

¹² France abandoned 65 percent (15 of 23) of its wind energy demonstration projects approved by the CEC between 1983 and 1989. As of May 1990, France had used only 14 percent of its CEC-allocated funding for approved wind energy demonstration projects. This utilization compared to: UK, 71 percent; Italy, 93 percent; Germany, 99 percent; and Denmark, 100 percent [59].

will furnish 20 of its 300 kW turbines for this project. The turbines will have a significant percentage of French-manufactured parts. The smallest of the three projects is a 2 MW grid extension near Port-la-Nouvelle by the developer Tramontana, using four Danish Vestas turbines. The project has received funding from both the EC and ADEME. Tramontana is also involved with a joint venture (in cooperation with EDF) to install two German 100 kW Ventis turbines on the Caribbean island of Martinique. ADEME's goal for wind energy is to increase French consumption to 500 MW by the year 2005. Plans are to accomplish this goal primarily by using existing turbine technology from other countries. A provisional 1993 budget request for wind energy, outlined by France's Director of the Program for the Priority of Renewable Energy, is 3 million francs (\$0.6 million) for research and 8 million francs (\$1.5 million) for commercialization [57, 60].

A few small French companies make their living by selling wind energy products primarily to foreign turbine manufacturers. The most successful of these is Atout Vent (translated as "The Wind is our Trump Card") [55], the sole French manufacturer of turbine blades. Using a unique manufacturing process to vacuum-mold carbon sheets onto a polystyrene core (under heat), plus computer-aided blade design, Atout Vent has successfully entered a market previously dominated by only five blade manufacturers (Danish, Dutch, and American) [61]. Atout Vent is manufacturing the turbine blades for the Dunkerque wind farm expansion [57]. In a search for domestic investors, Atout Vent had experienced resistance [61], but a minority share of the firm was recently purchased by the French group Porcher Textile. Porcher Textile is a market leader in technical glass fibre for electronic applications, as well as in carbon fibre projects. Porcher Textile's largest subsidiary is Burlington Glass Fiber in the US. This association is to lead Atout Vent to establish a US manufacturing facility [62].

3.2.2.2 Solar Thermal

Negative pressure from the French government and utility industry, as well as a largely unfavorable public perception of solar thermal technology, has caused France to fail to capitalize on its quick start in this area. Today there are dim prospects for the

successful advancement of either significant research or commercialization of solar thermal technology in France. Significant expenditures for solar thermal technology in the years immediately following the oil crises led to impressive technological advances and the construction of several advanced experimental facilities. This initial momentum has given way, in the wake of a strong French affinity for nuclear power and continued low prices for fossil fuels during the 1980s, to an environment where neither the French public, nor industry or government (in general) recognize the potential future importance of solar thermal technology.

The 1993 ADEME budget for solar thermal technology includes Ffr 2.2 million (about \$0.4 million) for research and Ffr 17.3 million (about \$3.0 million) for commercialization. ADEME will spend less on solar thermal research in 1993 than it will spend on research in solar PV (by a factor of 6.3), wind (by a factor of 1.4), geothermal (by a factor of 5.4), or biofuels (by a factor of 1.6). However, ADEME's spending on solar thermal commercialization is the largest of any of these other technologies [57]. This seems to be an acknowledgement of France's early research successes in the field.

France constructed the first solar thermal facility in the world to produce electricity while connected to a utility grid. This was the industrial-sized solar furnace at Odeillo in the eastern Pyrenees. This furnace (which has a horizontal optical axis) was also the first facility to use a field of free-standing heliostats operating under automatic control¹³. Sixty-three heliostats arranged on the slope of a hillside reflect solar energy onto a large focusing parabolic concentrator. The building which supports this concentrator also contains a pair of small research furnaces. These are also heliostat type furnaces, but with vertical optical axes¹⁴. The

¹³ Information taken from a brochure "Solar One in Perspective," based in part on a report by the same name prepared for Sandia National Laboratories by Jerome Weingart and Peter Bos.

¹⁴ Information taken from an article on solar furnaces by Takemaro Sakurai, designer of the solar furnace at Tohoku University in Japan (complete citation unknown).

Odeillo solar furnace complex is operated by the Centre National de la Recherche Scientifique (CNRS), France's largest agency for basic research. The large furnace provides very high temperatures (up to 3000°C) to evaluate materials for direct conversion of solar radiation into heat [63]. Among its many uses, the furnace was used to test thermal tiles for the European space shuttle.

The Themis solar power tower was an experimental 2.5 MW French facility which differed from other early designs, in that it used molten salt, rather than water, as the working fluid as well as for thermal storage. In fact, Themis was the very first molten salt facility in the world with a capacity greater than 1 MW. Themis was built by the nuclear utility Electricity of France (EdF), and operated from 1983 to 1986. The use of molten salt for storage was a technological breakthrough which allowed decoupling of the operations of the solar receiver and the turbine generator in times of reduced solar availability. Power towers using molten salt storage are now a major focus of ongoing research worldwide [30]. The salt technology used in Themis was developed by the French. However, the French used a lower temperature molten salt (HITEC) than does the US today¹⁵. The Themis plant also featured a cavity receiver, rather than a cylinder¹⁶.

The Themis plant is now inactive and under the control of CNRS (it is near the Odeillo furnace). CNRS remains a strong proponent of molten salt technology, but human sources indicate that EdF has no interest in its commercialization. Since EdF is the *only* French utility, the chances for French domestic construction of a commercial solar power plant are almost nil. This is not to say that some private French firm could not try to market the Themis molten salt technology elsewhere. It is further rumored that EdF built Themis only

because of political or public pressure (or both), and was never very motivated to make it a technical success (other than perhaps its control system, the technology of which could perhaps be applied to EdF's nuclear power interests). This lack of commitment by EdF to Themis was reflected in a history of equipment malfunction at the plant. The malfunctions were primarily associated with the mechanical aspects of the plant operation, and were not reflective of problems with its solar aspects, which displayed admirable performance. Unfortunately, French opponents of solar thermal technology successfully represented these malfunctions as symptoms of technical nonviability [56].

3.2.2.3 Solar PV

France spends very little on PV R&D (about \$4.6 million in 1993, of which \$2.3 million is for research and \$2.3 million is for commercialization, based on currency exchange rates in effect on December 14, 1993 [57]). Additionally, France is participating in the EC program THERMIE, which has established a small PV demonstration program in France, equipping houses with roof-top solar arrays in the Franche-Comté and Rhône-Alpes regions [57]. Largely because of the country's overcapacity in nuclear-generated electricity, official interest in PV as a future element in French energy strategy is minimal [58]. All told, France is not a significant player in the present PV market, and all indications point to it remaining in the background for the near-to-medium term.

French PV companies produce primarily for export and, at a total production of 2.8 MW of modules in 1992, represent only about 5 percent of total world production of 57.9 MW. However, Photowatt produced 2 MW of that total, making it one of the largest PV producers in Europe, following BP Solar, Deutsche Aerospace (and technically, Siemens Solar) [65]. A new factory built by Photowatt in 1991 near Isere, was designed to produce up to 9 MW annually and is expected to come on-line in 1995. However, recent reports in the French press indicate that Photowatt is in dire financial trouble due to its past reliance on government-financed initiatives in the French Overseas Departments in French Polynesia and the Caribbean. The company is reported to have lost \$750,000 in 1992 (based on a turnover of about \$2.3 million). It has experienced several weeks of

¹⁵ The nitrate salt used in the US has a higher heat capacity, and operates at temperatures typical of those in conventional utility practice for high efficiency turbine-generator operation [64]. Technical experts consider the US-used molten salt system to be superior.

¹⁶ A cavity receiver is suitable when the heliostat field is located on only one side of the central tower.

down time at its plant this year and is faced with making layoffs [66].

Other French PV companies are NAPS France and Total Energie. NAPS, which is owned by the Finnish firm, NESTE, was previously Chronar (France). While its sales numbers for PV modules are modest (0.8 MW in 1992), it has established itself as one of the largest designers and installers of turnkey PV systems in Europe, and is the only fully integrated PV company in the world (R&D, module/BOS production, systems design and installation, and marketing) [67, 68]. NAPS receives no government subsidies and is said to benefit mainly from Northern European Church activities in the developing world¹⁷. Total Energie is active in cross-border PV activities, namely its 50 percent partnership with Phototronics of Germany in the development of a 1 MW demonstration pilot plant at Putzbrunn near Munich. Its presence in world markets is negligible.

An important statement on French PV efforts is reflected in a recent report addressed to the French Minister of Industry, concluding that erratic foreign aid programs would not establish a viable PV industry in France, and that concerted efforts are needed to help target niche markets in developed countries [66]. Based upon the level of French spending on PV and other renewables, this concerted effort is apparently not being made. France is therefore not expected to be a significant player in the world PV market in the near-to-medium term.

3.3 GERMANY

3.3.1 Policy Overview

The primary challenges facing German energy policy over the near term are the integration of the new federal states (Länder) of the former East Germany and the reconciliation of the roles that domestic coal and nuclear power will play in the

country as a whole in the future. Tied to these challenges is the question of what new technologies and resources can be utilized to address these supply concerns in light of Germany's powerful environmental movement. Germany is the birthplace of the Greens Party and the GreenPeace movement and therefore has a significant history with regard to environmental politics.

High pollution levels and defective nuclear plant designs have led to the closure of all nuclear and a majority of thermal power plants located in the eastern Länder, putting pressure on an already strained energy portfolio in the western Länder. Overall, Germany is import dependent, with energy imports representing 52 percent of total energy supply in 1991. Oil and natural gas represent 38 percent and 17 percent of total supply, respectively, and are almost completely made up of imports (98 percent for oil, 75 percent for natural gas). Coal and nuclear power are the largest domestic sources of energy, representing 31 percent and 11 percent of total energy supply, respectively. Additionally, these resources provide over 85 percent of German electricity (coal: 59.3 percent, nuclear: 27.5 percent) [44]. However, both are currently under fire by powerful environmental factions as well as by Germany's EC partners.

The nuclear and coal industries have been Germany's hedge against energy import dependence since the 1970s. The coal industry has traditionally been a powerful force in German politics and has enjoyed a long history of substantial subsidies and national protection. Germany's nuclear program is one of the safest and most advanced in Europe. But concern over the Chernobyl accident in Russia in the 1980s, complaints by EC trading partners over the restriction of coal imports, and the international efforts underway to reduce CO₂, SO₂, and NO_x emissions have brought social and political pressure on these industries, forcing the German government to consider all of its options with regard to energy alternatives. German interest in renewable energy is more the result of concerns about the environment than about energy security [6], however, the partisans of renewable energy are competing for attention with the nuclear and coal industries [69]. Although the political will to pursue renewables continues to persist in the

¹⁷ Activities and monies spent by these organizations could not be confirmed by the print date of this report.

German Bundestag among most political parties (as well as with German members of the European Parliament), it appears that proponents of nuclear and coal are being successful in their attempts to push renewable energy to the bottom of the current energy agenda [70].

Germany has nevertheless developed one of the world's most vigorous programs in the development of renewable energies up to this time. In 1991, the German federal government spent DM 328 million (approximately \$198 million) on research related to renewable energy and conservation. One third of this, DM 109 million (approximately \$66 million), was spent on solar PV alone, making Germany's program the world's top funded effort in PV technology [71]. Wind energy, hydro and biomass have all received support. Policy measures to promote renewables have also been put into place, including a law promoting the sale of renewable-based power to the public grid at a minimum price related to commercial electricity rates¹⁸. Low-interest loans are also available for small and medium-sized businesses investing in renewables. And large-scale demonstration projects provide purchase and installation subsidies for residential applications of renewable technologies.

Large German corporations are also very active in participating in the R&D process in energy efficiency and new energy technologies, indicating a general anticipation within the private sector of the potential commercial demand for environmentally friendly energy technologies in the near term. Germany's position as one of the world's most preeminent exporting countries reflects the traditional focus that German

commerce has had with regard to directing its enterprises toward overseas markets, and could serve as an indication that German companies may be anticipating the establishment of completely new export industries and markets - especially in certain parts of the developing world.

German reunification has caused severe budget strains on the German government and its research institutions. Many of these institutions are facing prospects for layoffs in the coming months or years. The current environment of change and upheaval has made it very difficult to achieve continuity in German RD&D efforts in renewables technologies. Although budget constraints due to the costs of reunification will most likely lead to spending reductions in the near term, environmental damage in the former East Germany, coupled with Germany's import dependence, powerful domestic environmental opinion, and the potential for the development of a new, job-creating export industry will ensure that its commitment to renewables will continue well into the next century. As a measure of this, the first all-German energy projection for 1990-2010 by the Swiss-based Prognos Institute is forecasting that renewable energy will increase its contribution from two percent of German energy production in 1989 to 3.5 percent in 2010, with the largest share being generated by water, waste, straw, and wood [73].

3.3.2 Energy Programs

3.3.2.1 Wind

Germany currently is second to Denmark in a list of EC nations involved in wind energy, when viewed in terms of installed capacity. However, the German wind energy program must overcome economic obstacles created by reunification and by early over-subsidization if Germany is to remain an EC leader in the technology. German reunification has led to severely strained budgets, in which the national priority given to wind energy RD&D is likely to slip. Germany is likely to fall well behind Denmark and the Netherlands, in a virtual tie with Italy and the UK, in terms of installed domestic wind energy capacity by the year 2000 [7]. Early German wind turbines were primarily large demonstration machines that were not particularly

¹⁸ Germany's "buyback" regulation, put in place in 1991, is a reflection of political support for renewables. The law requires electric utilities to buy renewables-generated electricity at a rate equal to at least 90 percent of the commercial rate for electricity (roughly DM.14/kWh; approximately \$0.08/kWh) [57, 72]. Renewables and PV lobbying groups are currently trying to push for a 100 percent "true cost" reimbursement of PV electricity [72]. The combination of the budget crunch and the on-going recession will most likely keep this proposal on the back-burner for a while.

efficient because of overly-generous or poorly conceived subsidies and incentives. This situation has been improving, and Germany has recently made a significant move toward commercialization. Germany's wind energy program would benefit in the long run from more exposure to true market forces [74].

Since 1975, the Federal Ministry for Research and Technology (Bundesministrie für Forschung und Technologie, or BMFT) has supported German wind power development with numerous R&D and promotion programs¹⁹. Two demonstration programs for turbines in the range of 80 kW to 800 kW were initiated in 1986. In 1989, the "100 MW Wind" program was begun cooperatively by the BMFT and the Ministry of Economics. Its aim was the deployment, market introduction, and commercial evaluation of small and medium-scale Wind Energy Conversion Systems (WECS) over a five year period [20]. Because of enthusiastic private sector response, this program was extended in 1991 to become the "250 MW Wind" program. Of the new 250 MW, 50 MW is reserved for applicants and sites in the former East Germany [20]. This is a cooperative program between the BMFT, the Project Management Biology, Energy, Ecology (BEO), and the concerned Federal States which emphasizes demonstration projects having a research component (see Footnote 7). The program, which currently emphasizes energy production, has been quite successful. Since its beginnings in 1989, nearly 100 MW of capacity has been installed. (Support for any one project is limited to 10 years). Electric utilities have accounted for less than one percent of the proposals for participation in the 250 MW Wind program to date [20]. However, several German utilities actively support wind technology²⁰.

Using an assumed exchange rate of 1.7 DM per dollar, the BMFT spends roughly \$16 million annually for wind energy [7]. (This statement is in line with the funding data shown in Appendix B.) Not counting the 250 MW Wind program, roughly 50 percent of 1992 funding for German wind energy RD&D came from the BMFT. Additional funding was mainly provided by the Federal States [20]. The States have generally tried to augment the 250 MW Wind subsidies, such that each project received a total of 50 percent support. Recently, some states have begun awarding their highest subsidies to the most promising turbine designs [75]. The "El Dorado-Programme Wind" was established in 1991 to promote field tests of wind turbines and hybrid systems (such as wind-diesel) [20]. The El Dorado program offers public funding for turbine testing under a variety of climatic conditions in less developed countries. A 1991 law committed German electric utilities to pay roughly \$0.11/kWh (a national wind tariff) to other producers who provided them with wind generated electricity (this is about 90 percent of the utilities selling price to the end consumer). This law has been very successful in promoting the German wind industry. This payment is in addition to the roughly \$0.04/kWh received by wind energy producers who are participants in the 250 MW Wind program. The combined subsidy of \$0.15/kWh is ten times that contained in EPAct.

Germany is studying various alternatives for stimulating a commercial wind energy market, now that the end of the 250 MW Wind program is in sight. One proposal is for a 30 percent capital investment subsidy, to be introduced in a five year program. The proposal is viewed as practical and equitable in terms of benefit to potential operators. Investment tax credits are viewed as inappropriate because of their built-in inequities. Germany's goal is a healthy mix of investment from private and corporate sources [76]. One area of current controversy involves the most appropriate manner of allocating grid connection cost for new wind generation facilities. At present, wind turbine operators pay all costs associated with connection of their machines [77].

On an absolute dollar basis, Germany and the UK spend more for wind energy RD&D than any other EC nation [6]. German RD&D funding for

¹⁹ Germany's Ministry of Economics (Bundesministrie für Wirtschaft) also supports renewables, including wind. One of their recent programs is the Future Energies Forum for renewable energy planning and education [7].

²⁰ These include PreussenElektra AG (PE), EWE (Energieversorgung Weser-Ems AG), and Bremer Stadtwerke AG [7].

smaller-scale turbines is being reduced in favor of large-scale turbine RD&D²¹, as well as funding for the study of issues of importance to the electric utilities. (These include reliability, maintenance, lifetime, annual production, and installation costs.) The study of large-scale machines is becoming more cooperative in nature, particularly among EC partner nations. CEC programs (WEGA) are also being used. An ad hoc committee, sponsored by the BMFT and consisting of representatives from industry, utilities, research institutes, neighboring countries, and the CEC, has recommended an ambitious research and testing program designed to gain knowledge about large-scale turbines while reducing the financial risk to potential manufacturers [20]. German researchers have also been actively pursuing innovative turbine design concepts which would greatly improve efficiency in the light wind conditions predominant in most of Germany [78].

Private German institutions which have recently entered the wind market include Enercon and Husumer Schiffswerft (HSW). Both Enercon and HSW sell turbines in the 200-400 kW range, but only Enercon offers a larger commercial machine. Enercon has just begun series production of a 500 kW machine, the E40, which has an environmentally friendly gearless turbine. This eliminates the need for potentially polluting gearbox oil [79]. Partially because of this innovation, some experts feel that Enercon is now more technologically advanced than US Windpower. HSW, but not Enercon, benefits from government RD&D funding [7]. HSW is developing a 750 kW commercial machine, but it is not yet on the market. A prototype has recently been installed for testing [80]. Tacke Windtechnik is a new player on the German wind energy scene. MAN Technologie AG (MAN) was unique to early German efforts in wind technology, in that it was involved in small turbines as well as large

demonstration machines (these include the WKA 60 and the AWEC 60).

However, MAN is no longer doing business. DEWI is an important German wind energy institute which recently opened a new turbine test field. The German company MBB (Messerschmidt-Bölkow-Blohm) has worked cooperatively with Italy's Riva Calzoni company to develop monoblade (single blade) horizontal axis technology [81]. MBB has recently focused on its own monoblade machines (the Monopteros series). MBB has currently stopped wind energy activities [20]. It is unclear how this has affected the German-Swedish joint company MBB-Kvaerner, which was developing large machines with capacities in excess of 400 kW. These include the 3 MW WTS 80-3 machine in Sweden, as well as Germany's 3 MW AEOLUS II turbine. Germany has also been involved in cooperative efforts with Spain in large turbine technology (the WKA 60 and AWEC 60 projects) [7].

3.3.2.2 Solar Thermal

Germany is the European leader in solar thermal technology, not only in the number and variety of ongoing programs, but in the quality of its research and development activities. German research programs cover the spectrum of low and high temperature applications, and passive and active solar system design. Germany is particularly interested in the solar production of hydrogen (one of their visions is that of a hydrogen-based economy). In the more near term, solar hydrogen production could provide fuel for a hydrogen-powered plane which Germany and Russia are developing in a joint project [9].

Current German interest in central receiver technology is strictly from an *energy export* standpoint. The German domestic solar resource is too poor to allow the economic operation of a domestic central receiver power plant. However, the Germans appear to have a long term vision of remote central receiver power production in northern Africa, with at least part of the power then returned to Germany for domestic consumption. The Germans favor (and are pursuing) volumetric-air central receiver concepts because they perceive the potential simplicity and ease of operation and

²¹ The International Energy Agency (IEA) defines a large-scale wind turbine system (LWTS) as one having a rated power of approximately 1 MW or more, and this includes not only stand-alone machines but groups of smaller turbines with a combined power of approximately 1 MW or more [20].

maintenance of such a system to be an advantage in remote areas [64]²². The Germans have developed a volumetric-air receiver known as VOBREC at the Deutsche Forschungsanstalt für Luft-und Raumfahrt, or German Research Institute for Aeronautics and Astronautics (DLR). This receiver is being incorporated for testing with a US-made Brayton engine. The US firm which built the engine is pursuing dish/Brayton solar system concepts.

Several German companies are active participants in the PHOEBUS Consortium, a joint venture working to design and build a 30 MW volumetric-air central receiver plant. The plant, most likely to be sited in Jordan, is currently in an intermediate component testing stage known as the Technology Program Solar Air Receiver (TSA). The TSA was initiated as a necessary step towards commercialization of the PHOEBUS technology, and involves a DM 5.75 million²³ reduced scale testing program at the Plataforma Solar de Almeria (PSA) in southern Spain²⁴, running through the end

²² This is the stated German position. Some experts would argue that the German volumetric-air mindset is more a result of their historical familiarity with this technology area. Others concede that the concept may turn out to be a market winner over competing technologies such as molten salt in central receivers (favored by the US).

²³ Not including costs for test performance and property rights acquisition.

²⁴ The PSA is jointly supported by the DLR and Spain's Instituto de Energias Renovables (IER) of the Centro de Investigaciones Energeticas, Medioambivalentes Y Tecnologicas (CIEMAT). It is the largest solar thermal testing center in Europe today. The center supports the development of central receiver components and parabolic dishes, and has ongoing testing programs in solar chemistry applications (including detoxification and photolytic hydrogen production from inorganic industrial waste streams), process heat applications (including desalination), and material testing. Its facilities include fields of tracking parabolic collectors, two central receiver systems (SSPS and CESA-1), and a solar furnace for high temperature materials and chemical research.

of 1993. The receiver and thermal storage systems are being tested while utilizing the existing Almeria CESA-1 tower, heliostat field, and water/steam cycle. TSA test results through early August of 1993 have been encouraging, and indicate the possibility of lower PHOEBUS capital and power generation costs than initially predicted. German companies involved with the TSA program include: Fichtner Development Engineering (FDE) (managing partner with responsibility for system engineering and the control system); L&C Steinmüller (power station contractors responsible for the receiver and system delivery); and Didier M&P Energietechnik (ceramic specialists involved with the thermal storage system). The DLR is responsible for the TSA test program and evaluations. Funding is being provided by the industrial partners, the German Federal Ministry of Research and Development (BMFT), the Ministry of Economics of the State of Baden-Württemberg, and by the US utility Pacific Gas and Electric Company. It is hoped that the full-scale PHOEBUS concept can be offered on a global basis in the spring of 1994²⁵. Many US experts express doubt that the technology can be scaled up so quickly from the 2.5 MW TSA component test to a fully operational 30 MW system.

Germany is extremely active in state-of-the-art dish/Stirling technology development, with numerous players involved. The German firm Schlaich Bergermann und Partner (SBP) in Stuttgart developed (in 1984) the technology for single-facet stretched-membrane concentrators. Their 17 meter concentrator was used with a 50 kW Stirling engine developed by United Stirling of Sweden AB. Three of these concentrator/engine systems have been operated: two in Riyadh, Saudi Arabia at the Solar Village of the Saudi Arabian National Center for Science and Technology; and, one in Lampoldshausen, Germany for use in research by the DLR. This was the first commercial prototype dish/Stirling system to operate in Europe [82].

²⁵ Information taken from "Technology Programme Solar Air Receiver TSA," issued by FDE for the PHOEBUS Consortium, August 1993.

SBP has since constructed a number of 7.5 meter single-facet stretched-membrane concentrators which incorporate some advanced changes to the membrane preshaping method and tracking scheme used in the 17 meter concentrator design. These SBP concentrators (as in their earlier model) have thin glass mirrors bonded to the membrane. The innovative preshaping method involves preforming the membrane beyond its elastic limit such that when the space behind it is evacuated, it displaces to a shape which is closer to a true paraboloid. The German manufacturer Solo Kleinmotoren recently produced a number of directly illuminated receivers for SBP dish/Stirling test systems using their 7.5 meter concentrators. Solo Kleinmotoren is also manufacturing 9 kW kinematic Stirling engines for use in these systems²⁶. Six systems have been erected to date: three are being tested at the PSA in Spain; one is in operation at Pforzheim, Germany; and, the final two are in Stuttgart, Germany (one being a now-dismantled prototype at the University of Stuttgart, and the other an operating unit at the Zentrum für Sonnenenergie- und Wasserstoff, or Center for Solar Energy and Hydrogen Research (ZSW)). SBP would like to mass produce their 7.5 meter stretched-membrane dish/Stirling system [82].

Dish/Stirling development is also underway at HTC Solar Forschungs-Centrum GmbH (Solar Research Center) (formally Bomin Solar) of Lörrach, Germany. They are developing two systems, one with a stretched-membrane concentrator and an HTC-developed 3 kW kinematic Stirling engine. The second system uses a fixed-focus concentrator (i.e., the focal point remains fixed while the concentrator tracks the sun), and uses an innovative storage approach to utilize excess heat for refrigeration (at night) or for domestic hot water heating (during the day) [82].

Both SBP and the DLR are active in the development of advanced receiver concepts for dish/Stirling systems. The two organizations are collaborating to develop a liquid metal heat-pipe receiver (this receiver concept is technologically state-of-the-art for several reasons). SBP is also

developing a hybrid receiver for use with their ZSW system [82].

Late in 1992, Germany's first totally solar house, developed by the Fraunhofer Institute of Solar Power Systems (ISE), was completed. Among its other innovative features, the house demonstrates the use of hydrogen technology for the first time in a German home (a hydrogen stove and a storage system which utilizes hydrogen are included) [83]. According to a press release issued by the BMFT in March of 1993, a new program called "Solar Heat 2000" will be introduced in the new laender (the former East Germany), with the goal of making practical use of integrated solar energy and energy conservation techniques in the extensive and ongoing construction and modernization work in that region [84].

German researchers at the German Aerospace Research Institute and the Institute of Organic Chemistry of the Technical University of Aachen have studied solar-photochemical processes in the Solaris experiment at the solar testing center of Almeria. Their process uses parabolic trough technology to focus concentrated solar radiation on a mixture of output chemicals and a sensitizer which is pumped through a pipe along the trough focus. The sensitizer (dye) absorbs light energy and triggers the desired photochemical process. The Germans claim that certain chemicals have been produced cost-effectively with this process [85]. Researchers at the Hahn-Meitner Institute are also studying solar energy, including photochemical energy conversion [86].

The DLR is constructing a solar furnace at Cologne²⁷ which should become operational early in calendar year 1994. The furnace was designed and analyzed with the help of the National Renewable Energy Laboratory (NREL) in the US. The DLR and NREL furnaces will be the only such facilities in the world with a primary concentrator focal point that is off-axis. This feature allows the performance of experiments more conveniently (i.e., at ground level). The

²⁶ This engine was originally designed by United Stirling of Sweden AB and manufactured in the US [82].

²⁷ This site is not ideal because of its poor solar resource. However, the location was dictated by the German State government which provided the funding.

facility will be used to study waste product detoxification including processing and breakdown of waste sulfuric acid, photochemical synthesis, and materials research [87].

ZSW is performing research on direct steam generation (*in situ* boiling technology) for parabolic troughs. Their HIPRESS test facility is useful for lab-scale experiments which provide a clear picture of the pipe internal environment for a range of parameters [88]. ZSW is collaborating with the DLR, Siemens AG Power Generation Group (KWU), and the Technical University Munich (TUM) on a joint direct steam generation research project known as GUDE [89].

3.3.2.3 Solar PV

The Federal Republic of Germany has had a PV R&D program since 1974. Between that year and 1990, the German government spent a total of DM644.4 million (approximately \$400-500 million) on PV technology R&D [71]. Since 1987, the German PV program, under the direction of the Federal Ministry of Research and Technology (BMFT), has been the most vigorous in the world. The federal contribution to PV R&D has been the world's largest in absolute dollars, as well as a proportion of the total energy budget, and as a proportion of the gross domestic product (GDP) (refer to Table 3.1 and Appendix B) [39]²⁸. Add to this financing provided by individual states (*Länder*) for R&D institutes located in their respective states, subsidies provided (by both the federal and *Länder* governments) for the purchase/installation of PV demonstration units, and the regulated resale of surplus electricity from renewable sources back to utilities, and Germany's support of PV technology becomes even more impressive.

Of equal importance is the fact that German PV manufacturing is dominated by two of the largest and most prestigious corporations in Germany,

Siemens²⁹ and Daimler Benz³⁰, as well as by one of Germany's largest electric utilities, Rhineland Westphalia Electric (RWE)³¹. Therefore, from a corporate standpoint, German PV R&D is backed by a considerable amount of potential financing, commercial expertise and market reach that can be applied to the research, development and dissemination of PV technologies at home and abroad³². German companies and research institutes are also eligible for cost-share participation in research, demonstration and dissemination projects organized and financed by the European Community (refer to Chapter 4).

A recent study of PV electricity application in Germany was conducted by Bayernwerke, in collaboration with RWE and Siemens. Small (less than 100 kW), medium (100-500 kW), and isolated (off-grid; batteries required) systems were analyzed, using C-Si and thin film tandem technology (CuInSi₂). From a cost and performance standpoint, the results favored the long-run application of thin film technology (efficiencies reaching 16-20 percent) in small-scale, rooftop applications, the cost of which was projected to be DM.66/kWh (approximately \$.40/kWh) by the year 2010. Medium-sized plants were projected to be DM1.0/kWh (approximately \$.60/kWh) by the year 2010, followed by isolated plants (the least efficient due to the BOS costs for storage) at DM4/kWh (approximately \$2.45/kWh) [93].

²⁸ All indications show that the federal government plans to continue spending at this level in spite of the growing strain that the costs of reunification are placing on the remainder of R&D spending by the Federal Ministry of Science and Technology (BMFT).

²⁹ Siemens is the primary owner of Siemens Solar (purchased from ARCO Solar in 1990) - the largest PV producer in the world, with 9.8 MW of modules shipped in 1992 [90]. A Bavarian Electricity Utility, Bayernwerke, is also a joint owner of Siemens Solar with a 49 percent share [57, 91].

³⁰ Daimler Benz owns Deutsche Aerospace (which owns Telefunken) and Messerschmidt-Boelkow-

Blohm (which owns Photronics).

³¹ RWE owns Nukem.

³² Siemens spends approximately DM7 billion (approximately \$4.3 billion) on research per year (11 percent of sales), and reportedly holds DM20 billion in liquid capital reserves [92].

Table 3.1 Energy R&D Spending [39].

1991 Government Energy R&D Expenditures								
\$ (millions)	U.S.	Japan	Denmark	France	Germany	Italy	Netherlands	U.K.
Energy R&D Budget	2536.71	2847.76	40.95	564.28	504.88	635.72	162.66	267.17
New Energy R&D	150.13	103.42	17.19	15.07	104.65	40.88	32.84	31.75
PV R&D	47.11	52.08	0	4.25	59.2	13.8	7.22	0
New Energy (as % total budget)	2.75	3.63	41.98	2.67	16.06	6.43	20.19	11.88
PV (as % new energy)	31.4	50	0	28	57	34	22	0
PV (as % total budget)	1.86	1.83	0	0.75	11.73	2.17	4.44	0
PV (as % 1990 GDP)	0.001	0.003	0	0.0006	0.007	0.002	0.004	0

These results are based upon a number of factors, including land cost, limited incident sunlight, and cheap existing sources of electricity. Germany is a relatively densely populated country, meaning that the land expense for large PV arrays would be a significant portion of the cost of large-scale domestic PV power generation³³. Second, Germany is a northern European country with long periods of cloud cover and inclement weather, thus the amount of usable incident sunlight is limited. Finally, conventional electricity costs much less than PV electricity: DM.15/kWh (approximately

\$0.09/kWh) vs. DM2/kWh (approximately \$1.25/kWh)³⁴. The projections for cost reduction are significant, but through the medium term (up to the year 2010), PV electric will be too expensive and impractical to be utilized on a large scale in Germany. Therefore, the German vision for PV projected by this study is that it will be an important long-term source of supplemental electricity domestically and a potentially significant new export technology in the short to medium term.

The objectives of Germany's PV program are to: 1) reduce costs (through decreases in the costs of materials and manufacturing, and by increasing cell

³³ At least 18,000 500 kW PV power stations would be needed to replace one 1,300 MW nuclear plant [94].

³⁴ Conventional cost is for nuclear-generated electricity [95].

and module efficiencies); 2) improve systems (BOS) reliability and efficiency (through the use of long-term field tests and demonstrations to help assess and develop better components); and 3) increase viability of PV through demonstrations and incentive programs. Single crystalline and multicrystalline silicon (SC-Si and MC-Si) is still considered to be the only PV material mature enough for medium to large-scale power generation. However, thin films and new compounds are receiving a great deal of attention in the laboratories (government as well as commercial) [71].

German R&D is carried-out in government research institutes, universities and corporate laboratories. The Germans have a long history of excellence in basic research and have been successful in this aspect of PV R&D as well, regularly setting record cell efficiencies. However, German PV R&D thus far has not been particularly successful at transferring these laboratory achievements to the factory floor. Indicative of this is the fact that notwithstanding the amount of money spent over the past several years, Germany has not yet won a significantly larger share of the world market³⁵. This could be the reflection of a lack of coordination between government research centers and corporate labs, as well as an over-emphasis by government programs on achieving higher cell efficiencies rather than improving manufacturing processes.

An example of this is the Research Association for Solar Energy (Forschungsverbund Sonnenenergie). The association was formed with the encouragement of the BMFT to promote cooperation in renewables research at government research centers³⁶. It is especially charged with

³⁵ This does not account for the purchase of Siemens Solar in 1990, which effectively increased the German share of the world PV market from 4 percent to 20 percent.

³⁶ Nuclear Research Centre Julich (KFA); Hahn Mertner Institute, Berlin (HMI); German Aerospace Research Institute (DLR); Fraunhofer Institute for Solar Energy Systems (ISE); Center for Solar Energy and Hydrogen Research, Stuttgart (ZSW); and Institute for Solar Energy Supply Technologies, Kassel (ISET).

maintaining continuity of purpose and preventing redundancy, while also ensuring that each center maintains the diversity and decentralization that is considered to be a strength in German research in this field [71]. However, corporate labs are, as yet, not members of the association, thus problems of commercial focus will most likely not be addressed by the creation of this association.

Additionally, Germany has yet to establish an government/industry association with the specific mission of commercializing PV technology. Programs of this nature already exist in the US (US PVMat) and Japan (PVTEC). PVMat and PVTEC are intended to develop manufacturing technology that could aid commercialization by reducing costs.

What Germany lacks in government/industry coordination in the lab it makes up for in the field. Demonstration projects are an essential component of German PV development efforts. In fact, the share of the BMFT budget for demonstrations has ballooned in recent years, increasing 166 percent in 1991. An example of this emphasis on field demonstrations is the "1000-Roofs" Project, considered to be the "center of gravity" for German PV demonstrations for the early 1990s [71]. Begun in 1990, the project is a joint effort by the federal and Länder governments to provide incentives to home-owners for the installation of roof-top PV SC-Si arrays. The federal government (through the BMFT) reimburses up to 50 percent of the purchase and installation costs in the "old" states of Germany and up to 60 percent in the "new states" of eastern Germany. The Länder governments provide reimbursement of an additional 20 percent. The remainder is provided by the investor. Thus far, the project has exceeded the expectations of the BMFT, accounting for 1,500 small (1-5 kW), grid-connected, roof-top PV arrays sold (1000 installed and 500 more approved) [72].

Larger demonstrations include five operating PV power plants of over 300 kW each, run by a joint effort of the BMFT, utilities, and PV companies. The largest and most modern plant in Germany is at Lake Neurath, near Grevenbroich. Developed as a joint effort by RWE (financing 75 percent), BMFT, and the state of North Rhine Westphalia (financing 25 percent combined), the DM14 million plant (approximately \$8.5 million) has peak power capacity of 360 kW, with the potential

for producing 270,000 kWh/year (good enough for about 70 households). The plant's arrays use six different types of cells based on SC-Si and MC-Si materials only (measurements showed that amorphous cells were not suitable for high power, high voltage (1,000 V) installations in this region). Cells are provided by Nukem/Solarex (MC), Nukem/Telefunken (MC), Nukem/Siemens (MC), Solarex (MC), Telefunken (MC) and Siemens (SC) [96].

The Lake Neurath plant is part of a three-step program by BMFT to develop 1 MW of grid-connected PV power generation in Germany. The other two plants, with capacities of 340 kW and 300 kW, respectively, are at Koburn-Gondorf and Pellworm. There are also demonstration projects for agriculture (Pfalzwerke - by University of Siegen; 34 kW), PV-hydrogen (Saudi Arabia - by Hahn-Meitner Institute; 100 kW; Neunburg vorm Wald - by Solar Wasserstoff Bayern; 280 kW) and hybrid (Fehmorn - by Telefunken; 140 kW (PV)) [71].

Demonstrations play a vital role in disseminating the virtues and advantages of PV technologies to utilities and the general public. However, the BMFT's role in demonstrations such as these is, by law, strictly for R&D purposes. BMFT does not have a mandate for market introduction and dissemination of its R&D products, which is the responsibility of the Ministry of Economics. The bulk of the money spent on PV by the German government is allotted to the BMFT; therefore, there is no official mechanism in place to specifically promote PV products on the market (domestically or otherwise) [72]. Any further spending on PV for such measures becomes a question of where the money will come from at a time of severe budget strains due to the costs of reunification.

German companies have continued to expand PV production facilities. The following is a sample of the new plants:

Photronics (50/50 subsidiary of Messerschmidt-Boelko-Blohm GmbH and Total Energie of France) has built a 1 MW/year PV pilot production facility at Putzbrunn (near Munich) that will produce large-surface (60x100cm²/1-4mm thick), thin layer, 5 percent, a-Si PV modules. The entire production process is fully automated and

computer controlled, and involves the application of the a-Si to glass substrates that are already fitted with transparent electrodes (thin film transistors). This is done using a vacuum process. The substrates are imported from Japan. Total cost for the plant is DM110 million (approximately \$67 million), of which DM45 million (\$28 million) is provided by the BMFT. These large-area modules are envisaged as being applicable to use in building constructions as facades, awnings, etc. In addition they could also be incorporated into auto construction as part of a rooftop air conditioning system [97, 98].

Nukem (subsidiary of RWE (Rhine-Westphalia Electric Group)) began operation of a new 1 MW/year pilot plant at Alzanaeu, which produces MIS (metal isolator silicon) inversion layer solar modules. Over DM50 million (approximately \$30 million) has been invested in developing this module design, DM20 million (approximately \$18 million) of which was provided by the BMFT. Of specific importance is the fact that the modules produced are of a monolithic design, and do not require the interconnection of individual PV cells. Due to this module design, the production process requires fewer stages, less material and less energy. Additionally, the module design is bifacial, thus leading to increased efficiencies of 15 percent for SC-Si and 13 percent for MC-Si. The modules, which have a surface size in excess of two square meters, are also ideal for use in building facades, roofs, and small-scale PV power stations [99].

Battelle has developed a new production method for crystalline CdTe compound Thin Film PV cells. The substrate is common glass, and the method of crystal growth, called closed-space sublimation, allows for high speed production of cells (six square meters per hour) with minimal material and efficiencies reaching 11 percent. Battelle estimates production costs to be DM200 to 300 per square meter, leading to an installation cost of DM2000-3000/kW. This is as much as 80 percent lower than the present price of PV cells [100].

German companies have had some recent successes overseas that have each been touted as the largest PV deal ever. First, in 1992, Telefunken won a contract with the Iranian national telecommunications company, TeleCom, Co. The contract called for the delivery of turnkey

production plants for the manufacture of MC-Si cells and modules, as well as enough silicon wafers, cells and modules for 2 MW of production capacity in Tehran. It also included the training of personnel and the supervision of the plant construction. The value of the contract is unspecified [101]. Second, in 1991, Siemens Solar won a contract to supply 640 kW of PV power to several countries in Saharan Africa. The contract is worth DM30 million (approximately \$18-20 million) and was designed and financed by the EC [102]. Elsewhere, Siemens Solar has been active in southeast Asia, India, and Mexico³⁷.

Siemens' purchase of ARCO Solar was designed to achieve just these kinds of results. It is not unreasonable to suggest that the Sahel contract in particular was won on the basis of ARCO Solar's international reputation. The combination of this inherited market presence, combined with the resources of the parent company, provide Siemens Solar with significant potential for tapping PV markets worldwide. Its acquisition places the German PV industry at the forefront of global commercial PV application.

In sum, the Germans look to PV as an integral element in their efforts to conserve conventionally produced electricity, and reduce emissions and energy dependence domestically. The magnitude of their efforts, versus the promise for large-scale domestic PV application in the short to medium term, indicates that future exports of PV are also a major consideration by the government and industry.

Technologically, the German PV program is world class. Commercially, the Germans lag behind the Japanese in translating their basic technologies to the factory (similar to the problems that exist in the US). Despite the level of support devoted to PV R&D by the federal and state governments, there is

some discontinuity of effort between basic research, development and demonstration and the commercial promotion of PV within Germany and abroad. Still, the continued commitment and combined efforts of German industry and the federal, state and EC governments will aid in the further reduction of costs and dissemination of German PV technologies throughout Europe and the world, ensuring that Germany will remain one of the most competitive PV producers in the world.

3.4 ITALY

3.4.1 Policy Overview

The issue of energy security is an especially pointed one in Italy. The country has no substantial domestic sources of energy. It produced only 18 percent of its total primary energy supply (TPES) in 1991, and its dependence on oil and oil imports (as a percentage of TPES) is among the highest of all the countries in the IEA (59 percent and 92 percent, respectively) [44]. In addition, an Italian referendum on nuclear energy in 1988 (post-Chernobyl) effectively shut down the nuclear power industry in Italy [7]. The moratorium ended in December of 1992, and as of yet, it is unclear whether the industry will be revived or not. Public opposition against the siting of new thermal power plants has also hampered the government's attempts to diversify Italy's electricity generation base through the use of coal - which is imported at a rate of over 98 percent [44]. Consequently, the options with which the Italian government must devise its energy policy are restricted, forcing policy-makers to consider every alternative.

Italy's most recent energy strategy, as laid out in its National Energy Plan (PEN, established in late 1988), attempts to integrate national environmental concerns with energy security policy. PEN is focused on: 1) conservation and energy efficiency; 2) expansion of indigenous energy sources; 3) development of independent electricity generation from renewables and co-generation; 4) expanded use of combined cycle gas turbines for electricity generation; and, 5) diversification of energy imports - sources and substances. From an environmental standpoint, the primary driving force behind PEN is meeting the UNCED and EC-

³⁷ Note: The extent to which the German government is aiding in Siemens', or any other German company's marketing efforts overseas is unclear at this time. The issue of "tied-aid" is a possibility; however, none of the unclassified sources used for this report to date have specifically referenced tied-aid for German PV projects or for PV projects of any kind, for that matter.

wide CO₂ emissions targets for the year 2000 and beyond³⁸. This includes a specific strategy to increase the share of renewables in the energy mix to three metric tons of oil equivalent (Mtoe) (up from 0.2 Mtoe in 1987) by the year 2000 [103]. Policies in place to achieve this goal include Law 10/91 which provides grants of 20 percent to 40 percent of investment costs to independent producers of renewables-generated electricity. Additionally, up to 50 percent of total investment costs are provided for "innovative" projects involving renewables (55 percent for large projects, 80 percent for solar heating) [39].

Energy R&D spending levels in Italy have traditionally been among the highest in Europe. According to the International Energy Agency (IEA), Italy spent the most on total energy R&D in 1991 of any European nation, approximately \$673 million [44]. Demonstration projects of various sizes have been established throughout the country, and Italian researchers have moved aggressively to promote international collaborative efforts.

However, the immediate future of renewable energy in Italy is currently being jeopardized by an ongoing governmental preoccupation with scandals, political upheaval, and fiscal austerity [81]. In addition, major government agencies responsible for alternative energy research and development are in such crisis that Italian renewable energy programs have been stalled since early 1992 [81]. This applies to ENEL (the National Agency for Electricity Production) as well as to ENEA (the National Agency for New Technologies, Energy and the Environment). ENEL is Italy's main utility company, and provides about 87 percent of Italy's electricity [7]. ENEA was Italy's nuclear energy agency before Italy abandoned nuclear energy, and now is struggling to adjust to its new identity while at the same time coping with a serious lack of funding [81]. ENEL began the first steps toward privatization in August 1992 [20], and embassy sources say that the process has "paralyzed" the organization³⁹. It is

hoped that privatization will help ENEL's image as an arm of the central government. This image has played into an over-riding suspicion of governmental programs that has made it difficult for ENEL to work with local authorities and citizens groups in support of renewable energy development [81]. In the past, ENEL tended to downplay foreign markets. That will probably change as they strive to increase profits and compete against private US, Japanese, and European companies.

The Italian government must resolve its energy policy in the short term in order to prevent Italy's vulnerability to international fluctuations in the oil and gas markets from becoming even more acute. The impasse over nuclear and coal-fired power plants and the budget restraints on new energy research act to inhibit immediate progress in this area. As a practical matter, however, Italy's immediate energy future will most likely entail a limited re-establishment of nuclear power, the construction of a number of modern, coal-burning thermal power plants and widespread implementation of various renewable energy technologies for small-scale residential and commercial applications. Because Italy is so well suited for a number of these technologies (PV solar, wind, and geothermal) - in addition to its import dependence - it is plausible that Italy could eventually become one of the most pervasive pioneers of practical renewables applications in Europe.

3.4.2 Energy Programs

3.4.2.1 Wind

Italy is attempting to capitalize on its RD&D expertise in wind technology, and is taking steps to develop appreciable domestic wind generated electrical capacity⁴⁰. Along with Britain, Italy is the EC country which has most emphasized

³⁸ Goals for the year 2000: reduce SO₂ by 75 percent; NO_x by 40 percent; and CO₂ by 32 percent [103].

³⁹ It is hoped that the privatization process will be completed during 1993.

⁴⁰ Italy's domestic wind resource is modest compared to that of northern Europe. Average wind speeds at local Italian sites considered suitable for wind energy development [81] are, at best, near the lower end of wind speeds for developed sites in California.

RD&D as opposed to wind power development [2]⁴¹. Domestic operating wind energy capacity in Italy is currently 6-7 MW (or about 11 MW considering experimental units)⁴². When healthy, Italy's development programs have been marked by close cooperation among the government, the main national utility company, and the major manufacturers [20], who are looking abroad (especially within the European Community) for market opportunities [81]. Relatively slow progress has been characteristic, with little involvement from small or privately owned manufacturers [6]. Italy's two largest wind turbine manufacturers have produced advanced products which may be technologically competitive on the world market. Development of these products was directly funded by the Italian government and the EC. Technological competitiveness may not translate to future market success for these Italian machines, since their greatest challenge will be price competitiveness with machines developed by other countries (such as the US and Denmark) with more mature domestic markets [81].

PEN set a target of 300-600 MW of installed domestic wind generating capacity by the year 2000 (see Footnote 7). The higher target will apply if large machines become economically viable by that time [6]. Installed domestic capacity will grow during the 1990s, encouraged by PEN and new legislative measures which provide incentives to wind energy investors [20].

⁴¹ In contradiction to International Energy Agency (IEA) data, knowledgeable Italian sources confirm that Italy is *not* the world leader in government expenditures for wind energy R&D. Italy's wind energy program was funded at about 43 million dollars over the seven year period 1986-92. Of this, 2.7 million dollars came from the European Community (EC). IEA data incorrectly states that the Italian government spent 24.4 million dollars in 1991 for wind energy R&D. In reality, this figure is roughly the total government expenditure over the seven year period [81].

⁴² Note that because of Italy's lower average wind speeds, a unit of installed capacity (in MW) in Italy likely corresponds to less useful energy than does an equivalent installed capacity in northern Europe or California.

However, growth will likely not meet established goals and expectations, due to several factors discussed in the following.

Private investment in wind energy development has been especially encouraged by recent incentives. Up to 40 percent of the costs of installing wind turbines can be covered by the government. In addition, premium payments of \$0.14/kWh for wind generated electricity sold to ENEL by private owners of wind energy plants have also been imposed. These premium rates will be in effect for five years (see Footnote 7). The Interministerial Committee on Prices (CIP) issued a special directive in November 1990 that was meant to provide private investors with financial backing for renewable electricity generation [6]. In lieu of a 30 percent underwrite of plant construction costs [81], a payment price of 150 lire (about \$0.10/kWh) is available to wind energy plants coming on line after January 30, 1991, for the first eight years of plant operation. The payment then drops to 75 lire (about \$0.05/kWh). The initial payments are reduced somewhat if the plant also receives certain other subsidies [20]. These production incentives, although large compared to US programs in absolute terms, are considered by knowledgeable Italian sources to be inadequate, given the high price of investment capital in Italy [81].

Four organizations play a major role in Italy's wind industry. They are: ENEL; ENEA; Alenia (a state owned aerospace firm with WEST wind energy systems, or Alenia/WEST, as a subsidiary)⁴³; and the privately owned Riva Calzoni company [81]. ENEL, ENEA, and Italy's Ministry of Industry plan and provide funding for Italian wind energy RD&D [7]. In addition, Italian ventures receive funding through the CEC THERMIE and JOULE programs [81].

ENEL cooperates in prototype wind turbine testing [20], and has a mountain test site at Alta Nurra in Sardinia to evaluate the performance of both domestic and foreign-made turbines in harsh high

⁴³ Alenia resulted from the merger of Aeritalia and Selenia in early 1991. Alenia/WEST manufactures medium- and large-scale turbines [20]. WEST stands for Wind Energy Systems Taranto.

altitude conditions. A second ENEL test site is located at Acqua Spruzza in the Appenines of central Italy [7]. ENEL has planned two new wind farms with a total capacity of 20 MW. Problems with local authorities, and political difficulties, have thus far prevented the realization of these facilities. One of the wind farms will use bi-blade horizontal axis machines from Alenia/WEST, while monoblade (single blade) horizontal axis machines (the M-30) from Riva Calzoni will be used at the other [81]. In addition, ENEL plans to build two more 10 MW wind farms, one at a hilly coastal site in Sardinia, and another in mountainous terrain in the Appenines in southern Italy. An additional eight to ten wind farms with a total capacity of 40 MW are envisioned for construction over the next five years [7].

Riva Calzoni has been a well-known manufacturer of mechanical and hydraulic equipment for over a century. Riva entered the wind turbine manufacturing field in 1978 [7], developing its M-30 machine in cooperation with the German firm MBB⁴⁴. Riva's major current activities are focused on the further development of its M-30 family of medium scale (250 kW - 350 kW) machines [20]. The M-30 is the only medium scale monoblade machine in the world today. Only half of its development funding was provided by Riva. The remainder came from ENEA (40 percent) and the EC (10 percent). The EC played a very large role in supporting the installation of the first commercial M-30 plants⁴⁵. Four have been placed in operation to date. A prototype variable speed M-30 is in operation in Germany, and an M-30 is being tested in Japan. Two M-30 machines have been installed at Tocco da Casauria in the first wind energy plant commissioned directly by an Italian community [81]. Riva Calzoni has also developed a small (5 kW) monoblade horizontal axis machine (the M-7), which they hope to use in standalone applications in isolated locations,

⁴⁴ MBB developed the rotor of the M-30 and then lost interest in the project, opting to focus on its own larger scale machines [81].

⁴⁵ Funding was provided by the EC VALOREN program, for the development of indigenous energy resources in disadvantaged areas of the community [81].

particularly in developing countries. EC support has led to initial M-7 sales to Brazil and Argentina [81]⁴⁶. Riva Calzoni is also designing the M-55, an 800 kW monoblade machine [7].

ENEA promotes the wind energy industry by providing both technical and financial support. The current ENEA program consists of four major areas: locating suitable turbine sites via development of a national wind resource map, and developing improved methodologies for locating sites; developing planning methods and turbine technology via cooperative research with universities, research organizations, and manufacturers; developing turbines, with a focus on innovative concepts; and, developing wind turbine plants [20]. ENEA joined in a cooperative agreement with ENEL, the CEC, and Alenia/WEST to develop the GAMMA 60, a two-bladed 1.5 MW horizontal axis machine which personnel at both ENEA and ENEL consider Italy's state-of-the-art turbine [81]. The GAMMA 60 is Italy's largest turbine, and commercial production from the machine is hoped for in 1994 [104]. The first GAMMA prototype (the first of three planned [7]) became operational at Alta Nurra in 1992. Its developers claim that the GAMMA 60 would be the first commercial large-scale machine in the world [81], and if it is successful, the Italians plan for it to play a major role in achieving their target year 2000 domestic wind energy capacity [7].

The GAMMA 60 has several innovative features designed to make it commercially viable. The goal in the machine design is to increase simplicity and lower manufacturing and maintenance costs by

⁴⁶ The jury is still out on whether monoblade designs possess technical advantages over machines with multiple blades. Monoblade horizontal axis machines can be visually disturbing (i.e., they just don't *look* right). The M-30 machine has a hydraulic yaw system which keeps the rotor downwind of the tower [81]. This is an unusual characteristic for an active yaw machine. It is normally considered advantageous to keep the rotor *upwind* of the tower, thereby avoiding tower wake effects which are a predominant blade load. Eliminating blades seems attractive in terms of lowering overall turbine weight, but this effect is somewhat negated by the need to add a large balancing counterweight.

eliminating all control components from the rotating parts⁴⁷. Domestic market prospects for the GAMMA 60 appear poor, because its extreme size and weight make it an impractical option for Italy's best wind sites, typically in remote mountain areas. Alenia/WEST intends to aggressively pursue the US market with its GAMMA 60 machine [81]. This is an interesting possibility since no US domestic producer is pursuing large turbine development. Alenia/WEST also produces the bi-bladed fixed speed 320 kW MEDIT machine. Like the GAMMA 60, the MEDIT has glass fiber composite blades and an upwind configuration. Future versions of the MEDIT will be variable speed with some GAMMA 60 technology incorporated. Thus far, Egypt has been the only foreign MEDIT purchaser [81].

3.4.2.2 Solar Thermal

Italian activities in solar thermal technology do not appear to be significant, and Italy is not viewed as a potential leader in this area in the foreseeable future. Only a short overview is provided here.

The field of "bioclimatic architecture" has been under study in Italy for more than a decade. This is a phrase used to describe a large body of information on the thermal characteristics of and energy use in buildings. An analysis of available information has been carried out within the Italian National Energy Project (PFE) [105].

The world's first scientifically rigorous central receiver system experiments were conducted in Italy (at the University of Genoa) in the 1960s. These early experiments led to the construction (in

⁴⁷ The GAMMA 60 uses an innovative technique to control the power flowing through its rotor and drive train. The most controversial aspect of the GAMMA 60 design is its fixed blade pitch. Yaw control is used to control power by adjusting the blade angle relative to the wind. The entire nacelle and rotor may be yawed out of and into the wind. This is considered by many experts a possible source of excessive wear, since large cyclic loads could be introduced into the blades, bearings, drive train, and tower. Alenia/WEST designers claim that these concerns are addressed with redundant failsafe mechanisms in the GAMMA 60 [7, 81].

Italy) of the Advanced Components Test Facility, a solar steam generator now located at the Georgia Institute of Technology in the US (see Footnote 13). The Eurelios central receiver plant in Sicily was sponsored by the Commission of the European Communities (CEC) [63]. This 1 MW plant, completed in 1980, used the same HITEC salt used in the French THEMIS plant for its thermal storage system [64]. It used steam for heat transfer [63]. The Eurelios plant has been pulled out of service.

The Trisaia Center in the region of Basilicata is conducting research into solar water desalination as part of a shift to environmental studies, away from its earlier mission as a research laboratory for the nuclear fuel cycle. The center, owned by ENEA, had been idle for some time when Italy abandoned nuclear research. The Italian government (with joint funding from ENEA) has supported the transition of the Trisaia Center's mission as part of a program to develop Italy's southern regions [106]. It is not clear whether solar thermal or solar PV technology (or both) is being pursued in the center's desalination research. Considering the chaos created within ENEA overall by its changing mission [81], including ENEA's attempts to reassign technical professionals who have spent their entire careers studying nuclear issues to new areas with which they are unfamiliar, the short term quality of solar thermal research at the Trisaia Center may be suspect.

3.4.2.3 Solar PV

Italy's PV program is one of the most vigorous in the world. Italy's PV technology base is not comparable to that of Germany, Japan, or the US. Thus, the Italian government has pursued PV development through aggressively organized PV demonstration projects and joint R&D programs, and has established subsidies for private and commercial PV installation as well as regulations requiring utilities to purchase renewables-generated electricity.

Italy's energy strategy has focused specific attention on PV as one of the most promising renewable energy sources for application in the near term. Italy's geographic location and climate (especially in the south) make it a viable place for the future (long-term) installation of medium to large-scale (100 kW - 1 MW), grid-connected PV power generators, as well as for short-medium term

installations of stand-alone and supplemental PV arrays on the roofs of residential, commercial and public buildings. Italy spends a substantial amount of money on all types of energy R&D annually⁴⁸.

The proportion of total energy R&D spending in Italy attributed to PV R&D and dissemination over the past several years has been significant⁴⁹. The primary focus of the Italian effort in this regard has been on cell R&D, the development of a standard PV module (PLUG, for PV low cost utility generator), wide-spread demonstration projects, and government subsidy and incentive programs. The primary players are the state-owned national utility (ENEL), the Italian Commission on Nuclear Energy and Renewables (ENEA), and the Italian PV companies, Italsolar, Anit and Helios⁵⁰.

PV research is conducted at ENEA's Center for PV Research (CRIF) at Portici, which functions as a locus for Italian and international cooperative research into a-Si, MC-thin films, and BOS technology. Another research center, DELPHOS (Demonstration Electric Photovoltaic System), is the site of a 300 kW demonstration plant and is specifically charged with research on large-scale PV systems. SC-Si research is conducted at the Cassoccia Center near Rome. All research in Italy is coordinated with Italian PV companies, ENEL, and other national laboratories [107].

ENEL's immediate goal is the installation of 25 MW of PV electricity by 1995. 11 MW are to be installed by ENEL itself, 2 MW by ENEA and 8.9 MW by the private sector. This is to be achieved through installations on the roofs of hundreds of

⁴⁸ In 1991, Italy spent approximately \$100 million more than Germany on overall Energy R&D (\$635 million vs. \$504 million) [39].

⁴⁹ Referring to Table 3.1, PV R&D accounted for 2.17 percent of Total Energy R&D in 1991. The proportion was 2.30 percent in 1990 [39].

⁵⁰ Anit and Italsolar are products of a recent restructuring of the Italian PV industry: Anit is a consortium organized between Ansaldo and the Italian Petroleum company, Agip. The aim is to produce turnkey PV power stations. Italsolar specializes in PV module manufacturing.

isolated homes and commercial buildings (financed up to 80 percent by the government), and the development of six large demonstration projects (three 100 kW projects and three 3 MW projects) [107]. In following this strategy, Italy will become one of the most prodigious PV markets in the world.

The significant portion of ENEL's projected installations that are attributed to the private sector are expected to result from private reaction to laws recently put into place to encourage PV use. The first requires utilities to purchase excess PV power from public and private installations at prices set by ENEL⁵¹. The second provides for government contributions of up to 80 percent of the costs of installed PV systems for buildings (domestic, industrial, commercial, touristic, agricultural and sports). This law extends benefits beyond those provided by previous legislation, which limited coverage to rural agricultural residences only. It also eliminates the 15 million lira cap on spending for PV equipment [107].

Current PV installations in Italy are dominated by small (1-1.5 kW), off-grid roof-top PV arrays for power generation in remote, isolated areas. Other applications are for telecommunications (0.5-10 kW), water desalination (up to 10 kW), water pumping (0.5-10 kW) and electrification for refrigeration (0.5-5 kW). All of these applications utilize PV arrays outfitted with SC-Si. Other applications (less than 100 W) use a-Si cells [108].

One of the largest utility-scale projects currently underway is a 3 MW PV power plant at Salerno, which when completed, will be the largest PV power plant in Europe. The plant will be comprised of 60,000 PV modules covering an area of approximately 20 acres and will cost an estimated \$64 million, all of which will be financed by ENEL. Initial module procurement was put out to international bid, with the French company Photowatt, the US company Solarex and the Japanese company Kyocera each winning contracts to supply 330 kW of PV modules. The Italian company Helios was contracted for 660 kW of PV modules. A second 3 MW power plant is to

⁵¹ Approximately 170 Lira/kWh (approximately \$.13/kWh) [107].

be installed by 1995. Its location has yet to be determined [109].

It is significant that ENEL has been given primary responsibility for most Italian activities regarding PV. ENEA, which is primarily a research organization, was formerly responsible for PV. The transfer of PV development responsibility to the national utility (ENEL) signals that the Italians perceive a degree of maturity in PV technology and the resultant need for the transition from the purely research phase of PV development to its economic application.

Thus far, Italian PV companies (Italsolar, Anit, Helios) do not have the capacity to produce their own SC-Si for the production of PV cells. As a result, Italian production costs are approximately 15-20 percent higher than those of other foreign manufacturers [108]. An indication of this lack of silicon capacity is reflected in the arrangement made by Helios in one of the Italian industry's only overseas projects. The project is a joint venture with South African, Russian and German companies to build a 1 MW PV power plant near Pretoria, South Africa. This venture will enable Helios to tap the growing South African PV market and establish a base for possible extension into the Australasian markets. The Russian company Moscow General Industries is to supply the single crystal silicon (SC-Si) ingots and wafers. (For more information on Russia, refer to Section 3.7). The German Marvol Group will do the marketing, and Italy's Helios will manufacture the cells, modules and PV systems. A South African company is to provide its expertise in local markets [110].

For the short term, Italy's primary significance in the PV industry will be as a market, serving as a sort of country-size PV laboratory. Its role in demonstrating PV, generating collaborative efforts, and disseminating information about PV systems capabilities and developments will be crucial to the advancement of sales and applications in the industrialized world as well as the developing world. The degree to which Italy is successful in implementing a significant PV generation system may depend upon the decisions that must soon be made regarding the reinstitution of its nuclear program and the use of coal in thermal plants. Public opposition against both of these electricity sources remains quite pervasive. However, Italy's

severe energy dependency and the threat that this poses for Italy's national security and continued economic growth may eventually prove to be more powerful than the environmental forces at play there now.

3.5 UNITED KINGDOM (UK)

3.5.1 Policy Overview

After some hesitation, the United Kingdom (UK)⁵² has acquired the political will to include renewables in its long-term domestic energy plans. Originally, UK interest in renewable energy technologies arose mostly out of concern for the security of energy resource supplies [6]. However, more recent events have pushed the UK towards renewables, most notably wind, in order to meet environmental commitments⁵³. The increased use of renewables will allow the UK to diversify its electrical generating capacity, which at present is heavily dependent on coal, nuclear, and oil (65 percent, 22 percent, and 9.4 percent of 1991 total electricity generation, respectively [44]) [21], and which is likely to increase its dependence on coal once available oil and natural gas reserves from the North Sea are depleted. The United Kingdom is presently very near to net energy self-sufficiency, having abundant indigenous supplies of oil, gas and coal and a well-established nuclear power industry⁵⁴.

The UK government has a target of 1,500 MW of new electrical generating capacity from renewable energy sources by the year 2000 [112]⁵⁵. UK

⁵² The UK consists of England, Wales, Scotland, and Northern Ireland.

⁵³ Britain cannot reduce its CO₂ emissions to levels agreed to at the 1992 Rio summit without further stringent energy efficiency measures, increased taxation on domestic fuel and power, or by the increased use of renewables [111].

⁵⁴ The UK's import dependence in 1991 was just four percent of its total energy supply [44].

⁵⁵ The installed electrical generating capacity in the UK is currently 70,000 MW [113]. Total UK

energy policy objectives over the near term have focused primarily on the privatization of its national energy industries (most notably, its coal industry), diversification of supply, and most recently, the reduction in the environmental impact of its energy sector.

The development of electricity-generating renewable technologies has been encouraged by the introduction of the Non-Fossil Fuel Obligation (NFFO) in the 1989 Electricity Act, which privatized the electricity supply industry in England and Wales⁵⁶. NFFO was primarily developed to support the nuclear industry, but it has provided a positive financial incentive for renewables and has accelerated some of these technologies into the marketplace because of a guaranteed market and premium price for electricity generated using renewable technologies.

The first round of the NFFO in 1989 marked a turning point in UK governmental support for renewable energy technologies [5]. Under the NFFO, RECs (Regional Electricity Companies) are mandated to purchase a certain amount of capacity from non-fossil sources (primarily nuclear, with a specific percentage mandated for renewables, primarily wind). In addition, a levy is imposed on

electricity consumption ranks third in the EC, trailing only Germany and France [7].

⁵⁶ Non-nuclear generating capacity in the UK is now controlled by three private generation and transmission companies. These are: National Power and PowerGen (power generation); and, NGC, the National Grid Company (power transmission). In addition, there are 12 Regional Electricity Companies (RECs). The RECs can purchase electricity from National Power, PowerGen, Nuclear Power (the non-private entity responsible for nuclear generating capacity in the UK), or from other RECs, and each REC is allowed to own or have direct interests in a limited amount of generating capacity. Large industrial users can purchase electricity from the RECs, National Power, PowerGen, or from any other source, and can connect directly to the grid via NGC. Before decentralization, National Power, PowerGen, the NGC, and Nuclear Power were combined into the Central Electricity Generation Board (CEGB), and the RECs were called Area Boards [7].

the price of electricity generated using fossil fuels [114], which is then paid to the non-fossil producers [7]. One aspect in which the NFFO program is lacking is that it is not structured to favor small scale developments [115].

The first two rounds of NFFO project solicitations require power distributors (RECs) to purchase at least 560 MW of renewable power by 1998 (see Footnote 7). The third round requires the purchase of an additional 300-400 MW, but in contracts that run 15-20 years. A fourth round in 1995, and a fifth in 1997, are also expected. Elimination of the 1998 deadline in the third round reduces project risk to the point where lower levys are required on fossil fuel generated electricity for payment to the renewable energy producers. This is partially because it becomes easier with longer contract durations to attract long term financial support. This reduces overall project cost. The new 15-20 year contract terms are consistent with UK government policy to create an initial market niche for renewable energy technologies, while then allowing the price of renewable-generated electricity to gradually come into line with other generation options without the need for further financial support [116].

The UK renewables industry has been effectively "on hold" during the extended period of time between the second and third NFFO rounds [117]. This much-criticized delay period will translate to a potential three year gap in renewable technology orders, since the third round is not scheduled to go into effect until November 1994 [116]. Scotland has recently announced its own Scottish Renewables Order (SRO) in separate NFFO-like legislation. The SRO provides for 30-40 MW of new generating capacity from renewable energy sources [118]. It is not clear how this new capacity is to be apportioned between the leading candidates of wind, hydro, and biofuels. Scotland was slow to receive its first renewables obligation, partly because of an overcapacity in electricity generation, led by hydropower. Despite this, and as evidenced by the new SRO, the political will does exist for the establishment of a renewable energy program in Scotland.

3.5.2 Energy Programs

3.5.2.1 Wind

The UK overcame a very slow start [5] to establish a reputation as a leader in wind technology RD&D. Current British wind energy programs are dominated by commercial scale projects backed by large companies or electricity industry partners [115]. Unfortunately, available price guarantees fail to accommodate demand because of severe limitations in the total installed wind generated electrical capacity which is allowed to benefit from them. In this sense, the UK is not taking full advantage of its domestic wind energy market opportunities⁵⁷.

A movement towards local community involvement in British wind energy is evolving. This, coupled with utility industry decentralization, will help the UK considerably over the next decade in developing its wind resource potential [115]. Britain has taken other steps recently which position it favorably for future growth in the wind energy industry. Britain has a well established system for premium pricing of the power generated from wind energy systems, and Britain has the most favorable wind resource in Europe. Due in part to successful programs such as the NFFO, Britain is poised to emerge as Europe's site of choice for further wind farm development. The UK, and Scotland in particular, possesses some of the best wind resources in the world [5, 11]⁵⁸. Because of Scotland's abundant wind resources, the SRO is disappointingly small to many observers [117].

An appreciable fraction of the renewable power purchases mandated by the first three NFFO rounds must be wind generated. The amount of the obligation to be allocated in the third round is

expected to remain at roughly 20 percent, as was the case for the first two rounds [116]. Many in the British wind energy community were among those who advocated extension of the NFFO subsidies well beyond 1998, as has occurred in the recent third round [119]. Unfortunately, the third NFFO round may only accommodate 15 percent of the wind energy projects that current developers would like to build, according to a recent survey. The 85 percent of projects unable to obtain NFFO price guarantees would likely remain unbuilt [120].

Britain has invested in wind energy RD&D since the 1970s, at a rate of roughly \$6 million annually for the past decade. The technical reputation of British work in this area is excellent, most notably in basic aerodynamics, structural modelling, and material properties [7]. Principal funding assistance for UK wind energy projects comes from the Department of Energy (DoE), the Department of Trade and Industry (DTI), and the Commission of the European Communities (CEC). RD&D activities for wind research in the UK have been prioritized by the British Wind Energy Association (BWEA). The Department of Energy and the Science and Engineering Research Council (SERC) have funded basic research on materials, fatigue, blade profiles, resource availability and offshore application of wind power [21]. Prior to utility decentralization, considerable research was done by the Central Electricity Generating Board (CEGB). Three groups carrying out important design studies for DTI are the Wind Energy Group, Ltd. (WEG, which is a joint venture of the Taylor-Woodrow Construction Company and the British Aerospace Corporation), Renewable Energy Systems, and Windharvester Ltd.⁵⁹ [20].

WEG turbines include the 33-meter, 300 kW, horizontal axis MS-3, which has been installed at four wind farms in Wales, Yorkshire, and Cornwall, as well as on the European continent and in California, and its precursors, the MS-1 and MS-

⁵⁷ The UK could well afford to be more aggressive. By the end of 1991, the UK only had an installed wind energy capacity of 12 MW, and much of this was in the form of research and demonstration (not commercial) machines [7].

⁵⁸ According to various sources, Scotland possesses between half and two thirds of the UK wind resource.

⁵⁹ Windharvester Ltd. has recently acquired the rights to technology developed by Howden Wind Turbines, Ltd., a subsidiary of the large steel designer and fabricator James Howden and Company, which has left the wind industry partly due to financial losses from blade failures on one of its early machines [7].

2. All of these machines have excellent operational histories. WEG is now developing the WEG400 (MS-4), a new and larger 35-meter machine which began prototype testing in Scotland in 1991. The WEG400 can be configured as either a 400 kW or 450 kW machine. Its design includes two blades and an upwind teetering rotor, like the MS-3, but has reconfigured blades and a softer drive train to allow it to operate more quietly and efficiently [121, 122]. WEG also designed and built the 3 MW LS-1 horizontal axis turbine, which became operational in 1988. WEG and National Power have recently formed National Wind Power Plc., which, unlike WEG, is specifically interested in the development of wind farms [7]⁶⁰.

Prior to when it left the wind industry, Howden developed some impressive machines. These included the 1 MW HWP-1000 (1989) and the 750 kW HWP-750, and the 330 kW HWP-330. The HWP-1000 was one of three demonstration turbines compared in the CEC WEGA program (refer to Chapter 4, Section 4.3.1) [123]. Many of the HWP-330 machines were installed in Altamont Pass in California, and it was early blade failures on these machines that helped push Howden out of the wind business. Besides all of the horizontal axis machines discussed above, British research into vertical axis technology has proceeded through Vertical Axis Wind Turbines, Ltd. (VAWT). This firm has designed innovative non-Darrius style machines rated at 100, 160, and 500 kW. Only a few of these machines have been built [7]⁶¹.

The DTI RD&D program is managed by the Energy Technology Support Unit (ETSU) at Harwell [20]⁶². The DTI program is divided into technology development, and studies of commercialization and exploitation of the resource. The technology development area is divided into

design studies and turbine technology development, which includes numerous advanced concepts in, for example, stall regulated rotors (using flow visualization and particle image velocimetry or PIV), advanced control algorithms, structural dynamics, and advanced materials. DTI is also involved with regional resource planning studies, turbine noise and visual intrusion studies, studies of the integration of wind generated power into the electricity distribution network, and studies of the effect of turbines on broadcast signals. The SERC R&D program is managed by the Rutherford Appleton Laboratory (RAL), and funds academic research. Some of the current areas of interest include advanced PIV concepts, nondestructive testing (NDT) using infrared imagery, and nonsteady aerodynamics [20]. Scotland's National Wind Technology Center is another important national lab.

The number of established UK manufacturers of wind turbines is relatively small. One of these, the British wind power company EcoGen, is backed by two foreign joint venture partners: the US company SeaWest (one of the world's largest buyers of wind machines), and the Japanese general trading group Tomen. This partnership has won 75 MW of NFFO contracts, in which Mitsubishi turbines will be installed atop US towers. While the UK's 1993 turbine installation rate will exceed that of any other country [11], about 80 percent of the generating capacity for NFFO wind projects either operational or under construction as of September 1, 1992 was provided by manufacturers other than those in the UK (the manufacturers were primarily from Denmark and Japan) [20].

3.5.2.2 Solar Thermal

The United Kingdom (UK) has responded to its exceptionally poor solar resource not with the long term vision of Germany, but more with the pragmatic viewpoint of Denmark. As a result, the UK will not be a major player in the future solar thermal technology picture. More than half of the solar radiation received in the UK is diffuse (scattered in passing through the atmosphere), which severely limits the viability of most solar

⁶⁰ These wind farms will use the most advanced turbines available, whether or not they are WEG designs.

⁶¹ These machines have straight blades, typical of vertical axis turbines designed in the UK [123].

⁶² Harwell is an important national lab, and is the UK's equivalent of the National Renewable Engineering Laboratory, NREL, in the US.

thermal technologies in that region⁶³. While the UK Department of Energy (UK DoE) has recognized passive solar concepts as economically attractive, even promising, the same cannot be said of other solar thermal applications. Viable domestic uses within the UK include solar hot water heating and the heating of swimming pools [21]. The UKs Renewable Energy Advisory Group (REAG), a twelve member board of independent industrialists, scientists, and economists, has recommended that solar water heating and passive solar gain through building design continue to receive R&D funds [124].

Flat plate collector work began in the UK in 1947. As the 1970s began, only two small solar companies were working in the UK. By 1976, solar water heaters were found to be economically justified (in terms of their payback period) by the UK Section of the International Solar Energy Society. Recognizing a potential domestic market, the UK DoE launched in 1977 a program to encourage active solar heating. The program was not very successful (with the exception of swimming pool heating), in part because of falling oil prices and only small rises in the price of conventional fuels [21].

The UK DoE estimates that an annual domestic contribution of up to 14 Mtce (million tonnes of coal equivalent) could be had from passive solar technologies. The DoEs Passive Solar Programme is coordinated with other government programs for building R&D (such as those of the Department of the Environment, the Energy Efficiency Office, and the Building Research Establishment). The UK DoE is performing a number of design studies (as opposed to field tests), and is monitoring energy flows and perceived environmental quality in a number of domestic and non-domestic buildings equipped with passive solar energy systems. Similarly designed buildings without passive solar features are also monitored to provide

a comparison. The final goal is to develop a comprehensive technology transfer program useful to homeowners, builders, officials, and others. This program will help soften existing institutional barriers to solar energy utilization within the UK, namely, a lack of education about and experience with solar energy applications, and, the fact that developers of public sector buildings have typically not considered energy use as a guiding factor in building design. One indicator of a change along these lines: most of the 500 retail and leisure developments under construction in the UK as of 1987 featured atria, an attractive passive solar feature. The single largest solar housing project in Europe, the Bourneville Village Trust Solar Village, is located in the UK. It was partially funded by the Commission of the European Communities, and was begun in 1984. Several different house types are included in the project. The Bourneville Village "Demonstration House" combines both active and passive features [21].

3.5.2.3 Solar PV

Despite the UKs negligible solar power program, BP Solar (a subsidiary of British Petroleum) is one of the world's leading PV companies in the design and installation of PV systems for off-grid electricity, benefitting from British Petroleum's financial resources and worldwide reach⁶⁴. BP Solar is one of the few PV producers (NAPS France being another) that does not receive significant financial aid from its home government.

BP Solar sells and installs complete PV systems, some of which contain CSi modules produced under a license awarded by Prof. Martin Green of the University of New South Wales (UNSW), Australia⁶⁵. BP Solar maintains a production facility in Australia which provides excellent access to the markets of Asia and southern Africa, specifically, Indonesia, the Philippines, Sri Lanka, India and South Africa. BP Solar also has a production facility in Spain, giving it access to the markets of Europe and North Africa.

⁶³ Dover Tower, a holding company in London, owns the equipment from the defunct LUZ SEGS X project, and is viewed as a potential supplier for a proposed demonstration parabolic trough power plant in India. No other potential tie between the UK and solar thermal electricity production has been found.

⁶⁴ British Petroleum, the fifth largest corporation in the world, shipped 3.5 MW of PV modules in 1992 [65].

⁶⁵ UNSW (and Prof. Green) is renowned for PV-cell research.

Recent activities in these markets include a joint venture with an Indian PV manufacturer, and a joint project in Sri Lanka between BP Solar and the Australian High Commission (AHC), which has installed 1,000 0.55 kW household systems. Another 34,000 homes are currently targeted for installation in Sri Lanka. BP Solar and the AHC are to install 25,000 of them, with the Dutch government installing up to 6,000. The remaining installations are to be divided among several other companies. Funding is to be supplemented by the Asian Alternative Energy Unit of the World Bank [125].

BP Solar's interests are strictly commercial. There are no political or social movements pushing its efforts. In fact, it is the political, social and developmental efforts of countries and non-governmental organizations around the world that are *pulling* its efforts by creating demand and providing funding for projects that BP Solar competes for and wins. Granted, the EC probably has opened some doors for BP Solar projects; primarily, though, BP Solar is self-sufficient and successful.

BP Solar is definitely a force to contend with in the future international PV marketplace. The benefits that the company gains from the resources and global presence of its parent company are significant. Long-standing relationships that have been established by British Petroleum worldwide provide BP Solar with an especially competitive advantage in extending its own presence and products into potentially lucrative markets. Access to licenses from research centers such as the University of New South Wales allows BP Solar to direct the bulk of its resources toward the development and marketing of PV systems rather than to basic research, thus ensuring a more commercial approach to its technology development efforts than that of many of its competitors.

3.6 JAPAN

3.6.1 Policy Overview

Japan is one of the most import dependent of all the IEA countries, importing 84 percent of its total

primary energy supply in 1991 [39]. Security of supply and conservation have therefore been the primary bases upon which Japanese energy policy has traditionally been shaped. As a result, Japan has become one of the most energy efficient countries in the world. It is also one of the world's most aggressive developers of nuclear energy. Nevertheless, imported fossil fuels continue to be the most significant Japanese energy source, with oil and gas imports accounting for 67 percent of the total Japanese energy supply in 1991 [44].

In addition to security of supply, growing international concern over the environmental damage caused by fossil fuels has begun to play an increasingly pivotal role in the development of Japanese energy policy. The Japanese government has expressed its view that expanded use of fossil fuels by developing countries and the resultant increase in pollution and environmental degradation is one of the most important factors facing the world economy in the 21st century [126]. In accordance with these concerns, Japan was among the signatories of the UNCED protocol, pledging to stabilize its CO₂ emissions at 1990 levels by the year 2000. Japan will need to significantly increase both its energy conservation activities and its utilization of clean sources of electricity in order to realize its pledge.

The dangers of potential global warming have been brought close to home in Japan, which, as an island country, is especially vulnerable to the potential of rising sea levels - a possible consequence of global warming. It has been estimated that a one meter rise in ocean level could inundate most of coastal Tokyo [127]. The Japanese government has therefore taken a turn toward integrating strategy planning in the energy and environmental fields with that of economic growth, placing much more emphasis on international cooperation and technology transfer to developing countries than ever before.

Japanese import vulnerability has forced the Japanese government to spend a considerable amount of resources in the research and development of new energy technologies over the years. Since the 1970s, the Ministry of International Trade and Industry (MITI) has spent billions of dollars funding programs in nuclear and non-nuclear RD&D. Although nuclear power has been and remains the primary focus of Japanese

energy research, the New Energy and Industrial Technology Development Organization (NEDO, which is part of MITI) established two specific long-term programs for the development of energy conservation and non-nuclear energy technologies: the "Sunshine" and "Moonlight" projects. Since their inception in 1974 and 1978, respectively, over half a trillion yen (approximately \$6 billion) has been spent on these projects combined.

The most remarkable measure of Japan's new energy focus is the consolidation of the Sunshine and Moonlight Projects into the "New Sunshine Project" (NSP) in 1992. The NSP is a product of MITI's judgement that in order to address global environmental threats it will be necessary not only to develop new, environmentally benign energy technologies, but transfer them to developing countries, where the threat of environmental damage is the greatest in the near-term [128]. The three main components of the NSP are: 1) Innovative R&D Program⁶⁶ focused on the development of environmentally friendly technologies such as clean coal, fuel cells, photovoltaics, ceramic gas turbines, battery storage and superconductors; 2) International Collaboration Program on Large Projects⁶⁷ focused on hydrogen conversion, lean-burn engines and CO₂ fixation and absorption technologies; and, 3) Co-operative R&D Program on Appropriate Technology⁶⁸ focused on the transfer of new energy technology and techniques to developing countries [44]. In turn, NEDO itself has been reorganized into three new sections: 1) New Energy Promotion Department, which will promote the commercialization and dissemination of new energy technologies; 2) Clean Coal Technology Center; and, 3) Global Environmental Technology Department, which will perform R&D on technologies and methods to reduce the environmental effects of conventional fossil fuels.

The fiscal year 1993 (FY93) budget for the NSP is ¥53.9 billion (approximately \$515 million), representing 24 percent of the total MITI budget. The amount of this budget directed toward "Solar Energy" for FY93 is ¥7.7 billion (approximately \$70.6 million at current exchange rates), an increase of ten percent over 1992, and 58 percent of all Japanese government funding for renewables R&D in 1993 [129].

In addition, MITI has instituted a Green Aid Plan, which will work with existing governmental agencies (Japan International Cooperation Agency (JICA), Overseas Economic Cooperation Fund (OECF), and NEDO) to establish and coordinate energy and environmental R&D projects and demonstrations in neighboring Asian countries, with the ultimate goal of selling Japanese "green" technology and providing Japanese firms with access to the energy markets of these countries. Green Aid's budget for 1993 is \$120 million, about five times its budget in 1992. Japan's particular geographic focus with regard to these efforts is Asia and the Pacific Rim - especially the countries of the Association of South East Asian Nations (ASEAN) [126]. MITI has reportedly targeted Indonesia as the primary target for "Green Aid" in 1993 [130].

The NSP and the Green Aid Plan have placed considerable focus on the international application of renewables and other new energy technologies, while domestically, nuclear power remains the centerpiece of Japan's national energy portfolio. Although new energy technologies are being aggressively introduced and demonstrated throughout Japan and provide significant potential for reducing Japan's reliance on imported fossil fuels as well as for reducing environmental damage at home, the transfer of these technologies abroad and the development of new markets in neighboring Asian countries seems to be one of the over-riding priorities of the Japanese program in new energy technologies. It is therefore likely that Japan's efforts in developing these technologies will greatly out-weigh the capacity of its own domestic energy sector to apply them in the short term.

The successful commercialization of all types of Japanese technologies has in the past been enhanced by aggressive marketing tactics by Japanese companies. These tactics have in many

⁶⁶ budgeted with ¥500 billion (approximately \$5 billion) through the year 2000 [44]

⁶⁷ budgeted with ¥900 billion (approximately \$9 billion) through the year 2020 [44]

⁶⁸ budgeted with ¥150 billion (approximately \$1.4 billion) through the year 2010 [44]

instances included the establishment of market footholds through temporary cut-rate pricing schemes. However, Japan's current ability to underprice their competitors on world markets is being slowly undermined by socio-economic factors. Hard work for relatively low wages is part of the post-WWII Japanese culture, and arose in part because of rapid expansion in their work force. Current labor shortages are forcing wages upward and reducing the ability of Japanese companies to lower their prices to below-market levels [131], even on a temporary basis. Therefore, Japanese advances into long-term international markets in all areas of technology will depend more and more upon competitive improvements in their basic research and development. This comes at a time when Japan's poor economic health is causing many Japanese companies to cut back on their research expenditures. Current negative trends may have occurred too late to adversely impact Japanese competitiveness in renewable energy technology areas which are already commercially viable in some markets, such as wind and certain solar thermal applications, but tangible impacts on other technologies with maximum potential in the medium to long term may be felt.

3.6.2 Energy Programs

3.6.2.1 Wind

Japan could become a major player in wind energy technology, but neither the government nor the private sector has identified it as a priority. The Japanese government position on wind power has heretofore been cautious. Major governmental objectives are lowering costs and increasing efficiency [132]. Also of major concern is the question of whether it is even possible to construct turbines which can operate reliably in Japanese environmental conditions (i.e., the yearly typhoon season). Partly because of this concern, Japan joins the US in not pursuing large machine technology [133]. As a result, Japan will likely not be a major player in the developing European market. However, Japan could position itself to capture a portion of the longer-term market in lesser developed countries (LDCs).

Mitsubishi Heavy Industries, Ltd. (MHI) possesses both technical and manufacturing experience in

wind energy⁶⁹, and has exported significant numbers of small- to medium-sized turbines to the US and elsewhere. Mitsubishi's current turbine is not technologically competitive with those of some other countries. The company has marketed it successfully using low pricing and an outstanding warranty. Mitsubishi's corporate resolve is unclear⁷⁰.

Japan's domestic wind resources are limited. A 1991 Prime Minister's report committed the Japanese government to assess the domestic wind resource, with a view to selecting sites for future wind energy installations [134]. Funding for the Japanese wind energy RD&D program, which is directed by the New Sunshine Project Promotion Headquarters in the Agency of Industrial Science and Technology (AIST) of MITI, increased by a factor of roughly three from fiscal year 1990 to fiscal year 1992. Even with this funding increase, the current level is small (roughly \$7.7 million in fiscal year 1992, and \$9.0 million in fiscal year 1993) compared to levels for several of the other countries considered in this report [20]. NEDO accounted for \$6.5 million of MITI's 1992 funds, an increase of \$3.4 million from 1991 (see Footnote 8).

NEDOs major research activities in 1992 concentrated on: economic efficiency and effective land use for large-scale wind systems; operation and control research; wind resource assessment; and fundamental aerodynamic research [135]. NEDO is heavily involved in the construction and operation of large scale test plants. NEDOs 1992 activities include development of a 500 kW wind turbine prototype, and construction of a 1 MW experimental wind farm. Other Japanese sources interested in wind energy are the Mechanical

⁶⁹ MHI has been active in wind energy technology since 1980.

⁷⁰ The Japanese firm IHI has also produced a turbine which is being tested alongside the Mitsubishi machine and the M-30 monoblade machine made by Italy's Riva Calzoni. The tests are being performed by the energy agency of the island of Hokkaido [81]. IHI designed Japan's first national pilot machine, a 100 kW horizontal axis machine installed on Miyake Island in 1982 [133].

Engineering Laboratory (MEL, which like NEDO is part of MITI) and the National Institute for Resources and Environment (NIRE). They evaluate NEDO activities and perform basic research in wind energy [20]. MEL has performed basic studies on rotor aerodynamics, control and transmission systems, noise and vibration, and airfoil sections since 1978 [133]. Private Japanese companies actively gather information on wind technology from readily available US sources. The majority of Japan's nine electric power companies have some interest in wind power generation, albeit small [136]. At the end of 1991, these nine companies, along with the Electric Power Development Corporation, established "specific equipment projections" through fiscal year 1995, with target dates for introduction. The goal is 16 domestic wind power facilities with about a 3700 kW capacity within four years [137].

Tohoku Electric Power Co. is spending roughly \$12.4 million on the design and construction of five three-blade rotor, constant speed, 275 kW wind turbines at Tappi Wind Park on the northwestern tip of Japan's main island of Honshu. The project is partially intended as a public demonstration of the potential of wind power [138]. Toyo Engineering Corporation of Tokyo, the parent firm of Toyo USA Inc., has worked to purchase 20 US Windpower 56-100 turbines with financing provided by the municipal electric facility of the town of Tachikawa. A few of the turbines are already operational [139].

3.6.2.2 Solar Thermal

Japan is primarily a follower in solar thermal technology development. Their overall ranking would place them behind the US, Germany, and Israel, but ahead of the remaining study countries in this area. Japan is a leader in Stirling engine manufacturing, but has been somewhat less active in solarization of their engines. Japan is positioned to pursue a strong role in dish/Stirling technology as commercial opportunities materialize, due to active programs in Stirling engine development at many Japanese institutions. These programs have successfully improved upon the basic developments of several other nations. The Japanese are not, however, actively developing their own concentrators for Earth-based dish/Stirling systems, and instead rely on testing their engines with foreign dishes. The Japanese are

developing ceramic gas turbine engines for electric power generation, which would seem to position them well for advances in dish/Brayton applications. However, the Japanese clearly trail several countries in other technologies suitable for electricity generation, namely, parabolic troughs and central receivers⁷¹. As trough technology is well developed and by and large in the open literature, Japan could quickly become competitive with today's leading nations in this area if it chose to. However, the Japanese will not challenge the leading position held by the US and Germany in central receiver development. The Japanese are worldwide leaders in intelligent architecture for energy conservation.

Besides its considerable work in Stirling engine development, Japan's interests pertinent to solar thermal technology have been primarily confined to intelligent architecture for energy conservation, and in exploitation of potential export markets, particularly in less developed countries [140]. Technology development in solar thermal energy is viewed in many Japanese circles as essentially complete, with further advances confined to increases in efficiency and decreases in cost [141]. Japanese efforts in solar thermal technology are likely to receive a significant boost during the next decade, motivated by both environmental concerns and the need for increased energy self-sufficiency.

Considerable evidence suggests that an increased Japanese commitment to solar thermal R&D and application has already begun. The New Sunshine Project has as one of its major goals the saving of energy nationwide, particularly in the use of heat in homes and offices. The Japanese have already achieved a measure of success in this area. For example, researchers at Meiji University have developed and built a totally sustainable house that incorporates passive and active solar heating⁷².

⁷¹ The Sunshine Project central receiver near Nio has been removed from service. This 1 MW plant used steam as the heat transfer medium (a first-generation technology), and was completed in 1981 [63]. A major reason for the closure of this facility was the poor solar resource at the site.

⁷² Bill Stine, foreign travel report, "Japan Dish/Stirling Technology Inquiry Visits," California State Polytechnic University, June 1992.

The Japanese have long recognized the promise of Stirling engine technology, although commercialization in solar thermal applications has been delayed by technical difficulties. For six years starting in 1982, AIST sponsored the "Stirling Engine for Wide Use" development project as part of the Moonlight Project/Large-scale Energy Conversion Technology Development Project, which involved a cooperative effort between universities, government, and industry. Three Japanese national laboratories were involved in basic research: MEL; the National Research Institute for Pollution and Resources; and, the National Aerospace Laboratory (NAL). Four prototype engines were developed (by Mitsubishi, Toshiba, Sanyo Electric Co., Ltd., and Aisin Seiki Co. Ltd. [82]) under the leadership of NEDO. Japanese development efforts have been successful enough that commercialization of some of their products seems imminent (see Footnote 72).

The following institutions are considered the most representative of Japanese Stirling engine activities: Sanyo; Meiji University; NAL; Kawasaki Heavy Industries; Aisin Seiki; Nihon University; and, Tohoku University. Other Japanese institutions involved in this technology area include Mitsubishi, Toshiba, Tohoku Gaukin University, Sanden Corporation, and the Ship Research Institute. Of all these institutions, Aisin Seiki is the most active, as they support many projects including extensive testing and the simultaneous development of four different Stirling engines (both free piston and kinematic) (see Footnote 72).

True to their reputation, the Japanese have been quite successful in duplicating and then incrementally improving on existing technology in this area. Their early prototype engines were based on working models developed elsewhere (for example, in Sweden). Sanyo developed one of these engines which, because of the company's current unfavorable market assessment, is not being applied to dish/Stirling use. They are, however, using the engine for other purposes and could easily move into the dish/Stirling area with it when the market warrants. The academic work at Meiji University includes several studies related to advanced receiver and engine development, as well as the evaluation of calcium hydroxide as a storage medium. Solar utilization in space is of interest to

NAL, which has begun a joint research program with Germany's DLR to develop a liquid metal heat pipe receiver for their dish/Stirling space engines. Initial space experiments are expected around the year 2000. NAL is developing free-piston Stirling engines (their initial prototypes were designed and constructed by Aisin Seiki). Parabolic dishes for space applications (both unfoldable and inflatable) are under development by Kawasaki Heavy Industries (KHI), as is a free piston Stirling heat pump which could be applied to the development of an engine for dish/Stirling applications. Nihon University researchers are active in developing small internally heated solar Stirling engines, which have the theoretical advantage of reduced temperature gradients and potential lower cost. Other innovative Stirling engine research at this university is not directly related to solar applications. Tohoku University has a 10 meter, 70 kW solar furnace featuring multiple parabolic (rather than the typical spherical) dish facets. The furnace is being used for solar-pumped laser experiments (see Footnote 72).

Aisin Seiki (part of the Toyota family) has been extremely active in solar technology, particularly in the area of dish/Stirling systems. The company has been involved in Stirling engine development for approximately 20 years, and has invested approximately \$100 million in the area over that time. Currently, about 50 Aisin Seiki engineers are involved in Stirling engine activities. Solar energy uses are presently third on Aisin Seiki's list of priorities for Stirling engine applications, behind waste combustion and/or cogeneration, and gas heat pumps⁷³.

At two Aisin Seiki test facilities in Japan, US concentrators are being tested in tandem with a kinematic Aisin Seiki Stirling engine⁷⁴. At one of

⁷³ From notes taken by Rich B. Diver, Sandia National Laboratories, at a meeting between representatives of Sandia, Aisin Seiki, Hydrogen Engineering Associates (or HEA, a US firm), and McDonnell Douglas (also of the US), to discuss possible collaborative efforts - April 23, 1993.

⁷⁴ This engine (the NS30A) is reputed to be very good technically, and was developed under the Japanese government's NEDO project in 1987. The

these facilities, Japan's resort area on Miyako Island, Aisin Seiki has developed a directly illuminated receiver for use with their dish/Stirling systems [82]⁷⁵. Aisin Seiki is also active in free piston Stirling engine technology, and has used small (roughly 100 W) free piston Stirling engines to aid photovoltaic power systems on experimental solar boats and cars. In addition, tests of a US-developed multi-facet stretched-membrane concentrator (by Cummins Power Generation Inc.), in tandem with a 200 W prototype Aisin Seiki free piston Stirling engine designed for space applications, are underway in Sophia-Antipolis in southern France, at the European office of an Aisin Seiki owned research and development facility called the Institut Minoru de Recherche Avancee S. A. (IMRA) [82].

Tokyo Electric Power Company (TEPCO) has developed a roughly 300 kW gas turbine engine for use in non-automobile (i.e., fixed position) electric power generation, in a project sponsored by NEDO. They have also worked with ceramic engine coatings, and are developing a large (roughly 20,000 kW) fixed position ceramics gas turbine with a target completion date of 1995 [142]. It is unclear when (or if) this engine could be adapted for solar use. The most technologically advanced Brayton engines are ceramic, and Japan's developments with ceramic gas turbines would indicate that Japan is positioned to be a future technological leader in dish/Brayton applications.

engine has been modified for solar operation and is undergoing tests in Japan with a McDonnell Douglas glass-facet concentrator (at Kariya City) and three multi-facet stretched-membrane concentrators manufactured by Cummins Power Generation Inc. (on Miyako Island). For the Miyako Island tests, the engine is being derated to 8.5 kW [82]. The US firm Hydrogen Engineering Associates (HEA) appears on the verge of obtaining, via agreement with Aisin Seiki, one of the engines for evaluation.

⁷⁵ This receiver is much less efficient (65 percent versus 86 percent) than the direct illumination receiver produced by Solo Kleinmotoren in Germany. The two receivers have very similar thermal outputs at identical levels of solar insolation [82].

Several Japanese participants are involved in a new "Environmentally Harmonious Catalyst R&D Project," which has as one of its goals the study of a photocatalyst that generates hydrogen using solar energy and water. The project has been contracted out to the Research Institute of Innovative Technology of the Earth (RITE) from MITI through NEDO [143]. It is unclear how the Japanese program compares to ongoing German and Russian work in this area.

3.6.2.3 Solar PV

Japan has been the top world producer of PV modules since 1985. The Japanese government spends the second largest amount of money on PV R&D in the world, and has a long reputation for successfully nurturing its companies in the successful commercial application of technologies. The Japanese PV industry is dominated by some of Japan's largest industrial organizations, with enormous financial, technological, manufacturing and marketing resources. Coupled with Japan's extreme energy dependence, these facts add up to a formidable repertoire for leadership in the PV industry (in both the export and domestic marketplace) and the potential (and incentive) for maintaining that leadership over the long term.

However, during its period of market dominance, the Japanese focus of PV application has been almost exclusively on consumer products rather than power generation. The bulk of Japan's PV production during this time has been primarily made up of low-cost, low-efficiency a-Si cells, used almost exclusively in watches and calculators. As recently as 1989, the number of Japanese modules shipped in the consumer sector versus the commercial sector was 2:1 [144]⁷⁶. By comparison, the ratio of consumer modules to commercial modules shipped by the US that year was 1:4 (1:7 in 1992) [35]. Japan has, therefore, never been a leader in the commercial sector, which is the driver in what is considered to be the strategic application of PV - electric power generation.

⁷⁶ (Consumer Sector: 9.1 MW; Commercial Sector: 4.6 MW)

To the present day, three of the largest Japanese producers of PV modules, Sanyo, Kaneka and Sharp (collectively representing 56 percent of total Japanese PV module production in 1992), focus most of their commercial efforts on a-Si technology and consumer product applications [144, 145]⁷⁷. Only Kyocera, the second largest Japanese PV module producer in 1992 (representing 27 percent of Japanese module shipments) focuses the majority of its efforts on the commercial sector [144].

Kyocera (which is an acronym for Kyoto Ceramics) has developed its market share over the past four to five years (a period during which sales of consumer modules stagnated as a result of saturated markets and extreme cost competition), experiencing its most rapid growth between 1989 and 1991. During this period, Kyocera has been the driving force behind most trends in Japanese module shipments [144]. The company is a major producer of integrated circuit chips and industrial ceramics, and has strength in materials technologies. Its strength in the PV industry is in the manufacture of high quality MC-Si PV cells (16.4 percent conversion efficiency), the majority of which are exported to the US, Europe, and developing countries [146]. The company currently has two Japanese production facilities for MC-Si cells, the Sakura plant, at Chiba (5.6 MW/year), and the Kikaichi Plant at Shiga (500 kW/year). The Kikaichi plant's capacity is expected to be doubled by the end of 1993 [146].

Japan's leadership role in the global PV industry is therefore somewhat misleading. In terms of total numbers of modules shipped, Japan is still number one. But if end-use application is taken into account, the US is the world leader in commercial PV module shipments [35].

In recent years, however, the stagnation of the consumer PV market, combined with new technological breakthroughs and, most importantly, the genesis of the global environmental movement, have combined to provide a renewed sense of potential for near-term

⁷⁷ Sharp is also Japan's leading producer of high-cost, high efficiency SC-Si PV cells for space applications, which are not addressed in this review.

PV power generation applications. The Japanese government has become especially sensitive and responsive to the threat that environmental degradation holds for Japan and the world⁷⁸. As a result, the Japanese government has infused a sense of urgency on speeding the development and diffusion of environmentally benign energy technologies such as PV. This urgency is reflected in the formation of the New Sunshine Project and the Green Aid Plan. The government has also provided for increased visibility of PV through new demonstration projects, as well as through new incentive provisions and subsidies for the application of PV power generation domestically.

New Sunshine Project (NSP). The NSP goal for PV is to combine efforts to develop PV power production with those being made to develop adequate storage technologies. The aim is to decrease cost factors by increasing the potential supply of PV through accelerated promotion. The steps required to achieve this are 1) development of technology that allows transfer of lab efficiencies and breakthroughs to the factory; 2) development of mass-production through demand promotion; 3) promotion of decreases in production costs through demonstrations; and 4) promotion of transfer of technology to developing countries.

Specific PV R&D "breakthrough points" focus on

- 1) **PV CELL MFG. TECHNOLOGY**
Low-cost basic production technology for thin, polycrystalline solar cells.
- 2) **PV MODULE MFG. TECHNOLOGY**
Mass-production tech. for polycrystalline cell modules.
- 3) **PV CELL RESEARCH**
Applications research for high quality, larger area and high reliability thin film solar cells.
- 4) **MATERIALS RESEARCH**
Elemental materials research for high efficiency solar cell compounds (GaAs,

⁷⁸ As noted in Section 3.6.1, it has been estimated that a rise in ocean levels of 1 meter could threaten most of coastal Tokyo [127].

CdTe, CuInSe₂).

- 5) **EVALUATION RESEARCH**
R&D for system evaluation technology and solar cell performance and reliability evaluation technology for all kinds of cells.
- 6) **BALANCE OF SYSTEM RESEARCH**
 - a) R&D for performance and reliability evaluation of BOS (inverters, power conditioners, etc.).
 - b) R&D for materials structure and construction of system and peripheral equipment stands [147].

Together with the establishment of the NSP, NEDO also established the PV Power Generation Technology Research Association (PVTEC) in 1990. PVTEC is made up of 24 corporations (including every major Japanese PV producer), the Central Research Institute of the Electric Power Institute (CRIEPI), and major Japanese universities and national laboratories. Its mission is to direct R&D and feasibility studies of commercial applications of PV technology by further integrating the R&D efforts of its members. PVTEC's budget is ¥60 billion (approximately \$570 million) for its first ten years (1990-2000) (about \$57 million/year) [148]. PVTEC's specific themes are as follows:

- 1) Development of mfg. technology for new type SC-Si solar cells (Thin-type and laminated type).
- 2) Development of mfg. technology for a-Si PV cells.
- 3) R&D of ultra-high efficiency PV cells.
- 4) R&D of technology to evaluate solar PV power generation systems.
- 5) Preliminary research on feasibility analysis, and survey on international trends of industries and technology in solar PV power generation.

Demonstrations. In concert with the NSP, eleven new PV demonstration sites, with a total capacity of 10-30 kW, are targeted for installation in 1993, with a budget of ¥845 million (approximately \$8

million) [149, 150]. Several measures have been taken by the Japanese government to encourage installation of PV demonstration arrays on the roofs of private homes, and on both public and commercial buildings. For example, in addition to a seven percent tax credit for PV installations, the government provides up to two-thirds of the cost of PV equipment purchase and installation, with the remaining third covered by either private investors, local self-governing bodies, and/or local gas/electric utilities [149]. In addition, builders have offered financial assistance of 5-10 percent of PV system costs to households agreeing to install solar systems. MITI expects to install PV arrays on up to 50 homes in 1993, and on up to 500 homes in the first five years. The expected cost per unit is ¥5-10 million (approximately \$40,000-\$50,000), and each unit will have a peak capacity of 3 kW [151]. All participants in this effort would also have the capability of selling surplus electricity to local utilities at a rate of approximately \$.29/kWh. This rate is scheduled to decrease to \$.18/kWh by 1995, and ultimately to \$.07/kWh after the year 2000 [152].

The largest Japanese PV power demonstration plant was established on Okinawa in 1990; testing of the plant began in 1993. The \$19 million plant is a joint project financed by NEDO, built by Mitsubishi Electric (MELCO), and operated by Okinawa Electric Power. The 750 kW plant is sufficient to power an entire village. It is equipped with a storage battery that has a capacity of 3,000 kWh and a 300 kW diesel generator for backup on cloudy days. The objective of such a large project is to validate the capability of a single PV power generation system in providing remote-site electricity for an entire community (at the village-scale) [153]⁷⁹.

⁷⁹ NOTE: It is worth noting that the price that NEDO pays PV cell manufacturers for their products is well below the market price. Cells delivered to NEDO are purchased at around ¥600/W^P (approximately \$5-\$6/W^P), which is about cost, while the market rate is ¥1,200-1,500/W^P. While these terms do not please Japanese manufacturers, given the lack of alternative customers, they are compelled to comply. (Source: AmEmbassy, Tokyo; From *Nikkei Weekly*, 1/4/93.)

Technology Transfer. Central to the new theme of the NSP is the Japanese government's alleged commitment toward promotion and transfer of PV technology abroad, the bases of which are 1) the need to transfer new technologies in the interests of global environmental protection, and 2) the insurance that Japanese companies gain a competitive advantage in the PV markets of recipient countries through technology transfer [154]. More importantly, domestic applications of PV in the short to medium term will be restricted by the limited usable incident sunlight in Japan (caused by the latitudinal and climatic conditions found on most of the Japanese islands), as well as by the high costs attributed to the severe space limitations inherent in one of the most densely populated countries in the world⁸⁰. Therefore, the potential for domestic PV power generation in Japan will most likely be limited to supplying supplemental power, thus aiding in the conservation of conventional energy sources. These applications will probably be restricted to "utilization on isolated islands and on rooftops of dwellings"⁸¹. Given this assessment, solar power plant capacity for the year 2010 is projected to be 4.6 gigawatts (GW) [155]⁸². Japan's projected total electric generating capacity for the year 2000 is 240.5 GW [39].

Application of Japanese PV technology in developing countries, however, is anticipated on a much wider, even a grand scale. This is hinted at by the long-term designs of "Project GENESIS" (renamed the "WE-Net," or World Energy

Network)⁸³. The project proposes the establishment of a world-wide network of PV power generation stations located in the arid regions of the world, producing hydrogen and interconnected by superconducting cables able to transport PV electricity from the sources of supply to the sources of demand. The targeted date for completion is the year 2030. The total projected cost for the project is \$150 trillion (which is why Japan is stressing that it must be an international venture) [156]. MITI's Agency of Industrial Science and Technology (AIST) plans to spend ¥300 billion (approximately \$1.8 billion) on the project for the initial period 1994-2010 [157].

In the shorter term, Japanese authorities recognize the potential for expanded electricity demand in the developing world (especially in the newly industrialized countries of Asia), as well as the environmental dangers that their explosive economic growth could pose for the world if their electricity needs are met with purely conventional technologies. In anticipation of this, the NSP calls for the establishment of "joint validation PV research" efforts with potential client countries in the developing world, in order to determine the appropriate technologies to transfer (given the specific local solar conditions, natural environment, technological competence and social conditions), and to establish a working relationship with the potential buyers of future generations of Japanese PV technologies.

As of the end of 1992, there were already four validation projects underway across Asia. NEDO commissioned domestic firms with extensive R&D experience to work with Nepal, Thailand, Malaysia and Mongolia to develop PV systems that are best-suited to the current national conditions and needs of each country [154] (refer to Table 3.2).

⁸⁰ The low average incident solar radiation levels in Japan requires that PV applications be composed of higher efficiency (and higher priced) PV cells/modules and/or a greater number of cells/modules. Additionally, land prices in Japan are among the highest in the world, adding further to the expense of Japanese PV applications that are not either "dual use" or BOS independent.

⁸¹ From interview with Masayoshi Hayashi, Chairman of the New Energy and Industrial Technology Development Organization (NEDO) [155].

⁸² 1 GW = 1000 MW.

⁸³ "GENESIS" - Global Energy Network Equipped with Solar cells and International Superconductor grid

Table 3.2 Japanese "Joint Validation PV Research" Projects in Asia.

Country	Duration	Capacity Installed	Contractor
NEPAL	1992-95	4kW initial; 40kW later	Showa Shell Sekiyu
Theme:	Accelerated validation of solar battery use (for water pumps) in a highlands region (extremes of hot and cold)		
MONGOLIA	1992-94	300 -240W sets	Kyocera
Theme:	Joint development of portable PV systems (for nomads)		
THAILAND	1992-	4kW initial; 40kW later	Showa Shell Sekiyu
Theme:	Joint development of auto battery re-charges (batteries used as primary source of remote village power for lighting, TV...)		
MALAYSIA	1992-96	10kW initial; 110kW later	Fuji electric
Theme:	Joint research/testing under tropical conditions (heat/humidity damage prevention)		

To summarize, the Japanese focus on the consumer sector of PV and low-grade, low-cost a-Si technology is beginning to end. Worldwide environmental concerns, coupled with renewed domestic efforts to reduce energy dependency, have provided Japanese PV manufacturers with sufficient impetus, and led to sufficient government-sponsored R&D support, to pursue the commercial sector of the PV market. Japanese domestic application of PV will be limited to conservation efforts in the short-to-medium term, with the potential for extensive supplemental power production from rooftop arrays and small substations dependent upon the development of inexpensive but efficient PV cells. Substantial efforts by the Japanese government to promote PV use abroad could serve to establish lucrative future markets for Japanese PV technology and pave the way for technological breakthroughs in the short to medium term.

There is no doubt that, through these efforts, Japan will maintain its position as one of the world's leading PV producers. However, given the increased efforts being made worldwide, Japan will be subject to an acutely more competitive international PV market than has existed in the past.

3.7 RUSSIA

3.7.1 Policy Overview

Russia's interest in renewable energy technologies is driven by a crisis situation in the Russian fuel and energy complex. Domestic fossil fuel extraction is experiencing a significant multi-year decline caused both by current political instabilities and a deteriorating energy infrastructure. At the same time, demand for fuel is expected to increase once Russia's economy begins its recovery. Russia's hopes that nuclear energy use would expand to satisfy a large part of future power demands have been proved false. This is due primarily to both demonstrated and perceived environmental concerns. Public concern exists about not only nuclear energy, but about traditional sources of energy as well [9].

While Russia faces its current energy crisis, it is poised for dramatic increases in its energy efficiency. Partly because fuel prices in the former Soviet Union were kept artificially low compared to worldwide levels, energy efficiency was not encouraged on either the supply or demand side⁸⁴.

⁸⁴ The energy intensity of the national product in Russia is currently 1.5 times higher than that of the

Steps toward improved efficiency taken by much of the rest of the world during the energy crisis of the 1970s were never taken in Russia⁸⁵. The Russian government is now seeking ways to improve energy efficiency while increasing overall energy production and protecting the environment [9].

One of the primary impediments to these efforts is the extreme difficulty the government and private developers are facing with regard to financing. Billions of dollars are needed in the oil sector alone. A recent study concluded that the Commonwealth of Independent States (CIS) will need roughly \$135 billion in investment in its electric power industry during the new decade just to replace the capital equipment that wears out during the 1990s and to provide for a very modest growth in production. Most of the capital will have to come from foreign private investors [159]. But inflation, declining government revenues, and dubious investment laws and procedures are preventing private investment from occurring and leading to a dramatic decline in Russia's once considerable science and technology infrastructure. Poor pay and diminished prestige has led to a "brain drain" among Russian scientists, engineers and technicians, with many moving to other countries or working for foreign companies in Russia. This phenomenon has led to an overall decline in research activity in nearly every scientific facility in Russia, which explains the eagerness with which Russian scientists and research institutions are seeking external collaborations [160].

Aside from the financial and technical limitations, Russia's huge domestic fossil fuel reserves are a disincentive to renewable energy development. In addition, the Russian electric power industry is fully subsidized by the government, and most consumers have had little reason to be interested in

US, and two times higher than that of Western European countries [9].

⁸⁵ During the 15 year period from 1970 to 1985, the energy intensity of the Russian national product declined by 15 percent. Over the same time, it declined by 71 percent in the US, 72 percent in Great Britain, and 78 percent in Japan [158].

renewable energy sources⁸⁶. An exception exists in eastern Siberia, where remote settlements have relied on expensive and unreliable diesel powered generators, rather than on connection to a grid. The potential for renewables (most notably wind) in this area has long been recognized [13].

In September 1992, the Russian government approved a plan called The Concept for the Energy Policy for Russia in the New Economic Situation. The policy set forth in this plan is meant to address the problems of the fuel and energy complex, and to encourage energy conservation as a fundamental part of the Russian economy. This policy is primarily focused on the oil and gas sectors, but does also encourage the use of renewables. Initial targets for renewables include recreational areas, sites of ecological disasters, and isolated regions. Russia's scientific-technical program called Ecologically Clean Power Engineering⁸⁷ contains a plan for developing ecologically clean technologies and processes. The program is divided into seven areas, including one called "nontraditional power engineering" which is focused on renewable energy development (including solar, wind, geothermal, and biomass). International scientific, technical, and economic cooperation is a fundamental goal of the program [9].

Russia's overall energy strategy is developed by the Krzhizhanovsky Power Engineering Institute (ENIN) in Moscow. This includes strategy for nontraditional sources of energy. ENIN has expressed interest in joint ventures with Western industry and governments for renewable energy research. Two possible funding sources are available: the Ministry of Energy and the Ministry of Scientific Research. One problem caused by the breakup of the Soviet Union is that most research institutes have been reduced to local or regional entities. They are struggling to survive by broadening their activities and seeking Western markets for their capabilities (see Footnote 86).

⁸⁶ Thomas R. Mancini, foreign travel report, Solar Thermal Technology Department, Sandia National Laboratories, Albuquerque, NM, November 13, 1992.

⁸⁷ The program was created in 1989 [9].

In the short term, Russian energy concerns will remain centered on its fossil fuel and nuclear energy sectors. New energy technology programs have been significantly weakened in recent years and face even further cutbacks in funding and loss of personnel. International collaboration is most likely the best option for the continuation of Russian renewables RD&D. Western financing and participation can ensure the survival of technology programs that offer considerable benefit to international research programs.

3.7.2 Energy Programs

3.7.2.1 Wind

A significant Russian market in stand-alone wind turbines will be penetrated during the next decade by Western developers able to find innovative solutions to Russia's foreign currency problems. Opportunities for grid-connected wind turbine development in Russia will be more limited over the same time frame⁸⁸. Government cutbacks in defense spending will prove to be a short term boon for Russian wind energy development, as defense plants seek to redirect their production efforts to civilian industries. Wind generated electricity could be used to help rebalance the existing grid throughout the CIS as it reorganizes in better alignment with individual country borders. The biggest challenge to the Russian domestic wind energy industry in the long term is whether it can overcome current problems with a lack of coordination, limited capital, and a lack of readily available modern construction materials. Because of these problems, the Russian wind energy picture is likely to be dominated by foreign interests in the long term.

⁸⁸ This prognosis is consistent both with the former Soviet Union's long-term program for alternative energy development, which emphasized a plan for the series production of small standalone turbines, as well as the continuing policies of the current Russian Federation. During the period from 1990 to 1995, Russia hopes to produce roughly 28,000 standalone windpower installations in a capacity range from less than 100 kW to as much as 500 kW. A few larger installations are hoped for, including a proposed 50 MW facility in the Greater Yalta area, to begin production by 1995 [9].

Prior to the breakup of the Soviet Union, as many as 16 different research organizations within the USSR were developing wind power equipment, although most considered wind technology a low priority. An exception was Vetroen (Wind Power), a scientific production association in the Ministry of Land Reclamation and Water Resources. Vetroen, which by 1988 employed more than 2000 associates, was created in the mid-1970s. Its work has included the development, production, installation, testing, and repair of over 1500 wind power devices. Vetroen remains in existence today. The formation of independent (not state-supported) Russian wind power organizations was stimulated by government-organized design competitions under the auspices of the USSR State Committee for Science and Technology. One of these independent groups is the Borey scientific production organization, which produces small wind-powered units for remote area use [9].

Most small- to medium-sized turbines developed and produced in Russia have until recently been of the horizontal axis type. However, vertical axis designs have received consistent attention from some researchers who are strong advocates of the concept, and several prototypes have been assembled. Several obstacles have plagued wind energy research and development in the former Soviet Union, and continue to present problems for the Russian Federation and the other newly independent States. Actual construction of wind energy facilities has been hampered by poor coordination between designers and developers. A lack of availability of state-of-the-art materials has meant that low-quality steel and other inferior materials have been used to construct the turbine blades and other components produced by Vetroen and others. Frequent mechanical failures have been one result, and spare parts are practically impossible to obtain [9].

In 1989, scientists within the Soviet Union tried to alleviate some of these problems by founding the Association for the Advancement of Wind Power Engineering⁸⁹. The goals of the organization were

⁸⁹ Sponsoring organizations included the USSR State Committee for Material and Technical Supply, the Ordzhonikidze Moscow Aviation Institute, and

to unite the efforts of Russian government organizations involved with wind energy, including the identification of potential needs and applications, and the provision of technical, legal, and other services to users of wind power technology. Two new certification centers are planned to provide centralized services to all Russian organizations involved in wind energy research. One is tentatively planned to be built in the Russian Federation republic of Dagestan, which is the site of a wind power testing range near the town of Dubki. The other will be located on the Kola Peninsula. These centers will augment an existing testing facility near Novorossiysk, which will continue operation for the time being [9].

The Institute of Hydraulic Engineering at the A.F. Ioffe Physico-Technical Institute in St. Petersburg, Russia (a joint-stock company) has built and begun testing four 250 kW horizontal axis machines. Its experience is in machines with capacities from 40 W to 1 MW (the design for a machine of the latter size has been completed, and it is to be fabricated by a local military plant, through a contract let by the Ministry of Energy). The Institute has also produced a few thousand very small (2 kW) machines (of dubious reliability) for use by collective farms, lumber operations, fishing villages, and the like along the shores of the North Sea, Gulf of Finland, and the Caspian Sea (see Footnote 86). Two windpower stations near St. Petersburg are nearing completion. They are on Kotlin Island, in the western region of the Gulf of Finland. Two St. Petersburg research centers have collaborated on the projects. They are: the Central Boiler-Turbine Institute and Energomash Institute, a state interindustry association. The sizes of the projects are thought to be small [161]. Energomash is one of several enterprises building equipment for prototype turbines designed by the Soviet Ministry of Power and Electrification's Zhuk All-Union Design, Surveying, and Scientific Research Institute (Gidroproyekt) [9]. The director of the wind energy department of the Moscow Aviation Institute (who is a member of the Russian State Committee for Renewable Energy) has been working with Bergey Wind Turbines of Norman, Oklahoma, to initiate a technology transfer agreement in which several Russian factories

the USSR State Committee for Science and Technology [9].

would be converted to small (10 kW) wind turbine production through transfer of designs, expertise, and necessary manufacturing equipment. The primary application would be for agricultural electricity supply⁹⁰.

A Dutch-Russian joint venture known as Vetroenergetika has been formed to facilitate the manufacture and sale of wind turbines in the CIS. Vetroenergetika is jointly owned by the Russian Dalreco Group (in Siberia) and by the wind energy company LMW of the Netherlands, and has assembled several dozen small turbines for use in stand-alone applications in eastern Siberia. The success of this joint venture has been made possible by an innovative business arrangement with the Dutch fish company Kalkman Vis. The sale of Siberian salmon by Kalkman Vis provides the Western capital needed to purchase LMW wind turbines [13].

Russian sources indicate that wind power units with a capacity of 5-15 MW have been constructed in the former Soviet Union, but scientists there are experiencing serious engineering problems with such large scale designs. Many (perhaps all) of these very large machines are likely derived from innovative concepts for wind generation. Russian scientists have described several of these. One involves a huge, apparently vertical toroidal structure (i.e., a doughnut-shaped piece of hardware) which supports two long (say, 60 meter) vanes which rotate in opposite directions⁹¹. The vane motion would induce a lower air pressure on one side of the toroid than the other. This air pressure difference would provide an added "boost" to the vanes as they pass through its center, thereby increasing the efficiency of the machine [9]. It is unclear whether any machines of this type have actually been built, but Russian scientists claim that an output of 20 MW could theoretically

⁹⁰ Eric Martinot, foreign travel trip report, Energy & Resources Group, University of California at Berkeley, summer 1992.

⁹¹ A logical assumption is that the vanes are mounted at midheight on opposite sides of the toroid, and rotate in a horizontal plane such that they would each be traveling in the *same* direction when they pass through its center.

be achieved. They also admit significant drawbacks to the concept, as well as high cost of the electricity produced [9]. A quick survey of US experts failed to find one who had heard of a similar concept proposed elsewhere.

Wind machines with capacities of 20-25 MW, in which vanes are supported by individual or common ring-shaped supports rather than fastened on the central shaft, have been proposed as simpler and more economical than some other concepts. Again, it is unclear whether such machines have been built. Machines having multiple vertical vanes which move together along a common horizontal circular path (they are fastened to common supporting upper and lower rings) have also been proposed [9]. This sounds like a concept that has been experimented with in the US. A prototype machine of this kind having a 20 meter diameter has been undergoing field tests in the former Soviet Union since 1987. Magnetic levitation of the assembly using a generator could, in theory, be used to increase efficiency. Further concepts for high-altitude wind platforms have been suggested [9], but seem beyond the range of practicality.

Despite the fact that Ukraine is outside the scope of this assessment, wind energy developments there are significant and deserve mention. Most currently operating turbines in Ukraine are estimated to be 15 years behind Western technology [9]. However, Ukraine has developed the design for a Savonius-style vertical axis turbine. In Ukraine, the Ministry of Power and Electrification is seeking foreign partners for wind energy development. Two US companies are involved in joint-venture projects there. SeaWest Power Systems is financing a 500 kW wind farm using Mitsubishi machines in the Crimea (see Footnote 86), where wind power has been used successfully since the mid-1980s [9]. The project is the result of a protocol of cooperation signed prior to the dissolution of the Soviet Union. The agreement between SeaWest and the Ukrainian Ministry of Power could lead to significant additional installed capacity by the year 2015, depending on political and economic factors [162]. US Windpower has begun installing five thousand turbines having a total capacity of 500 MW in the Crimea. This huge project is a joint venture between US Windpower, the Ukrainian electric utility Krimenergo, and PHB Ukraine (a subsidiary

of American and British consultants), who have cooperated to form a new Ukrainian company called Windenergo. The project will roughly double US Windpower's worldwide installed wind energy capacity. Impetus for the project was the need to replace lost capacity caused by the close down of Chernobyl. Windenergo will manufacture and sell the turbines. Payment to US Windpower will be made in spare parts for repair of turbines already installed in the US. These parts are being produced by 25 Ukrainian suppliers [163, 164]. This payment scheme for the US Windpower Crimean project is an example of the sort of innovation that could significantly improve the near term prospects for grid-connected wind energy development in Russia. A collective farm in the Crimea has all of its energy needs met using a combination of wind, solar, and biomass technologies, after farm specialists, working with the former Soviet Union's Ministry of Power and Electrification, assumed sponsorship [9].

3.7.2.2 Solar Thermal

In some respects, Russian renewable energy technology has considerable catching up to do. For example, solar energy hardware on display at a 1990 Crimean conference on renewables was described as "vintage" by Western standards [9]. Such problems are not a reflection on the quality of research personnel in the former Soviet Union, but on past government priorities and the lack of attention given to renewables technology. This is not to say that in certain areas, Russian renewable energy technology is not world class.

The Union of Soviet Socialist Republics (USSR) was the site of the world's earliest documented study of a central receiver power system. The crude mechanical arrangement (conceptualized in the early 1950s by the Krzhizhanovsky Institute⁹²) consisted of large tilting mirrors mounted on railroad carriages which rolled on semicircular tracks around a tower holding a steam boiler. All position and orientation adjustments of the mirrors were performed manually (see Footnote 13). Currently, the solar electric generation power

⁹² Information taken from "Crimea Solar-Electric Power Plant," a publication of the Russian Foreign Trade Organization Sovelectro, Moscow.

station SES-5 is located in the Crimea⁹³. It was designed by the Riga branch of the "Electro-project Institute" and 13 other organizations, under the scientific guidance of the Krzhizhanovsky Institute, and constructed by the Zaporozhe building department "Dneprostroy" (see Footnote 92). This central receiver system has a rated capacity of 5 MW (which has never been achieved). Sources familiar with the facility have described it to the author as a "technological loser ... where 40 percent of the mirrors don't even hit the tower" SES-5 is a low temperature water/steam system (basically in the class of "early first-generation" central receiver technology), with a circular heliostat array of 1600 separate 25 square meter panels (see Footnote 92). The lack of effective mirror alignment indicates an inadequate control system (the SES-5 control system was designed by the Byelorus Heat and Power Engineering Institute - see Footnote 86). SES-5 became operational in September 1985 (see Footnote 92). It is not operational at this time, although the Ukrainians claim that they plan to upgrade the heliostats, receivers, and control system (see Footnote 86).

One complicating factor in the current state of Russian solar thermal research is that much of the applied research conducted by the former Soviet Union was performed in southern regions which are now separate States. This is because the northern part of the former Soviet Union has a poor solar resource. One example is the SES-5 central receiver. Another is a 2.8 meter tracking parabolic dish, also located in the Crimea, which has been used for metallurgical research. The Obekt-Solntse solar furnace in Uzbekistan can achieve temperatures above 3000°C, and has been used to produce specialized materials, including heat-shielding materials for aerospace use. This furnace is very similar to the French horizontally aligned Odeillo furnace, except that the primary concentrator is supported by an open structure rather than a building. The governments of many of the separate States of the Commonwealth of Independent States (CIS) have expressed interest in continuing research in renewables, but their efforts are severely hampered by lack of capital [9]. In an attempt to help mitigate this problem, the Israeli government has decided to provide state-backed

guarantees for Israeli companies which sell solar and other alternative energy projects in the former Central Asian republics of the USSR [165]⁹⁴.

Several Russian enterprises manufacture equipment, such as flat plate collectors, for low temperature solar thermal applications. Collector quality has been quite low, particularly in the area of corrosion resistance. However, the Ecologically Clean Power Engineering program outlines a national plan for the production and installation of nearly six million square meters of solar collectors, roughly 90 percent of which will be of new types comparable with the best models produced in the West [9]⁹⁵. The Alternative Energy Laboratory of the Institute for High Temperatures (IVTAN) in Moscow has one test station on the Caspian Sea and another in Moscow. This institute is involved with the development of domestic water heating systems, various storage technologies, and salt-gradient ponds. Their major motivation is to provide energy for agricultural processes. IVTAN operates a solar furnace (*not* the Obekt-Solntse furnace) which was used for Russian Space Agency metallurgical work. They also have a large scale solar simulator, also built for the Russian Space Agency. IVTAN is doing some work with heat pipes and concentrated solar energy, but the extent of their activities is unknown. IVTAN is trying to become involved with certain solar activities conducted by the International Energy Agency (IEA) (see Footnote 86).

Russian development of dish/Stirling systems has been sponsored under the Ecologically Clean Power Engineering program since 1989. The quality of Russian research into dish/Stirling technology, as generally reported in the open

⁹⁴ One promising area is the potential sale of Israeli rooftop solar collectors to the government of Kazakhstan (in a barter arrangement involving cotton and oil).

⁹⁵ Improved solar collector quality has been aided by Russian defense industry conversion. An association called ARKVES has built an improved collector, but found the Russian market unresponsive because of high installation costs and inadequate promotion of the benefits of solar thermal technology [166].

⁹³ The Crimea is in Ukraine along the Black Sea.

literature, is not particularly impressive. However, Russia's atomic industry has substantial experience in applicable technology areas such as high-temperature heat-transfer fluids (i.e., molten salt and liquid metals). Much of the relevant research was conducted as part of the Russian military program. A major player in dish/Stirling technology is Russia's Institute of Physics and Power Engineering. Russia's objectives are to capitalize on existing expertise in their atomic, aerospace, and defense industries in developing new technologies for large-scale electricity generation. They also hope to find alternative uses for dismantled military equipment [82].

Russian researchers are strong in the area of gas turbines⁹⁶, which would indicate some potential for measurable Russian contributions to Brayton engine development for solar applications. The Institute of Physics and Power Engineering is within the Astronautics Academy of the CIS. Their activities include solar tracking and control systems, liquid-metal receivers, new materials, and linear generators. Several experimental prototypes have been produced. A small (1 kW) kinematic Stirling engine was converted from space applications and utilized isotope heating. The Institute has designed an innovative 2 kW free-piston Stirling engine with a linear alternator, and is working to integrate their engine with a liquid metal heat pipe receiver, in a hybrid system utilizing gas. They have also designed a 10 kW free-piston engine, also to be integrated with a liquid metal heat pipe receiver. The Institute has built or is designing concentrator dishes for both the 2 kW and 10 kW engines [82]. These concentrators are not sophisticated by US or European standards, however, they are adequate for engine testing purposes. A Stirling engine laboratory is also located at the Tashkent Institute of Engineers of Irrigation. They are also working with a 15 meter diameter solar furnace (see Footnote 86).

The GELIOS group within the Ukrainian Academy of Sciences has been working on solar thermal technology for 35 years. Their work with solar

bowls⁹⁷ has been applied to heating buildings with hot water. Their initial work dealt with space applications, namely, the concentration of solar beams for welding and sintering metals in space. They are also using concentrated solar energy to irradiate seeds prior to storage⁹⁸. Also in the Ukraine, the Institute of Materials Science has used solar furnace technology to charge phase-change materials for later use of the energy in space (see Footnote 86).

Russian (formerly Soviet) interest in space-based solar power for earth is driven by a combination of geographic and climatic factors, including low solar energy density, high variability, and limited sunlight at high latitudes. The practicality of such systems is questionable, although the Russians view its potential implementation sometime in the years between 2005 and 2020. The Astrofizika Scientific Production Association is working on the concept of a multi-billion dollar international cooperative venture for a space-based solar power station, where microwave radiation would be transmitted to earth and converted into commercial current. Collectors one to two kilometers in diameter would be required. Technical problems associated with microwave conversion have been addressed by the former USSR Academy of Sciences' Institute of General Physics. They have developed a working model of a high efficiency beam converter. Another technical problem associated with this concept is with energy losses of the microwave beam as it passes through the atmosphere. Scientists at the Minsk Radio Engineering Institute (in Belarus) have devised a new method of reducing losses by focusing the energy flow [9].

3.7.2.3 Solar PV

On the basis of its long-time experience in space applications of C-Si PV on its satellites and space stations, Russia has a significant base for PV technology development. However, owing to the current overall instability in Russia and the drastic decline in financial support provided by the

⁹⁶ Alvin W. Trivelpiece and William Fulkerson, foreign travel report, Oak Ridge National Laboratory, Oak Ridge, TN, November 21, 1989.

⁹⁷ A solar bowl is a fixed dish with a moving focus.

⁹⁸ This seems to dry the seeds, sterilize them, and increase the rate of germination after planting.

government for science and technology, near-term Russian breakthroughs in terrestrial applications of PV are doubtful. Although joint ventures and/or licensing of Russian technology by foreign PV producers is a possibility, it is reportedly difficult to do so, given the lack of legal and official experience in Russia concerning licensing and determining ownership [167] (see Footnote 86).

One particular role that Russia does play in current international markets is as a source of industrial-grade silicon for foreign PV manufacturers (refer to Section 3.4.2.3, which describes a joint venture with Russia in such a role, involving Italian, German, and South African partners).

Production capacity goals for solar PV established by the Ecologically Clean Power Engineering program show little sign of being achieved, due to the negative factors mentioned above as well as a limited availability of the raw material base for crystalline silicon, and a lack of automation. Russian scientists are actively seeking to lower the costs of silicon cells. This includes work being performed at the Institute of Solid-State Physics of the former USSR Academy of Sciences [9].

The Russian Kvantempagro Scientific and Industrial Association, in conjunction with the Ioffe Physical Technical Institute, has succeeded in completing part of a large-scale experiment erecting a "solar tree" in the Chernomorskiy Settlement in Krasnodarsk Kray on the Black Sea. Nine of a planned twenty cottages have been built with 4 kW capacity solar batteries on each roof, interconnected on a local grid. Surplus power is diverted into the system. Average daily output of electricity per unit is about 10 kWh, which exceeds the average need for a family of four. Other parts of the experiment (construction of agricultural and power generation facilities) are unfinished due to financial difficulties and raw material constraints [9].

Available information shows that a majority of active research and development in solar PV occurred in southern latitudes (now separate republics) of the former Soviet Union. The Ioffe Physical Technical Institute, mentioned above, appears to be a leading institution in this area [9].

CHAPTER 4: EUROPEAN COMMUNITY

Those countries presented previously in this report, excluding Japan and Russia, are all members of the European Community (EC). The governing bodies of the EC are the European Council, the Commission of the EC (CEC), and the European Parliament. Treaties giving these governing bodies the legal authority to participate in defining and implementing various policies that were formerly within the exclusive domain of individual, national governments are the European Union (Maastricht, 1990) and the Single European Act (SEA, 1987).

4.1 POLICY OVERVIEW

EC policy makers seek to integrate and compliment various energy R&D efforts undertaken by national governments and commercial enterprises within each member country, and to form one European energy market. The motivations to set these goals are pervasive European concerns over environmental and energy security issues⁹⁹, and the need to more effectively compete with US and Japanese technology. A single European energy market would radically change the way the European supply system is organized, and give a larger role to independent power producers [6]. The SEA and Maastricht treaties are designed to further the harmonization of social, economic, and developmental conditions between the member states of the Community (requisites in creating a single market)¹⁰⁰. The CEC is also considering instituting a carbon tax on

fossil fuels. Either of these actions would provide a significant boost to renewable energy options (see Footnote 7).

In the 1980s, one of the primary concerns of "Euro" policy makers was the establishment of a "European Industrial Policy" that could serve to counter the competitive edge held by US and Japanese companies in technology development. The European Industrial Policy was established to begin addressing environmental, energy, and technology competitiveness issues. The result was the conception of the Framework Programs, a series of multi-year programs first implemented in 1984 that focused on EC-directed and EC-cost-shared R&D and deployment of a wide range of technologies and techniques [169].

The SEA and Maastricht treaties then amended the EC charter by providing for the formulation of a "European" research and technological development policy, having status equal to other key Community areas such as economic, social, and competition policy [170, 171]. R&D policy as put forth in the Maastricht treaty in particular, was designed to bring all research in the European Economic Community under one single master plan (the Framework Programs). The goal was to ensure that EC research efforts no longer served just to give European companies a competitive edge, but that it would serve all EC policies (health, social, environmental, agricultural, and the like) that contribute to the improvement of "quality of life" [172]. This was a vast improvement on the previous situation, in which EC efforts in R&D were based on loosely defined interpretations of the treaties of the European Community: The Treaty of Paris, concerning the Coal and Steel industries; EURATOM, concerning European Atomic power;

⁹⁹ Europeans are typically much more environmentally aware than Americans, and this perception has been advantageous to the European renewable energy market.

¹⁰⁰ The Maastricht treaty has stumbled along a bumpy path since its negotiation, most notably due to stiff opposition by certain groups in Denmark, France, Britain, and Germany. The accord creates a common foreign policy and joint central bank and single currency by 1999 for the twelve signatory nations. Until very recently, it appeared doubtful that the treaty would ever be implemented. However, Germany's highest court has rejected constitutional challenges which were the last major obstacle for the accord [168].

and the Treaty of Rome, concerning the development of the European Common Market. In none of these treaties had a specific charter for EC-wide R&D efforts been established [169].

Tied to this effort of economic and technology integration was also the necessity of consolidating European energy policy. Energy prices, infrastructure, and portfolio division play powerful roles in defining national economic competitiveness, living standards, and trade balances. Social and economic integration of Europe requires that these sectors become harmonized across all EC member states as a precursor to the successful establishment of a single internal market. Therefore, the development of a Single Energy Market (SEM) became an essential element in the movement towards European integration. The SEM requires the reduction of barriers to energy trade within the Community, the elimination of state subsidies to national utilities, the development of extensive international infrastructure - and the establishment of an EC-centered R&D program that assures dissemination of new technologies and techniques throughout the community.

Environmental concerns and the issue of energy supply security are also vital components of the burgeoning EC energy policy agenda. Problems and events in the 1980s (acid rain, Chernobyl, the establishment of the "Greenhouse Effect" theory, the detection of ozone depletion in the upper atmosphere), and the beginning of the 1990s (the Gulf War, the collapse of the USSR) had powerful effects on both popular and leadership perceptions over how much and what kinds of energy should be consumed in Europe - and the world in general. For the first time, environmental concerns became directly linked to the development of energy strategy.

Efforts to stabilize or reduce air emissions of NO_x and SO_2 were first begun by then West Germany in the early 1980s. Strict emissions standards were developed for existing and new power stations, requiring utilities to invest approximately DM21 billion (approximately \$13 billion at current exchange rates) to retrofit 37 GW of coal-fired power stations [173]. In order to defray the cost disadvantages of this action, the West German government sought to have its regulations applied throughout the EC. In 1984, the EC proposed

uniform reductions in NO_x and SO_2 emissions of 60 percent and 40 percent, respectively, by 1995 [173]. However, because of the variance in energy portfolios across the EC and the resultant variance in cost burden, several member states balked at having to bear the brunt of the burden. A compromise agreement was therefore reached in 1988 (Large Combustion Plant Directive, or LCPD), allowing some countries to move slower than others in reducing these emissions.

In 1988, the EC took the initiative with regard to CO_2 emissions reduction efforts. In an effort to circumvent attempts by West Germany and the Netherlands to force their own emissions programs on the rest of the EC (as Germany had done before), and also to establish a position for itself at the 1992 United Nations Conference on the Environment and Development in Rio de Janeiro (UNCED), the EC established the goal of Community-wide stabilization of CO_2 emissions at 1990 levels by the year 2000 [173].

These efforts constitute the heart of the ECs environmental policies, and are integral to the design and application of EC efforts in developing and implementing programs in energy efficiency and new energy technologies. The anti-nuclear movement in Europe has also brought a great deal of pressure upon national governments (especially in Germany and Italy), forcing some to halt further construction of nuclear power plants, and in other cases (Italy), to close down all existing plants. To date, anti-nuclear sentiment has yet to make a significant impact on the policies of the CEC. Approximately 75 percent of the EC energy research budget is still directed towards nuclear fission and fusion¹⁰¹. The reasoning here may well be based on the diverse mix of energy portfolios within the Community - including a substantial investment in nuclear energy by France - and the political pressure placed on the CEC not to move too quickly in attempting to dictate energy policies to member states that are still reconciling to themselves the tradeoffs of surrendering certain sovereign rights to the EC in exchange for economic integration and its benefits.

¹⁰¹ Approximately 796 MECUs out of a budget of 1.1 billion ECUs allocated under the 3rd Framework Program (1990-1994) [174].

The energy crises of the 1970s and Europe's critical reliance on imported oil and gas led many member states to develop national energy strategies centered on the creation of state energy companies and the development of indigenous energy sources (such as nuclear, coal, or hydro) to reduce the burden of dependence on energy imports. These national strategies resulted in the establishment of very diverse energy portfolios and dependency levels across the EC - with some states having extensive nuclear power installations (France, Belgium); some with significant domestic coal production (Germany, Spain and the UK); some that are petroleum (natural gas) exporters (Netherlands) or self-sufficient (Denmark); and some with no significant domestic sources of energy, and which are heavily dependent on imports of all sorts (Italy, Ireland, Greece, Portugal, and Luxembourg). Regardless of the energy mix, however, overall dependence on crude oil - specifically for transportation purposes - remains at about 80 percent across the Community [173].

In the 1980s, the combination of cheap oil prices, growing environmental activism, and efforts by the EC to create a Single Energy Market (and eliminate state energy monopolies) made many indigenous sources of energy less attractive from an environmental standpoint as well as a cost standpoint. Yet, the commitment that governments made to some of these sectors has become very difficult to dismantle - especially in the case of Germany, where reform of the government's support for the domestic coal industry is politically charged and not to be undone overnight. Cases like Germany's illustrate the difficulty the CEC faces in attempting to harmonize energy policy - and environmental policy for that matter. Coal will continue to be a significant source of domestic energy in the EC for the short to medium term, and is therefore an important element in R&D planning for the CEC. Across the board, dependence on oil will continue, and given current projections for future EC consumption and economic growth patterns [175], this dependence will become even more acute in the short to medium term, threatening continued economic growth, environmental recovery, and energy security.

The sector that will produce most of this oil dependency growth is transportation. As time goes

by and the economies of the EC (and of Eastern Europe) continue to grow, demand for transportation will follow suit. None of the indigenous energy sources of the EC are applicable to the transport sector in the short term. Therefore, a great deal of pressure is being brought to bear on efforts to develop new transport fuels that are import neutral. This casts natural gas aside because, although the Netherlands and the UK (and prospective new EC member, Norway) have significant gas reserves, they are not nearly sufficient to meet the transport demands of the EC as a whole.

The answer to this dilemma is twofold. First, efforts are being mounted to strengthen political and economic ties between the EC and its principal suppliers of petroleum products - especially natural gas¹⁰². Secondly, focus has been placed on the promise of *biofuels* as a transportation fuel substitute. Aside from their energy value, biofuels are also being appraised for their potential merit in the current restructuring of the Common Agricultural Policy of the EC. Successful development of these fuels would therefore serve to provide the Community with two substantially important products: domestically produced transport fuels; and, a solution to the politically charged problem of reducing agricultural subsidies as a condition to the final conclusion of the Uruguay Round of the GATT negotiations on world trade¹⁰³.

In sum, increasing pressure is being brought to bear on the existing energy mix and infrastructure in the European Community. Anticipated economic growth and the increased use of electricity as a proportion of primary energy demand, combined with public opposition to the construction of conventional power stations, and increasingly strict environmental guidelines, will

¹⁰² The two biggest suppliers of natural gas to the EC are Russia and Algeria.

¹⁰³ Member states (especially France) have been fighting to maintain agricultural subsidies in response to violent protests by their farmers over the efforts by the international trade community to establish more liberal trade conditions with regard to agricultural products.

force tough decisions by policy-makers over how best to expand power production in a way that is: cost effective; socially and politically acceptable; and, environmentally and developmentally appropriate. EC energy policies are thus focused on three primary objectives: the continued development of the internal market (and sustained economic growth); secure (and affordable) energy sources; and, environmental protection. In order to simultaneously achieve these objectives, prudent energy strategy requires a balanced approach that addresses immediate needs while laying the foundation for the long term.

From a technology development standpoint, the EC has focused its energy research on technologies and techniques that have short term applicability: energy efficiency; conservation; clean coal (gasification and liquification technologies); oil and gas (exploration, exploitation, transport, and storage); and, nuclear fission (waste treatment, new plant design). Concurrently, efforts are also being made toward the development and application of technologies that have a more longterm potential: renewable energy; hydrogen; and, nuclear fusion.

The principal aims of EC R&D efforts are: transnational cooperation between industry and science; support for basic research; and, integration of research and technology (harmonization and standardization). EC research funds are not subsidies, but grants awarded only on the basis of merit and satisfaction of specific selection criteria. Funds are distributed without any regard to national proportionality. If imbalances occur between member states, the only remedy is for prospective participants to increase performance where necessary to win additional EC funding [170]. EC research projects, as a rule, are specifically directed toward "pre-competitive" technologies (pre-industrial development, not market-ready), with the disclaimer that there be reasonable promise of technological and economic applicability. This is done to ensure that EC research does not lead to any distortion of competition and the development of the internal market [169].

Programs funded by the CEC typically involve cost-sharing. Cost share participants may be national government agencies, manufacturers, utilities, or academic institutions. Project proposals must be submitted by at least two

independent organizations from at least two member countries of the EC. Specific preference is given to proposals from small-to-medium sized enterprises (SMEs). The reasoning behind this is that SMEs are considered to be "hot beds" of technical innovation, yet they often have the most difficulty in finding research capital and personnel, and are at a distinct disadvantage when attempting to compete at the international level. Other proposals that are given preference are for those projects that originate or are targeted at less-developed regions within the EC, thus fulfilling the aim of promoting regional harmonization. One CEC objective is to strengthen the technological base of southern tier EC countries relative to northern tier countries [7].

4.2 ENERGY PROGRAMS

The EC has strong programs in place to encourage and coordinate the development of renewable energy sources. The CEC has funded economic studies on the costs of various power generation technologies using both conventional and renewable energy sources. These studies have led to increased utility awareness and interest in renewable energy sources, and have stimulated the formulation of national energy and environmental policies and plans [7].

4.2.1 2nd Framework Program

The *Framework Programs* are comprised of several task-specific areas. The 2nd Framework Program (1987-1991), which was devised after the signing of the Single European Act, was the first to substantively address efforts to integrate EC R&D efforts (in particular, in the energy arena). The JOULE (Joint Opportunities for Unconventional or Long-term Energy Supply) program was established by the 2nd Framework. Its objective was to address non-nuclear energy projects, and to encourage joint efforts in basic energy research. The JOULE concept was a direct culmination of all previous R&D programs organized under the auspices of the EC dating back to 1975, combined with the new perspective given to EC-directed R&D by the Single European Act (SEA). The JOULE program falls under the Directorate-General (DG) XII: Science, Research and Development.

A strong emphasis of the JOULE program was placed on the development and dissemination of innovative energy technologies and techniques that could be quickly applied to the private sector. Such policy would serve to improve the economic competitiveness of European industry, whether through improved efficiency or the development of new products and markets for European companies. The focus was placed primarily on increasing the contribution of solid fossil fuels (coal) and renewables in the medium to long term, and increasing energy efficiency and rational use in the short term. The 122 million ECUs (MECUs)¹⁰⁴ allocated to JOULE was roughly ten percent of total energy spending (2.3 percent of total spending) under the 2nd Framework. EC funding for any project was limited to 50 percent of total cost¹⁰⁵. Third-party contractors from states outside of the EC were eligible for participation under special circumstances, but were not able to benefit from EC financing, and were responsible for all general administrative costs. The effective life of the JOULE program was to last three years and three months, starting January 1, 1989.

4.2.2 3rd Framework Program

The 3rd Framework Program (1990-1994) was established during a period of tremendous change in Europe and the world. The Cold War came to an end; Eastern European countries began the conversion from Communism toward Capitalist Democracy; environmental concerns throughout the world were forcing policy-makers at the highest levels to consider the long term effects on energy production and consumption on the world climate and eco-system; and, the Maastricht Treaty, coupled with the SEA, moved the EC closer than ever before toward economic and political integration.

The 3rd Framework therefore reflected a change in R&D priorities, with more weight given to

¹⁰⁴ This is roughly \$145 million at the current exchange rate.

¹⁰⁵ Universities and Research Centers were eligible for either 50 percent funding of total project cost or 100 percent of additional marginal costs.

environmental research, new energy technologies, and the dissemination of information and mobility of researchers from these programs. Additionally, as a result of the disappointing degree of dissemination and end-use application of research results under the JOULE program, the CEC determined to focus subsequent research programs towards a more pragmatic approach, with ultimate marketability of technologies and techniques as a central theme of the JOULE II program (expected to run from 1991 until 1994). Like JOULE, the JOULE II program falls under DG XII. JOULE II further stresses the involvement of SMEs, as well as dissemination of results and the promotion of technologies in the marketplace.

Two other programs were added to help achieve these goals. THERMIE was developed to promote new energy technology applications within the Community (and in some cases, beyond). THERMIE (expected to run from 1990 until 1994) also provides funding for demonstration projects in energy conservation. With THERMIE, the CEC means to promote energy technology within Europe. One driving factor is the need for a strong European energy base to support a common European internal market. Dissemination projects within less developed regions of the Community are given preference [59]. THERMIE pays as much as 40 percent of project cost, and as much as 35 percent of the cost for a second demonstration¹⁰⁶. Projects costing more than 6 MECUs must be joint ventures of firms between two member states [176].

ALTENER was developed to specifically promote *renewable* energy technology applications, and was established as a direct result of the CO₂ emissions stabilization program established by the EC in 1990. A goal of ALTENER is to increase the contribution of renewables from the present four percent of EC energy demand to eight percent in the year 2005 by supporting various demonstration projects [177]. The program also seeks to triple the production of "environment-benign" electricity from renewable sources such as the sun, wind, and biofuels [178]. ALTENER was

¹⁰⁶ In order to promote cross-border technology transfer, second demonstrations must occur in a different country than first demonstrations.

specifically designed to compliment the programs in basic research and energy technology promotion (JOULE II and THERMIE), and will run from 1993-1997. THERMIE and ALTENER are both in DG XVII: Energy [179].

It is interesting to note the spending patterns that have been established by the 3rd Framework Program. The total budget to date for JOULE II, added to additional funding expected in 1993-1994, comes to roughly 335 MECUs (about \$398 million at current exchange rates) [172]. The budget for THERMIE (which is to cover the same time period, 1990-1994), is 700 MECUs (about \$800 million at current exchange rates) - over twice as much. In contrast, ALTENER's budget is a paltry 40 MECUs (about \$47 million).

Several conclusions can be drawn from these facts. First, given the difficulty and controversy involved in attempting to integrate research programs that most member states still consider to be proprietary, it is much more beneficial - in the short term - to attempt to capitalize on technologies that are already developed and ready for commercial application, and thus establish a track record of success and momentum. Second, the application of more conventional, short-term, non-nuclear energy technologies and techniques such as clean coal, energy efficiency and conservation (covered by THERMIE) will have a more immediate effect on the energy balance and environment than renewables - especially with regard to the reduction of emissions. Third, the more conventional technologies are more likely to be cost competitive - in the short term - and will therefore not have a negative effect on economic competitiveness.

Despite these realities, renewables still receive support from both THERMIE¹⁰⁷ and ALTENER, as well as by a number of other programs aimed at promotion of indigenous energy potential (VALOREN), regional development (STRIDE), and technology transfer (SPRINT). Biofuels are held in especially high regard in Brussels (for reasons already mentioned), and technologies such

as wind and PV are expected to play important roles in promoting development efforts in some of the peripheral regions of the Community - as well as providing for a potentially significant export industry aimed at lesser-developed regions throughout the world [180]. For example, EC consultants have participated in projects in China, Thailand, and North Africa, which are target markets for the output of EC technology development programs [181]. Vigorous demand overseas could help to accelerate the learning curve associated with the new technologies that the CEC is attempting to apply within the Community itself.

The primary role of renewable energy technology development in the EC will be, in the short term, to serve in the effort to stabilize emissions throughout the Community. Therefore, in the short to medium term, the EC will not be stressing the widespread implementation of renewables as a replacement of conventional sources of power, as much as for energy conservation and remote regional development. With regard to biofuels, however, the EC is expected to make a great deal of effort - in the short term - in development and market application, as well as to ensure that any farm lands taken out of food production due to GATT can be immediately transferred to biofuel crop production.

4.2.3 4th Framework Program

The 4th Framework Program (1994-1998) will build upon the themes of its predecessors: promotion of cooperation between member states; enhancement of EC competitiveness in "strategic" sectors; and, improved integration of R&D expenditures. In particular: generic, pre-competitive research will continue to be emphasized; EC-wide standards will be promoted; improvement in the coordination of National programmes will be sought; and, improvement will be sought in the dissemination of results to the private sector - particularly SMEs. Early estimates of the budget indicate an amount near 13 billion ECUs (about \$15 billion at current exchange rates) - a doubling of the 3rd Framework budget [182].

An additional focus of the 4th Framework will be an emphasis on cooperation with "third countries." This is specifically targeted toward the countries of Eastern Europe and the former Soviet Union. For environmental as well as energy security reasons, the CEC is promoting the expansion of EC

¹⁰⁷ THERMIE targets one-fourth of its total 700 MECU budget to renewable energy sources (for 1993, about 24 percent of its 137 MECU budget) [176].

programs in energy efficiency, nuclear safety, and new energy technologies in this region¹⁰⁸. Likewise, efforts are also being made to further integrate the energy strategies of the EFTA countries (Norway, Sweden, Austria, Finland, and Switzerland) with those of the EC, in anticipation of the extension of EC membership to those countries in the near future.

4.3 SUPPORT FOR SPECIFIC TECHNOLOGIES

4.3.1 Wind

European Community nations are well positioned to dominate near- to mid-term developing worldwide markets for wind energy technology, due in large measure to current EC policies and programs. The American Wind Energy Association frames the EC challenge as follows¹⁰⁹:

The European Wind Energy Association, with the support of the European Economic Community and member country governments, has successfully crafted a massive research and market development program that has the capability of launching European wind technology into a Sputnik-like leap over their US competitors. Europeans have put together a \$200 million annual development program that will provide vastly increased resources for

¹⁰⁸ As testimony to the EC commitment, the Russian Federation has recently been accepted into membership in EUREKA, the European program for developing new technologies (including environmental) which was founded in 1985 on France's initiative by way of a civilian alternative to the US "Star Wars" project [183]. Admission of Russia to EUREKA is seen as a major political signal of European support for the reform program of Russian President Boris Yeltsin [184].

¹⁰⁹ Testimony of Michael L. Marvin, Director of Governmental and Public Affairs of the American Wind Energy Association, before the House Appropriations Committee, Subcommittee on Foreign Operations, March 1, 1993.

international market development efforts. Our federal support remains at less than 20 percent of that figure.

Industry experts predict that Europe will possess 62 percent of worldwide installed wind energy generating capacity by the year 2000 [4], a near reversal of current US capacity dominance and an indicator of the expected continued success of EC policies and programs. EC research in wind energy is a coordinated effort combining a broad range of industry, government, and university participants under a structure provided primarily by DG XII and DG XVII. The JOULE program provides significant funding for wind technology, including the development of large machines. The THERMIE program has also boosted European efforts in wind energy [7]. Direct technical support for wind energy in developing nations is provided principally by three other DGs. The DG XVI: European Regional Fund includes the VALOREN and Integrated Mediterranean Programmes for the support of projects to improve the local energy infrastructure of less favoured regions. The DG I and DG VIII: European Development Fund emphasizes projects in Africa, the Caribbean, and the Pacific Ocean. In addition, the VALUE programme within DG XIII further promotes successful CEC wind energy R&D projects [19].

DG XII programs relating to wind energy fall into three semi-chronological programs¹¹⁰. These are: early R&D (1985-1989); JOULE (1989-1992); and FUTURE (1991-1995). Early R&D activities included: development of the European Wind Atlas, a detailed resource assessment for EC countries; utility penetration studies to look at potential integration of wind energy into existing European electricity grids; and, economic studies mentioned earlier. Three large horizontal axis demonstration turbines, the WEGA or AWEC¹¹¹ series, were developed and installed during this time as well, driven primarily by national utilities in Denmark, the UK, Spain, and Germany. Their

¹¹⁰ Some projects overlap into successor program time frames.

¹¹¹ These alternative names stand for Advanced Wind Energy Converter (AWEC), or Wind Energy Groß Anlagen (from the German, for WEGA).

rated capacities were 1 MW, 1.2 MW, and 2.0 MW, and they became operational in 1988 and 1989.

Wind energy activities sponsored within the JOULE program include both grid-connected and standalone applications. JOULE funding for wind was in the range of \$4-5 million per year between 1989 and 1992, and activities begun prior to 1989 were continued under JOULE. Wind activities within the FUTURE program will include the development of advanced large turbines (800-1200 kW) having comparable economics to current commercially available Danish turbines in the 400-500 kW range. Support for both horizontal axis and vertical axis designs is expected for manufacturers from at least four countries. The FUTURE program will also fund the continued development of standalone machines.

The Energy Demonstration Program (EDP) of DG XVII, begun in 1978, has included wind energy activities since 1983 [59]. The EDP aims to promote new technologies through demonstration, utilization, and communication. A total of 96 wind energy projects out of 460 proposed between 1983 and 1989 have been funded by the EDP. The projects averaged about ECU 300,000 in CEC support, about 25 percent of total cost. The projects span the range of turbine sizes from 3 kW to 3000 kW (3 MW), and include various power control techniques and basic types (horizontal axis versus vertical axis). Medium to large turbines from the study countries of Germany, the UK, and Italy are included in those supported by the EDP. The three largest are the 3 MW AEOLUS II variable speed horizontal axis machine by MBB-Kvaerner in Germany¹¹², the 1.2 MW WKA 60 horizontal axis machine by MAN that is part of an off-grid hybrid German system integrating diesel and wind¹¹³, and the 1.5 MW Italian GAMMA 60.

4.3.2 Solar Thermal

The JOULE program included the development of solar thermal applications under the category of "Rational Use of Energy." As an energy-conservation measure, funding could be provided for the conversion from conventional energy sources in buildings to solar energy systems. Funding was also made available for integrated design of passive solar systems. Under the JOULE program, up to 50 percent of the funding required for solar component development and testing could be contributed, and small and medium-sized (SME) firms were favored to receive funding due to their continuous demonstration of innovation in efficiency and in the use of renewable energy sources [185-187].

The JOULE II program enhances the JOULE program's treatment of solar energy in support of two specific projects. One project, Solar House, is the pre-standardization of research in solar components to be applied to the building sector and in urban planning. The objective of the project is to contribute to solar design concepts by (1) integrating the use of solar radiation and ambient heat for heating and power in buildings, and (2) employing modular and cost-effective building elements using new and traditional materials. The second project supported by the JOULE II program is the large-scale application of grid-connected solar power plants [170, 172, 188, 189].

Through the 3rd Framework program, the EC established a policy of division of effort. This policy stipulates that basic research in solar energy will be supported by JOULE II. The promotion and dissemination of any new solar energy technology to the market place in Europe is transferred to the THERMIE program [190-195].

A number of ALTENER programs have been designed in support of solar thermal energy and are intended to (1) develop common standards, (2) train architects in the use of passive solar, and (3) develop a "Guarantee of Solar Results" by manufacturers and designers. Toward these ends, work is being done to study the performance and life-span of solar collectors, and European-level standards are being developed for solar collectors and hot-water production systems. The European Federation of Thermal Solar Equipment Manufacturers is working to make the "Guarantee

¹¹² A constant speed sister machine, the WTS 80-3 (or Näsudden II), is to be built in Sweden.

¹¹³ The AWEC 60 is a sister machine supported by DG XII in Spain.

of Solar Results" part of each member state's building codes. Finally, ALTENER is helping the development of training and information centers to provide the general public with information on solar thermal energy alternatives [196-199].

4.3.3 Solar PV

The ECs most important role in PV is its provision of tied aid programs to developing countries and financing for demonstration projects and R&D programs. The amount of money spent is not as significant as the result: ensuring dissemination of technology and expertise among European PV producers, penetrating markets, and generating greater awareness and demand for PV within the EC itself as well as in the developing world.

The specific objectives for PV development under JOULE II are the same as every PV R&D program in the world: cost reduction through simultaneous improvement in cell efficiencies and the development of new production processes. The following are the main R&D topics:

- 1) Crystalline Silicon
- 2) Amorphous Silicon and other Thin Film Devices
- 3) Fundamental Studies (materials)
- 4) Pilot Systems (BOS)
 - a) Power Conditioning
 - b) Battery Control
 - c) Support Structures

JOULE II is also supporting research on rural applications of PV, rural electrification being an especially important goal for the CEC in its efforts to create better economic and social balance within the community itself. This effort has a particular focus on member states in the Mediterranean region.

International activity in PV promotion by the EC has been primarily focused on Africa. The specific method of promotion is through tied-aid programs by European aid agencies and EC participation in international joint venture projects. An example of the first method is the so-called "Sahel Project" - a large program designed to promote PV-powered water-pumping systems in the "Sahel" region of Africa, which encompasses about nine developing countries. The project was established in 1988 and is reportedly financed 100 percent by the EC. As

of 1991, Siemens Solar had won a \$20 million contract to install and maintain approximately 1 MW in PV water-pumping systems as part of this project [200]. An example of the second method of EC PV promotion is its participation in a PV joint venture in Morocco, involving the European PV Industry Association, European governments and the government of Morocco, established in 1991. The Moroccan government had spent more than \$18 million on the project by the end of 1992, leading to the importation and installation of over 1 MW of PV modules and systems in the first half of 1992 alone [201].

In sum, EC PV promotion serves primarily to supplement the national efforts being made by its member states. Its value cannot be measured in terms of the total amount of money spent, but by the marginal added-value its programs provide to the overall effort to develop and disseminate PV technologies through the integration of research efforts, exchange and dissemination of research results, the development of technical standards and the market opportunities provided by overseas development projects and joint ventures.

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CHAPTER 5: OPPORTUNITIES FOR COLLABORATIVE RESEARCH

A concerted focus by US renewable energy policy-makers on domestic market development has worked to limit future opportunities for US economic expansion overseas. Many of these overseas markets will dwarf US domestic opportunities over the long term. Adoption of a more global viewpoint in the renewable energy arena could produce substantial US economic benefits. In particular, future collaborative relationships with other nations could be chosen to enhance our overseas presence. Target strategies might be to encourage cooperative agreements which allow the US to: 1) increase participation in resource assessment studies (such studies help identify potential markets and establish working relationships with other countries without jeopardizing US technological advantages); 2) increase overseas marketing efforts (involving joint ventures with receiving nations, particularly in developing countries) in both currently available and developmental technologies; 3) tap into the R&D expertise of other nations which have continued to pursue technology areas largely abandoned by the US either because of funding constraints or lack of a foreseeable domestic market (because of the traditional US domestic focus, these two issues have tended to go hand-in-hand). The use of cooperative agreements also provides valuable financial leverage for US participants vying to compete in a time of declining US R&D budgets.

5.1 WIND

For a technology like wind energy, which is rapidly moving into large-scale commercialization, established companies in the US and abroad are anxious to retain their existing proprietary advantages. This tends to discourage an open sharing of information in some leading-edge technical areas. The US would benefit by working to relieve the current technological disadvantage caused by an imbalance between the number of large wind turbine developers in the US (one) versus Europe (perhaps a dozen). This imbalance was caused by the economic shakeout of a domestic market which was first overly stimulated and then largely neglected for a number of years.

The US could leverage its current leading position in operations management and siting (based on our significant domestic experience) to enter into collaborative overseas developments as technical consultants. This could provide opportunities to enter developing markets which are at present largely inaccessible to US manufacturers (for example, in India) because of the tied aid programs of many of our competitors (for example, Denmark).

Current US leads in advanced blade development and variable speed machines¹¹⁴ are well worth protecting. Future wind energy markets will ultimately be determined by the economics of power generation, with technological and economic leadership being measured in cost per kilowatt hour. As a warning flag to US policy-makers, US excellence in efficient, lightweight turbines may be matched or even exceeded in the not too distant future by the Europeans because of their substantial investment in technology improvement.

The current US lead in vertical axis wind turbine (VAWT) technology appears largely inconsequential, as VAWT economics remain ambiguous relative to horizontal axis (HAWT) designs. For this reason, no advantages are seen to collaborations in VAWT technology. Besides resource assessment, the US would benefit from international collaborative programs in turbulence effects, avian mortality, off-grid applications, public education, and the development of common

¹¹⁴ Although a number of European manufacturers offer variable speed machines, the US is thought to have the advantage in commercial viability at present.

standards. Such collaborations would benefit all participants.

5.2 SOLAR THERMAL

When considering collaborative research options for solar thermal technology, several factors need consideration: 1) the economic window of opportunity for large-scale electricity generation using solar thermal options may be relatively short lived, as solar photovoltaics could displace both solar thermal and wind as the renewable energy option of choice at many sites in the long term; 2) a worldwide trend toward decentralization of electrical power generating capacity favors modular applications; 3) substantial market opportunities exist worldwide for less glamorous applications of solar thermal technology such as building heat, solar hot water, solar refrigeration, and water desalination.

The US could pursue a technical advantage in parabolic trough technology by becoming more involved with ongoing research in direct steam generation (in situ boiling technology)¹¹⁵. The technical complexity of in situ boiling has been a deterrent to further research in the area, however, ongoing collaborative work involving Germany, Israel, and major industrial concerns in several European countries promises to soon make possible the 10 to 15 percent reduction in operations and maintenance (O&M) expenditures envisioned by LUZ for a typical SEGS-type power generation plant.

Direct steam generation, if it is perfected by these or other overseas competitors, could provide the margin by which the US loses out on many existing and emerging market opportunities for large-scale power generation in developing nations. This is because many of these opportunities are immediate, and trough technology is the only large-scale power generation option currently

commercially available anywhere in the world. It would be risky for the US to assume that the potential overseas market benefits of direct steam generation in parabolic trough plants (lower operations and maintenance costs, elimination of the need for oil as the heat transfer fluid) would be outweighed by its potential drawbacks (potential safety concerns, technical complexity). Because of a largely unfavorable regulatory and investment climate in the US for renewable energy power generation, the domestic benefits of US investment into in situ boiling technology would likely be small. The key to increased US involvement is a judgement call based on the desire for more secure inroads into overseas markets.

Collaborative research with foreign countries in parabolic trough evacuated tube technology is seen as having a potential negative impact on the current US position. Evacuated tube technology employed at some of the more advanced LUZ trough plants in southern California is now proprietary to the Belgian company Belgo Instruments (the parent company to Solel Solar Systems, Ltd. in Israel). This company would be unlikely to divulge its technology secrets in a collaborative venture. Given US industry access to these plants for continuing operations and maintenance, this country is better positioned than our competitors (except perhaps Israel) in the evacuated tube area, and should continue with existing domestic research partnerships.

Improved absorption surface coatings for parabolic trough receivers is a promising area for collaboration. Current blackened chrome surfaces have economic and environmental drawbacks. Collaborative research opportunities may exist with India and Australia, where promising research developments in this area have been reported, and where US involvement might be leveraged into emerging solar thermal markets.

Further leverage into the emerging Indian market could be accomplished in at least two other ways: 1) place a US-developed dish/Stirling power generation system at an Indian research institute (perhaps the Solar Energy Center, or SEC) for evaluation; 2) invite India to become a partner in ongoing US efforts to reduce the operating and maintenance costs of the LUZ SEGS plants in California. Either of these options enhances US access to the Indian market with technology that

¹¹⁵The positive and negative aspects of in situ boiling technology is one of the most actively debated topics encountered by the authors in the course of their research. For the most part, US experts do not see its merit. Many foreign researchers are strong supporters. The authors have sided with the foreign viewpoint in this case.

should be well suited to that country's needs. (Germany's DLR is currently being considered as a new partner in the SEGS plant operation as well). The National Thermal Power Corporation (NTPC) in India has said that if the US Solar Two central receiver project is successful, they would be interested in establishing business agreements with US industry. The ultimate goal would be construction of a large central receiver in India, as well as technology transfer. Given the author's conclusions for the future of central receiver technology, particularly in the harsh Indian environment, this possibility seems somewhat unlikely.

Motivated by short-term profit needs, the US firm Cummins Power Generation, Inc. has proposed sending one of its dish/Stirling systems to the DLR in Germany for evaluation. There is a tangible risk (which Cummins is both aware of and concerned about) that the Germans could use this opportunity to negate the current US lead in free-piston Stirling engine technology. It is the opinion of many US experts that collaborative efforts with the Germans most often work against the US. The Germans almost always receive more information than they divulge. The Cummins plan is fairly symptomatic of the difficulty US industry has in sustaining long-term research and development programs.

Japan has expressed a desire to cooperate with other nations on systems technology R&D for large scale utilization of solar technology, an area where the US (and to some extent Germany) has a distinct advantage. The US could consider partnering with Japan in one or more large scale solar thermal developments in Southeast Asia, where Japan sees a tremendous opportunity to lead the region with green technologies. Now is an opportune time for the US to establish a commercial foothold in the Asian solar thermal market, before Japanese efforts to cooperate with other area nations progress beyond the planning stages.

5.3 SOLAR PV

Solar photovoltaic technology is considered to be near to market-ready in many parts of the world, and the degree of international competition in this technology sector is expected to become intense in the near to medium term. Further developments in

many near-market PV technologies are therefore considered to be proprietary by the developing organizations, which are consequently not inclined to participate in international collaborative efforts.

However, collaborative efforts may be welcome in sectors of the technology that are furthest from being introduced to the market, most expensive, and most time-consuming to develop alone. Examples of these are: 1) advanced materials development such as multicrystalline thin film semiconductors like gallium arsenide, copper indium diselenide and cadmium telluride; 2) balance of system (BOS) components; and, 3) large-scale demonstration projects.

Two countries that are potentially most amenable to participating in such collaborative efforts at present are Japan and Italy. Italy's "New Energy Plan" (PEN) calls for an ambitious expansion of the domestic application of renewable energy in order to aid in improving the country's energy security situation by reducing its reliance on foreign energy imports. As one aspect in achieving this goal, the Italian government has established a vigorous program of PV demonstration projects throughout the country, and has openly positioned its research facilities for collaborative research efforts with its fellow EC members and other interested international partners. The Italians are behind the US in materials R&D, but offer an attractive venue for developing and testing BOS technologies and establishing demonstration projects.

A note of caution is required, however. The political turmoil currently taking place in Italy has had negative effects on science and technology programs in the form of budget cuts and a decreased propensity for private companies to become involved in joint ventures with public enterprises, for fear of being implicated in the rash of bribery and influence peddling scandals racking the Italian government. This situation has unavoidably placed limits on some of the immediate goals of the Italian energy plan, and has led to some uncertainty about the viability of some of the programs begun under the PEN. As a result, collaborative R&D efforts in Italy will likely be limited until relative stability returns to the public sector.

Because of Japan's strong competitive position in nearly all segments of photovoltaic energy technology (the exception being concentrators), potential collaboration will most likely be in the form of basic research in areas of the technology that are furthest from the marketplace (such as "solar hydrogen"). Japan's New Sunshine Project (NSP) has specifically targeted funding for collaborative efforts in these types of long-term areas of renewable energy technology, environmental technology, and projects in developing countries. The "International Collaboration Program on Large Projects" and the "Co-operative R&D Program on Appropriate Technology" (both were previously described in Section 3.6.1) both offer considerable promise for joint research opportunities. International collaboration is being touted by the Japanese as the appropriate response by industrialized countries to the environmental and developmental threats posed by the rapidly growing economies of Southeast Asia.

International collaborative efforts that are least likely to be established anywhere are in the area of manufacturing technologies and techniques. This is one of the most important components in PVs short term market success, and is therefore the most proprietary aspect of the technology. Collaboration at this stage is primarily conducted on a national or, in the case of the EC, a community-wide basis only.

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APPENDIX A: TECHNOLOGY DESCRIPTIONS

This Appendix is meant to provide the reader with a conceptual understanding of the three renewable energy technologies of primary interest in this study. These are: wind; solar thermal; and, solar photovoltaics (PV).

A.1 WIND ENERGY TECHNOLOGY

Wind energy technology can be traced to the time of the ancient Egyptians. The earliest known windmills, which looked something like paddle wheels, were used in Persia. Early windmill concepts were improved in Holland with such innovations as propellor-type blades and the ability to face the windmill into the wind. All of these early wind machines used the concept of *drag* to convert the wind's kinetic energy into mechanical energy useful for many tasks such as grinding grain or pumping water.^a Modern wind machines, often called wind energy conversion systems (WECS), operate on the principle of *lift* to produce electricity. In these machines, the velocity of the blades exceeds that of the wind [1]. Modern machines are categorized according to the orientation of their rotor axis. Rotation in a *horizontal axis* machine is about a line which is parallel to the ground and oriented into the wind. Their blades resemble airplane propellers. *Vertical axis* machines rotate about a line perpendicular to the ground [2]. The fixed curved blade designs of many of these machines make them reminiscent of giant eggbeaters, a concept first patented by the Frenchman J.G.S. Darrieus in the 1920s [3].^b

^a From "Wind Energy," Energy Fact Sheet, American Wind Energy Association.

^b Darrieus-type machines have been tested in, for example, the US, UK, Canada, Japan, and Australia. Their peak efficiencies are comparable to typical horizontal axis machines, but adjustable blades on some horizontal axis machines have been used to improve their efficiency over a higher range of wind speeds. New vertical axis machine concepts are addressing this problem. Australian researchers claim that their Darrieus-type machine can outperform horizontal axis machines in power

Vertical axis machines with straight blades are also under development [1]. A third vertical axis turbine concept was invented by a Swede named Savonius. It uses both lift and drag principles; the drag starts the machine in motion by using cups or vanes to trap the wind. A combined Savonius/Darrieus concept was studied at one time, but was abandoned because of the very large size required for the Savonius vanes^c. All styles of modern WECS have the same major components: the rotor blade, hub, power shaft, gear box, generator, and tower [2].

Schematic diagrams of a typical horizontal axis wind turbine (HAWT) and Darrieus style vertical axis wind turbine (VAWT) are shown in Figure A.1. Both upwind and downwind HAWT operational configurations are shown. Most modern HAWTs operate upwind to avoid shadowing of the blade by the tower, which can generate objectionable noise levels and increase blade stress. An advantage of the VAWT is that its gearbox and generator are located at ground level, which simplifies routine maintenance. However, VAWTs are typically heavier than HAWTs, which puts them at somewhat of a capital cost disadvantage. This is because VAWTs require blades which are long enough to span the entire swept area of the machine. The economics of

production. The Australians have added adjustable flaps to the trailing edge of the rotor to modify airflow and performance, improving performance especially in light breezes [4]. The validity of the Australian claim has not been verified.

^c Information taken from "Vertical Axis Wind Turbines: The History of the DOE Program," a joint publication of the US Department of Energy, Sandia National Laboratories, and the American Wind Energy Association.

increasing the height of either a HAWT or a VAWT are comparable (in contradiction to the commonly held misconception that VAWTs cannot easily take advantage of the higher wind speeds and lower turbulence which typically occur well above the ground surface). VAWTs are supported by guy wires fixed to the top of the rotor tower (not shown).

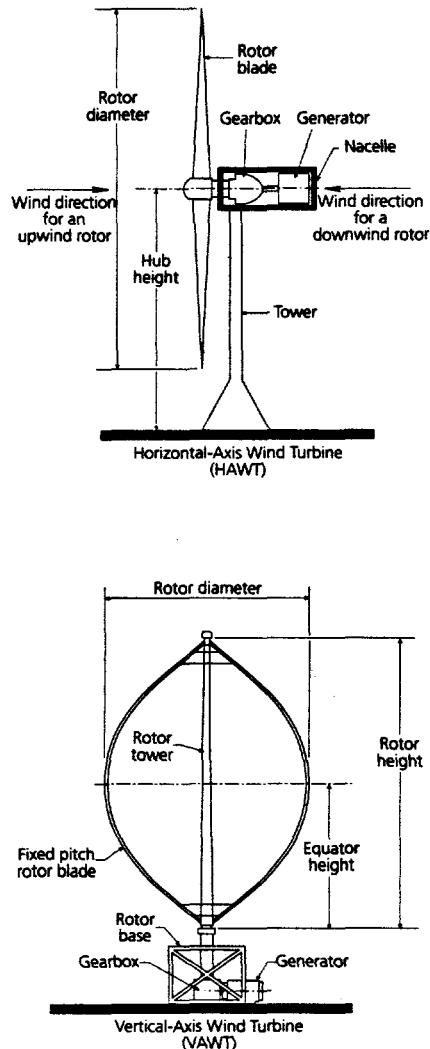


Figure A.1 Schematic representation of typical wind turbine configurations. Source: Alfred J. Cavallo, et al., "Wind Energy: Technology and Economics" in *Renewable Energy Sources for Fuels and Electricity*, ed. Thomas B. Johansson, et al., (Washington, D.C.: Island Press, 1993), 134.

A.2 SOLAR THERMAL TECHNOLOGY

Four primary areas of solar thermal technology are described: parabolic trough systems; parabolic dish systems; central receiver systems; and, non-concentrating collector technologies.

A.2.1 Parabolic Trough Systems

These systems consist of one or more trough shaped collectors lined with a highly reflective material that concentrates sunlight onto a linear receiver tube positioned along the focal line of the trough. A schematic diagram of a parabolic trough is shown in Figure A.2. Fluid within the receiver (which may be water or an organic fluid such as a special oil with a low vapor pressure at operating temperature) is heated by the radiant energy, and is then transported to the point of use by a well-insulated piping network. A complete parabolic trough system consists of five subsystems: the collector (concentrator) with its support and drive system; the receiver; thermal transport (the fluid within the receiver); a control system; and, thermal storage. The trough normally rotates about only a single axis to track the sun. This concept performs well and is cost-effective in the mid-temperature range (100°C - 350°C, or 212°F - 662°F). The main advantage of trough systems for electricity generation is that they are commercially available today. They also share the advantage of modularity possessed by parabolic dish systems.

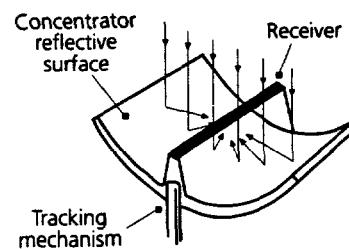


Figure A.2 Schematic representation of a parabolic trough. Source: Pascal de Laquil III, et al., "Solar-Thermal Electric Technology," in *Renewable Energy Sources for Fuels and Electricity*, ed. Thomas B. Johansson, et al., (Washington, D.C.: Island Press, 1993), 218.

Applications include industrial process heat, the production of mechanical or electrical energy such as for irrigation pumping, steam generation for enhanced oil recovery, and "total energy" production or cogeneration (i.e., the provision for both electrical and direct heating processes). Trough technology is being used to produce certain chemical components for pharmaceuticals, herbicides, and fragrances using solar-photochemical processes. Solar detoxification of water, to oxidize organics in solution or remove heavy metals from water, and solar detoxification in a gaseous phase, to oxidize volatile organics, both started out as trough technologies. It has since been realized that these processes are more efficient at lower light intensities than are provided with trough collectors. Trough technology is also used in certain water desalination processes, such as multistage flash distillation (refer to Section A.2.4).

A.2.2 Parabolic Dish Systems

The main component of these systems is a parabolic concentrator mirror that focuses sunlight at a focal point in front of the dish. A schematic diagram of a parabolic dish is shown in Figure A.3. Parabolic dish systems can be used for electricity generation (using dish/Stirling, dish/steam, or dish/Brayton technology), high temperature solar detoxification, or materials processing (using solar furnace technology). The three major types of concentrators which have been developed for parabolic dish systems, in ascending order of sophistication, are *glass-facet*, *full-surface paraboloid*, and *stretched-membrane*. Stretched-membrane concentrators, which consist of a thin reflective membrane stretched on a hoop, evolved as a continuing effort to reduce the cost of large concentrators. Whereas the significant designs for glass-facet and full-surface paraboloid concentrators came from the US, Germany and the US share the lead position in stretched-membrane technology. The US is most actively pursuing the multi-facet stretched-membrane concept. Japan has obtained access to the technology via concentrator purchases from US firms [5].

In dish systems used for electricity generation, a computer-controlled concentrator focuses sunlight onto a receiver located at the dish focal point. Circulating fluid in the receiver absorbs the radiant

energy. In a distributed system, the fluid (generally steam or steam-water) transports the energy from the receiver of each of a series of dishes to a central location, where it is used to generate steam and drive a turbine, or to heat water. A heat engine, such as a Rankine cycle, steam, or Stirling engine, may alternatively be integrated into the receiver to generate electricity directly at each dish. Each concentrator mirror is controlled with a two-axis drive mechanism. The circulating fluid can be heated to over 2200°C (4000°F), however, temperatures of only 427°C (800°F) to 815°C (1500°F) are required for efficient electricity generation. Working temperatures of 800°C (1470°F) are common. Ongoing research may lead to working temperatures as high as 5000°C (9030°F).

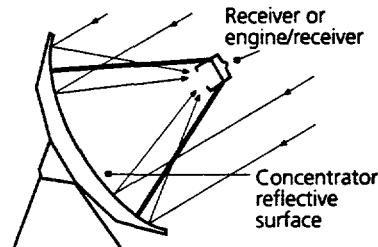


Figure A.3 Schematic representation of a parabolic dish. Source: Pascal de Laquil III, et al., "Solar-Thermal Electric Technology" in *Renewable Energy Sources for Fuels and Electricity*, ed. Thomas B. Johansson, et al., (Washington, D.C.: Island Press, 1993), 218.

A.2.2.1 Dish/Stirling Systems

Dish/Stirling systems combine a concentrator with a receiver and a Stirling engine. The receiver is the concentrator/engine interface. It absorbs concentrated solar flux and converts it to thermal energy. This energy heats the working gas of the Stirling engine. The two basic types of dish/Stirling receivers are "*directly illuminated*" *heater-tube*, and *reflux*. Most early dish/Stirling systems, and some current ones, use the directly illuminated receiver type, where an array of small heater tubes form the absorber surface. These receivers require highly accurate concentrators which produce a reasonably uniform incident solar flux. Unfortunately, state-of-the-art stretched-

membrane concentrators have precise focusing as a major technical challenge. Reflux receivers have numerous technical advantages over directly illuminated receivers. In these receivers, a heat transfer fluid (usually liquid metal) vaporizes on the receiver absorber surface, and then condenses on the Stirling engine heater tubes. This allows heat transfer at almost constant temperature. The condensed liquid returns via gravity to the receiver surface. The receiver surface is kept wetted either by immersion in a liquid pool (a *pool-boiler receiver*), or with a wick which draws the liquid metal from a small sump up to the absorber surface (a *heat pipe receiver*). Of the pool-boiler and heat pipe types, the heat pipe reflux receiver is safer because it uses a smaller amount of liquid metal heat transfer fluid. However, the heat pipe receiver is also subject to increased numbers of thermal stress cycles and greater variation in output power [5].

Stirling cycle engines are high temperature externally heated engines with an alternatively heated and cooled hydrogen or helium working gas. For dish/Stirling systems, an alternator or generator is connected to the engine. The two types of Stirling engines are *kinematic* (which are used with commercially available alternators) and *free piston* (which require a special alternator incorporated within the engine itself). The kinematic Stirling engine is similar in many ways to an automobile engine, in that it has cranks, pistons, and oil lubrication. A free piston Stirling engine has no cranks or oil lubrication, and the pistons are free to move. A free piston engine is more like a refrigerator compressor than an automobile engine. Most Stirling engines developed to date are of the kinematic type⁴, but in an effort to reduce sealing and wear problems associated with kinematic engines, several companies worldwide are working to develop free piston engines⁵. Of the kinematic and free piston concepts, many technical experts favor the free piston concept for control of longterm markets, primarily because of its mechanical simplicity.

⁴ Notable kinematic Stirling engines have been developed by Sweden, Japan, and the US. India is also working to develop a kinematic Stirling engine.

⁵ The US has developed the only commercially available free piston Stirling engine.

A.2.2.2 Dish/steam Systems

Dish/steam systems are far less efficient than dish/Stirling systems, but they have been perceived by some to be simpler, cheaper, and more easily maintained. These supposed advantages have been used by some to advocate the suitability of dish/steam systems for remote applications⁶. This is a false argument. Far less expensive means of steam generation are already well established.

A.2.2.3 Dish/Brayton Systems

Dish/Brayton systems combine a concentrator with a receiver and a Brayton engine. Brayton engines have existed since the 1800s, and are basically gas turbines. Compressed hot air is blown over the engine turbine blades, making them spin. Some technologists favor the spinning Brayton motion to the reciprocating action of a Stirling engine. Because of their long history and their current mass-production, Brayton engines should theoretically exhibit greater reliability and lower maintenance costs than Stirling engines. They are also less massive. However, Stirling engines are theoretically more efficient than Brayton engines⁷. The most advanced Brayton engines incorporate ceramics instead of metals. This allows operation at much higher temperatures.

⁶ The Australians are developing a dish/steam system.

⁷ US research has focused primarily on Stirling engines because of their efficiency, with only secondary regard to relative engine costs. Israel is currently a leader in Brayton technology, because they have an excellent solar receiver for a Brayton engine. An extremely massive volumetric receiver developed by Germany's DLR for dish/Brayton systems is being incorporated into a metal Brayton engine developed by the US, by way of a cooperative agreement involving the German government and the US DOE. Current plans are to test the Israeli volumetric receiver for comparison to the DLR receiver.

A.2.2.4 High Temperature Solar Detoxification

These processes use a tracking parabolic dish to clean contaminated soils using either *photolytic* or *thermal/catalytic steam reforming* chemistry inside an insulated reactor vessel at the dish focus. In a photolytic process, the ultraviolet (UV) portion of the solar spectrum is absorbed directly by organic molecules at high temperatures. The absorbed energy is used to break chemical bonds and oxidize the waste, converting it to carbon dioxide, water, and halogen acids which are easily neutralized to simple salts. In a steam reforming process, the sunlight is absorbed by a catalyst which reacts with steam to convert the organics to products similar to those in a photolytic process, plus significant amounts of hydrogen and carbon monoxide. These processes can be used to destroy dioxins and/or industrial solvents^b.

A.2.2.5 Dish Systems for Materials Processing

A *solar furnace* is an instrument to get high temperatures by concentrating solar radiation onto a specimen. This allows advanced materials processing to be performed in an environmentally benign manner, without many of the energy generation and transmission losses which can contribute significantly to operating costs for some other applications requiring fossil fuels [6]. Solar furnaces can be of the *direct-incidence* type, in which the parabolic concentrator is directed toward and tracks the sun, or the *heliostat* type, in which solar radiation is directed into a fixed concentrator by means of a turnable mirror or heliostat. Materials processing occurs at the concentrator focus. A heliostat type furnace with horizontal optical axis is widely used for large furnacesⁱ.

^b Information taken from a brochure "Solar Detox: Recent Research in Solar-Powered Pollution Cleanup," SAND91-2832/6216/1000, Sandia National Laboratories.

ⁱ Early development of solar furnace concepts occurred in Germany and then France, followed by Algeria, the US, and Japan. Powerful furnaces currently are in operation in the US, France, Israel, and the former Soviet Union [6].

A.2.3 Central Receiver Systems

This technology is characterized by a field of sun-tracking mirrors (heliostats) which reflect sunlight onto a receiver located on a tower, heating a fluid that circulates within the receiver. A schematic diagram of a central receiver is shown in Figure A.4. Working fluids may be water/steam, gases, molten salts, liquid metals (e.g., sodium), or solid particles (e.g., spherical bauxite). The five main components of a complete system are: heliostats; receiver; heat transport and exchange system (i.e., the fluid); thermal storage; and, the control system. Individual heliostats track the sun automatically in two axes, reflecting radiant energy onto the receiver. This concept is now being used commercially to collect thermal energy at temperatures roughly around 650°C (1200°F) using several hundred heliostats. Operating temperatures of 1500°C (2730°F) or higher may be achieved in larger systems during the 1990s. Applications of central receiver technology include turbine operation to produce electric power, process heat in industrial applications, or production of fuels and chemicals^j. The main advantages of central receivers are: the ability to collect energy at both high temperatures and low cost; and, because of their advanced thermal storage systems, the ability to produce electricity during short periods of cloudiness, or at night.

The most promising receiver concepts at present are *molten salt-in-tube (SIT)*, *molten-salt film* (called *"direct-absorption" receiver*, or *DAR*), and *volumetric-air*. These are all in the class of

^j Only three central receiver power plants, and two central receiver test facilities, are in operation in the world today. The power plants are SSPS and CES-1 (both at Almeria, Spain), and Solar One (Barstow, California, USA). The test facilities are at SNL (Albuquerque, NM, USA) and the Weizmann Institute (Israel). Solar One is due for a significant upgrade to Solar Two in the near future. The Russians are said to be interested in upgrading and restarting their SES-5 central receiver. In addition, a consortium of European and US companies and organizations have formed a joint venture named PHOEBUS, to design and build a 30 MW volumetric-air central receiver plant, preferably in Jordan.

"second-generation" receiver technology, and are successors to less sophisticated *water/steam* receivers, which represent "first-generation" technology. Only *water/steam* and SIT receivers are considered well enough developed and demonstrated to be "available" today. The DAR concept is in its infancy. Testing of the volumetric-air concept is ongoing. In an SIT receiver, salt flows through a series of narrow but long thin-walled stainless-steel tubes mounted on the receiver. The exteriors of the tubes are painted black to enhance solar energy absorptance. In a DAR receiver, no tubes are present. Instead, blackened salt absorbs solar energy directly as it flows in a thin film down flat, nearly vertical stainless steel panels. A volumetric-air receiver consists of layers of wire-mesh material which is penetrated by sunlight. The volume within the receiver becomes heated. Air ducts connect the receiver to additional equipment (including a large Brayton engine) on the ground [7].

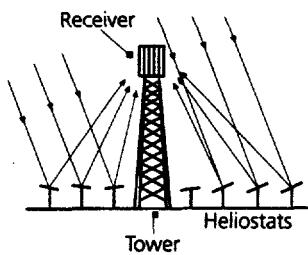


Figure A.4 Schematic representation of a central receiver. Source: Pascal de Laquil III, et al., "Solar-Thermal Electric Technology" in *Renewable Energy Sources for Fuels and Electricity*, ed. Thomas B. Johansson, et al., (Washington, D.C.: Island Press, 1993), 218.

A.2.4 Non-Concentrating Collector Technologies

Parabolic troughs, parabolic dishes, and central receivers all concentrate incident radiant energy to a single point or line. There are several solar thermal technologies in which this is not done. *Solar detoxification of water* is most efficiently performed at low light intensity (i.e., using non-concentrating collectors), because the titanium dioxide catalyst used is more effective under such conditions. *Solar detoxification in a gaseous*

phase is more efficient when non-concentrating (low-intensity) collectors such a *solar ponds* or *one-sun reactors* (such as flat plates or pipes laid on the ground) are used, because these collector types capture a portion of available *diffuse* ultraviolet light^a. In solar detoxification of water, the catalyst absorbs ultraviolet photons, thus becoming activated in the waste stream. Very reactive oxidizers are formed which attack the organic molecules. The resultant products are carbon dioxide, water, and perhaps easily neutralized, simple mineral acids^b. Low temperature detoxification can be accomplished using UV lamps instead of solar energy, and based on interviews with several experts, it appears that favorable economies of energy conversion may not exist for current or foreseeable solar collector systems when utilized in this way. Some researchers maintain that shallow ponds represent an economical option for the industrial treatment of wastewater. Overall, however, future market potential for low temperature solar detoxification is considered small.

Water desalination can be accomplished using *simple distillation*. A typical solar still design includes an insulated, dark-colored basin which is filled with saline or brackish water to a depth of six to 12 inches. A liner bed is covered with sloping, transparent glazing made of glass or clear plastic. The water is evaporated with solar thermal energy, condensed onto the transparent glazing, and then drained into a collection trough. The nonvolatile salts remain in the residual brine. The majority of solar stills were constructed in the 1960s or early 1970s, and very little development work has been done since. Such systems are thought to be uneconomical for large commercial applications, particularly if their performance is not enhanced using auxiliary heat, chemical dye additives, or successive stage operation. Desalination by *multistage flash distillation (MSF)*, although more commonly accomplished using trough technology, has been powered by a large solar pond. In the MSF process, salt water under pressure and

^a Roughly 50 percent of UV light is diffuse. Since only a very small amount of the total solar spectrum energy (say, two to three percent) falls in the UV range utilized for solar detoxification, it is vital to capture as much of this energy as possible.

elevated temperature is "flashed" in a series of multistage chambers at progressively lower pressures and temperatures, again causing separation of the nonvolatile salts. A major drawback of this concept is scaling and corrosion in MSF plants¹.

A.3 SOLAR PHOTOVOLTAIC TECHNOLOGY

The discussion on solar photovoltaic (PV) technology is broken into the following areas: the PV effect; the photovoltaic cell; the PV system; and, semiconductor (SC) materials.

A.3.1 The PV Effect

Photovoltaic electricity is produced by the *photovoltaic effect*. The PV Effect occurs when photons strike a semiconductive material with an amount of energy sufficient to dislodge electrons from their orbits around the atomic nuclei of the material. This produces free electrons (with a negative charge), as well as positively charged holes (the space the electrons once held in the atomic structure). The attraction and movement of free electrons to the holes creates the means for an electric charge.

A.3.2 The Photovoltaic Cell

The basic PV cell is made up of two layers of a semiconductive material, one that has a net positive charge (p-type) and is placed on the bottom of the cell, and one that has a net negative charge (n-type) and is placed on the top of the cell. These two oppositely-charged layers form an electric field which acts to drive positive and negative charges in opposite directions. When sunlight strikes these materials, freeing electrons and creating holes, the

differently charged particles are both attracted and repelled by the electric field to opposite sides of the cell. The positively charged holes are driven across the field to the p-type layer, while the negatively charged electrons are driven to the n-type layer. On the top and bottom of the cell are conductive electrical contacts. The flow of electrons to the top layer is tapped by the contact and conducted through an outside circuit that directs these electrons to the bottom contact and the p-type layer, where the electrons recombine with the holes and repeat the process. This flow of electrons creates a current that is tapped as electricity. A schematic diagram of a PV cell is shown in Figure A.5.

A.3.3 The PV System

A PV System is comprised of a number of cells connected together to compose a module, which are then put together to form an array. Importantly, the number of cells in a module and the number of modules in an array are not related to an economy of scale in any way. The effect of adding more cells/modules to an array is linear, increasing electrical output by a proportion directly equal to the increase in cells/modules.

There are two different types of arrays: 1) Flat Plate Arrays, which are large, flat arrays of PV modules able to convert direct as well as diffuse sunlight; 2) Concentrator Arrays, which are a conglomeration of lenses which magnify direct sunlight onto individual PV cells. Each of these arrays requires a support structure as well. Flat plate array structures can be: 1) fixed (non-moving); 2) placed on a single axis (to follow the progress of the sun throughout the day); or, 3) placed on a double axis (to allow for seasonal changes in the angle of sunlight onto the array, as well as follow daily progress of the sun). Because they only operate using direct sunlight, concentrator arrays *must be supported* by double-axis support structures in order to ensure that the sun is always perpendicular to the lenses.

Additional components comprising a PV system (called Balance of System) vary according to the specific application (i.e., small-scale remote for road signs and water irrigation systems, for example, and residential, or utility-scale). The variance in systems relates to the requirements for

¹ All references to water desalination in this Appendix are taken from a paper by David L. Block and Ingrid I. Melody of the Florida Solar Energy Center, titled "Assessment of Solar Desalination Processes," (complete citation unknown).

electricity conditioning, transmission, and/or storage. For example, utility-scale PV electricity generation requires: 1) electricity converters, i.e., equipment required to recondition PV-generated electricity, which is direct current (DC), to grid electricity, which is alternating current (AC); 2) storage technology for PV downtime (i.e., on cloudy days, or at night).

A.3.4 Semiconductor (SC) Materials

Variance in the atomic and molecular structures of different semiconductive materials relates to three specific characteristics by which they are judged with regard to their ability to conduct the PV Effect. First, each requires a different level of photon energy to dislodge electrons from their atomic orbits with enough force to propel them across the electrical field of the cell. This means that certain materials react to specific portions of the light spectrum, some requiring a high energy level to dislodge electrons, some a lower level. These energy levels are called the band-gap energies. The band-gap level indicates at which point the SC *begins* to release electrons when struck by photons. Light of lesser band-gap energy passes through the SC, creating heat. Light of greater band-gap energy is absorbed, but also creates heat^m. Thus, a material with a low band-gap energy is reactive to a wider range of the sunlight spectrum than a material with higher band-gap energy. This means that as sunlight hits a low band-gap material, a greater number of electrons are freed (relative to a high band-gap material), creating a larger current. However, there is a tradeoff. Because the band-gap energy is low, the force of these electrons (voltage) is low as well. The total energy output of a PV cell is calculated by multiplying the voltage by the current. The decision as to which semiconductive material is best to use is a function of this tradeoff.

The second important aspect concerning the structure of SC materials relates to the band-gap level as well, but is associated with the *efficiency* with which certain materials absorb light, rather than the *type* of light they can absorb. There are

^m Materials used in PV cells have band-gaps of 1-1.8 electron volts (eV).

essentially two categories of SCs in this regard: direct band-gap and indirect band-gap. Direct band-gap SCs freely accept photons of sufficient energy, and therefore absorb light efficiently (*efficiently* means that a substantial proportion of photons striking the SC collide with electrons to promote the PV effect). Indirect band-gap SCs do not accept photons so easily, requiring a "thermal vibration" or "phonon" within the structure to direct the photons toward the electrons. Thus, indirect band-gap SCs are not as absorptive.

An important aspect of absorptivity is its indirect relationship with regard to the *amount* of SC material required to create an efficient PV cell. Cells made with highly absorptive materials require relatively less material to absorb the same amount of light as a less absorptive material. This becomes important in the economics of cell manufacturing.

Thirdly, the material structure is directly related to the conduction of electrons once they have been released from their orbits. Crystalline materials have very orderly structures, being constructed of a fixed arrangement of atoms called a crystal lattice. Electrons conducted through crystalline material lose very little energy as a result of breaks and/or impediments (impurities) in the structure. Therefore, crystalline materials prove to be the most efficient semiconductors.

The conversion efficiency (the proportion of sunlight energy transformed into electrical energy) of the PV cell is directly related to all of these characteristics. For example, a material can be highly conductive, yet have an indirect band-gap, therefore reducing the amount of light that is absorbed, and thus decreasing the efficiency in which sunlight is processed into electricity. PV cells are primarily rated according to conversion efficiency. Thus, it is important to understand the tradeoffs involved in deciding upon the appropriate SC material. Following are some examples of the SC materials used today:

Single Crystal Silicon (SCS)

- Single crystalline structure - very efficient conductor.
- Low band-gap (1.1 eV) - high current/low voltage conductor.
- Indirect band-gap - low absorptivity.

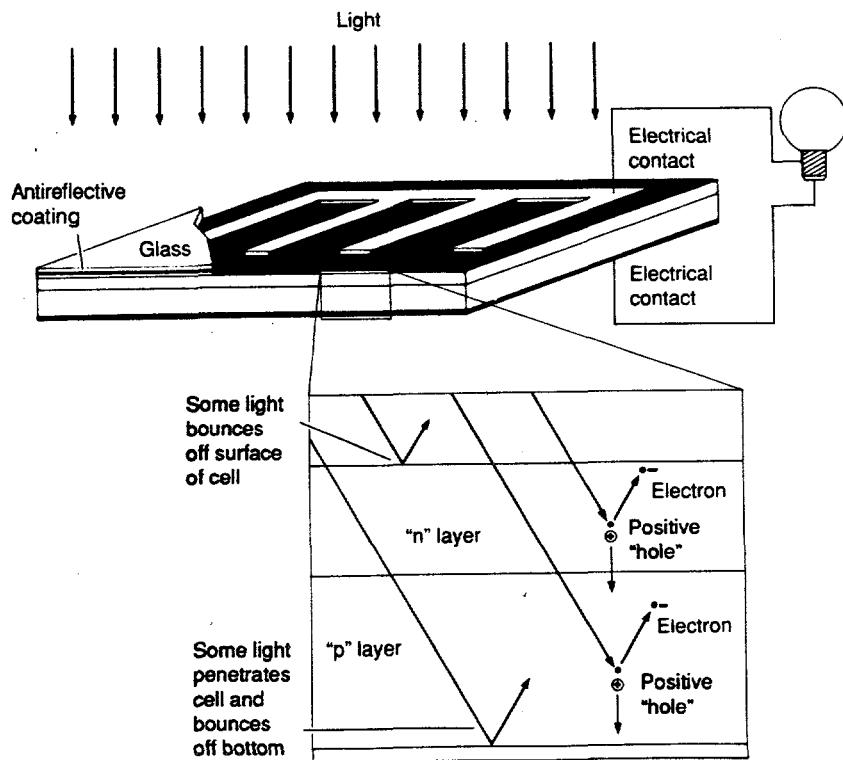


Figure A.5 Schematic representation of a typical photovoltaic cell. Source: Michael Brower, *Cool Energy: Renewable Solutions to Environmental Problems*, (Cambridge, MA: The MIT Press, 1992), 57.

Multicrystalline Silicon

- Imperfect crystalline structure - less efficient conductor.
- Has similar band-gap characteristics as SCS.

Amorphous Silicon (a-Si)

- Non-crystalline structure - relatively inefficient conductor.
- High band-gap (1.75 eV) - low current/high voltage.
- Direct band-gap - high absorptivity; (40 times that of SCS).

Copper Indium Diselenide (CIS)

- Non-crystalline structure - relatively inefficient conductor
- Low band-gap (1.0 eV). - high current/low voltage conductor

- Direct band-gap - very high absorptivity (99%).

Cadmium Telluride (CdTe)

- Non-crystalline structure. - relatively inefficient conductor
- Medium band-gap (1.44 eV) - ideal tradeoff of current/voltage.
- Direct band-gap - very high absorptivity.

Gallium Arsenide (GaAs)

- Single crystalline structure - efficient conductor
- Medium band-gap (1.43) - ideal tradeoff of current/voltage
- Direct band-gap - very high absorptivity.

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APPENDIX B: FUNDING PROFILES

The purpose of this Appendix is to provide historical funding estimates for the study countries (with the exception of Russia) for renewable energy in several technology areas (solar PV, solar thermal, and wind, as well as geothermal, ocean, and biomass). These estimates are presented in Tables B.2 through B.15. Included in the tables is information about the Gross Domestic Product (GDP) of each country, as well as the amount of total "New Energy" spending for the years 1990-1993. A pair of tables is presented for each country. The even-numbered tables give funding level estimates for each technology, along with statistics that show each spending level as a percentage of both total "New Energy" spending, as well as a percentage of GDP. The odd-numbered tables describe the data sources (often multiple and contradictory) used to derive the figures shown in the even-numbered tables. Funding information for the European Community (EC) is not presented in this Appendix. One information gap identified during the course of this study is that the EC does not normally publish funding information broken down by individual technology area.

B.1 DATA INTERPRETATION

Interpretation of the information in the tables will be aided by the following comments:

1. International Energy Agency (IEA) data is considered generally unreliable. Therefore, preference is normally given to alternative sources.
2. 1993 currency conversion rates have been used on 1990-1992 source data only when conversion rates for a particular year were unavailable. When available, currency conversion rates for the appropriate year of the data were used (available rates are given in Table B.1).
3. IEA 1992 Review [1] does not contain 1991 funding information for individual technologies.
4. Where multiple sources were available, sources in *italics* (Tables B.3, B.5, B.7, B.9, B.11, B.13, B.15) were chosen. Often, the chosen source was the most recent non-IEA source.
5. For identification of trends, and for performing comparisons between countries, expenditures as a percent of GDP are more reliable than expenditures

as a percent of total New Energy spending, because the definition of New Energy varies from country to country and source to source, often in an unknown way.

6. Government funding estimated here is not the *total* spending for each technology in a country - for example, anticipated funding by Italy's ENEL (now a private company) on geothermal energy electricity generation is expected to reach \$2.44 billion during the 1990s. If averaged over the decade, yearly ENEL expenditures of \$244 million would exceed the estimated funding provided for geothermal energy by *any* government by a factor in excess of six for any year 1990-1993. Therefore, the figures in the tables tell only one important part of the complete funding story.

The IEA defines "New Energy" technologies as including the six which are included in this Appendix, and *not* including fossil fuels (oil, gas, coal), nuclear, conservation, or energy storage. In the even-numbered tables for Denmark, France, the UK, Germany, and the US, "New Energy" technologies are equivalent to "Renewables." However, the definition of Renewables is not necessarily consistent.

Table B.1 Currency Conversion Factors.

Country	Currency	Dollars / Currency			
		1990 ^a	1991 ^a	1992 ^a	1993 ^b
Germany	Deutsche Mark (DM)	0.6186	0.6020	0.6403	0.5892
Italy	Lira (L)	0.000835	0.000806	0.000812	0.000598
Denmark	Danish Kroner (DKr)	—	—	—	0.1508
Japan	Yen (¥)	0.006897	0.007430	0.007888	0.009163
France	French Franc (Ffr)	0.1836	0.1771	0.1889	0.1723
UK	British Pound (£)	1.7841	1.7674	1.7663	1.4945
Russia	Ruble (or Rouble)	—	—	—	0.000808
European Community	ECU	—	—	—	1.13090

^a Source: *Economic Report of the President*, ISBN 0-16-041592-6, Transmitted to the Congress January 1993, US Govt Printing Office, Washington, DC, 1993. (Average conversion rates for each year).

^b Source: *Washington Post*, December 14, 1993. (Average conversion rates for 1993 were not yet available at the time this report was written. In hindsight, these data were not particularly representative of the yearly averages).

In the case of the US data, the IEA definition for Renewables is used for all years (i.e., only six technologies are included in the total "New Energy" figures for 1990-1993). Note that in Table B.14 for the US, the sum of the six technologies' "% of total" is 100 percent for each of the years 1990-1993. Note in Table B.15, Boxes B3 and B4, that Sources [27] and [29] showed much larger figures for total "New Energy" spending than did Sources [26] and [30], the ones that were chosen for use. This is because Sources [27] and [29] included additional technologies in their definitions of "New Energy," such as "electric energy systems" (electric field effects, reliability research, systems and materials research, etc.) and "storage" (utility battery storage, thermal storage, hydrogen storage, etc.). Not all sources were so explicit in their definitions, making proper source selection at times difficult. Japan defines "New Energy" technologies as: renewables; conservation; energy efficiency; and, environment. The EC definition includes "Non-Nuclear" technologies such as: renewables; conservation and energy technologies; clean coal; and, environmental technologies.

For reporting purposes, "Biomass" technologies are taken to include: wood (residential and industrial); biofuels or "biogas;" municipal solid waste (MSW) or waste incineration; and, wood chips and straw incineration, especially in Denmark.

In Table B.7, Boxes F1-F4, Source [11] included Germany's deep drilling program funding in its overall geothermal estimate. This is more accurate than other available sources ([2,10]) which do not include this significant program. Also in Table B.7, Box H1 cites Source [3], listed simply as "Author estimate." This particular estimate was derived as follows: in 1991 (Box H2 of Table B.7), the IEA (source [2]) reported funding was a factor of 3.4 below funding reported through Embassy sources (source [14]). The authors consider Embassy data to be the more reliable source. The estimate of Box H1 simply assumed that the 1990 IEA estimate was low by the same factor of 3.4.

In Table B.13, an estimate of \$18.9 million is given for Japanese funding of solar thermal technology in 1993. The figure was derived by subtracting Ffr 300 million (about \$51.7 million) for 1993 solar PV funding [6] from ¥7.7 billion (about \$70.6 million) for 1993 "Solar Energy" expenditures under the New Sunshine Project [22]. Unfortunately, this seems to be a common ambiguity in Japanese reporting of expenditures - no differentiation is made among the categories of "Solar" energy. A similar ambiguity exists in the 1992 information (see the note below Table B.13). This issue is related to another inherent difficulty with data interpretation for all countries - there is no way to distinguish between terrestrial and space PV applications, where terrestrial applications are the subject of the main report.

Funding information on Russian support of renewable energy technologies was not found during research for this study. Given the proper Russian contacts, there seems no reason to believe that such information could not be obtained. The budget for Russia's Ecologically Clean Power Engineering program might be considered a reliable source of information since the year 1989. Funding and schedule constraints precluded the authors from seeking this information. A logical first step would be to request the Foreign Systems Research Center (FSRC) of Science Applications International Corporation (SAIC) to perform a search and personal inquiries.

One important aspect for interpretation of Russian funding is the rapid devaluation of the Russian Ruble since the breakup of the Soviet Union. The authors obtained the following currency conversion information from the Interfax News Agency:

<u>Date</u>	<u>Ruble/\$</u>
January 3, 1992	150.0
March 3, 1992	140.1
June 2, 1992	112.6
September 3, 1992	210.5
December 1, 1992	417.0
January 5, 1993	417.0
March 9, 1993	650.0
June 22, 1993	1079.0
September 21, 1993	1036.0
December 14, 1993	1237.0

The currency conversion factor in Ruble/\$ shown above for December 14, 1993 is the inverse of the

currency conversion factor in \$/Ruble for the same date which appears in Table B.1. The significance of the rapid currency fluctuation is that for any 12 month period, even if funding data in Rubles was available from original Russian sources, it would be extremely difficult to convert the information to dollar equivalents in a meaningful way.

US funding for renewables is due for a significant rise in 1994. Expected spending for the six renewable technologies is: solar PV, \$78 million; solar thermal, \$33 million; wind, \$30.4 million; geothermal, \$24 million; ocean, \$0; and, biomass, \$58.2 million [29]. The total of \$223.6 million is an 18 percent rise from 1993 funding levels (compare to Table B.14 data).

B.2 FUNDING TABLES

Funding information is presented in Tables B.2 through B.15.

Table B.2 Danish Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
Denmark	63	63	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	8.6	17.2	18.2	—
Solar PV	0.0	0.0	—	—
as % of total	0	0	—	—
as % of GDP	0.0000	0.0000	—	—
Solar thermal	2.4	3.8	—	—
as % of total	28	22	—	—
as % of GDP	0.0038	0.0060	—	—
Wind	4.0	8.1	—	—
as % of total	47	47	—	—
as % of GDP	0.0063	0.0129	—	—
Geothermal	0.0	0.0	—	—
as % of total	0	0	—	—
as % of GDP	0.0000	0.0000	—	—
Ocean	0.5	0.5	—	—
as % of total	5	3	—	—
as % of GDP	0.0008	0.0008	—	—
Biomass	1.6	4.8	1.7	—
as % of total	19	28	9	—
as % of GDP	0.0025	0.0076	—	—

^a GDP – Gross Domestic Product

Table B.3 Danish Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$63 bil. [1]	\$63 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$8.57 mil. [2]	\$17.19 mil. [2] ECU 13 mil. [4]	Dkr 120.9 mil. [1]	—
Solar PV	0 [3]	0 [2]	—	—
Solar thermal	\$2.42 mil. [2]	\$3.75 mil. [2]	—	—
Wind	\$4.04 mil. [2]	\$8.13 mil. [2]	—	—
Geothermal	0 [3]	0 [3]	—	—
Ocean	\$0.47 mil. [2]	\$0.48 mil. [2]	—	—
Biomass	\$1.62 mil. [2]	\$4.85 mil. [2]	Dkr 11 mil. [1]	—

Table B.4 French Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
France	605	612	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	14.0	17.7	11.9	17.2
Solar PV as % of total as % of GDP	4.4 32 0.0007	4.2 24 0.0007	5.1 43 —	4.6 27 —
Solar thermal as % of total as % of GDP	1.3 9 0.0002	2.1 12 0.0003	— — —	3.4 20 —
Wind as % of total as % of GDP	0.6 4 0.0001	0.5 3 0.0001	— — —	1.9 11 —
Geothermal as % of total as % of GDP	3.5 25 0.0006	3.4 19 0.0006	— — —	2.8 16 —
Ocean as % of total as % of GDP	— — —	— — —	0.0 0 —	0.0 0 —
Biomass as % of total as % of GDP	4.2 30 0.0007	4.8 27 0.0008	— — —	3.5 20 —

^a GDP – Gross Domestic Product

Table B.5 French Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$605 bil. [1]	\$612 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$13.96 mil. [2]	\$15.07 mil. [2] Ffr 100 mil. [5]	Ffr 63 mil. [1]	Ffr 100 mil. [7]
Solar PV	\$4.41 mil. [2]	\$4.25 mil. [2]	Ffr 27 mil. [6]	Ffr 27 mil. [6] Ffr 27 mil. [7]
Solar thermal	\$1.29 mil. [2]	\$2.13 mil. [2]	—	Ffr 19.5 mil. [6] Ffr 19.5 mil. [7]
Wind	\$0.55 mil. [2]	\$0.53 mil. [2]	—	Ffr 11 mil. [6] Ffr 11 mil. [7]
Geothermal	\$3.49 mil. [2]	\$3.37 mil. [2]	—	Ffr 16 mil. [6] Ffr 16 mil. [7]
Ocean	—	—	0 [3]	0 [3]
Biomass	\$4.22 mil. [2]	\$4.79 mil. [2]	—	Ffr 20.5 mil. [6]

Table B.6 German Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
Germany	—	804	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	163.9	197.5	—	171.0
Solar PV	58.8	65.6	65.3	60.3
as % of total	36	33	—	35
as % of GDP	—	0.0082	—	—
Solar thermal	22.5	21.9	—	—
as % of total	14	11	—	—
as % of GDP	—	0.0027	—	—
Wind	14.2 ^b	20.5 ^b	16.3 ^b	—
as % of total	9	10	—	—
as % of GDP	—	0.0025	—	—
Geothermal	35.0	35.0	35.0	35.0
as % of total	21	18	—	20
as % of GDP	—	0.0044	—	—
Ocean	0.0	0.0	0.0	0.0
as % of total	0	0	—	0
as % of GDP	—	0.0000	—	—
Biomass	6.2	12.0	—	—
as % of total	4	6	—	—
as % of GDP	—	0.0015	—	—

^a GDP – Gross Domestic Product

^b As for all funding levels shown in this table, figures shown are estimated national government spending only. To account for additional support for wind energy provided by the federal states (Länder), these figures should be multiplied by a factor of roughly two [24].

Table B.7 German Budgets for "New Energy" Technology – Sources.

Year	1990	1991	1992	1993
GDP	—	\$804 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$98.16 mil. [2] DM 265.0 mil. [8] <i>DM 265.0 mil. [9]</i>	\$104.65 mil. [2] DM 328 mil. [8] <i>DM 328 mil. [9]</i> DM 318 mil. [12,13]	—	DM 285.5 mil. [15]
Solar PV	\$56.88 mil. [2] DM 95 mil. [8] <i>DM 95 mil. [9]</i> DM 91.9 mil. [10]	\$59.2 mil. [2] DM 107 mil. [8] <i>DM 109 mil. [9]</i> DM 104 mil. [10] DM 100 mil. [12-14]	<i>DM 102 mil. [8]</i> DM 94.9 mil. [10] DM 95 mil. [14]	<i>Ffr 350 mil. [6]</i> DM 100 mil. [15]
Solar thermal	\$22.46 mil. [2]	\$21.88 mil. [2]	—	—
Wind	\$13.55 mil. [2] <i>DM 22.9 mil. [10]</i>	\$15.13 mil. [2] DM 17.8 mil. [10] <i>DM 34 mil. [12]</i>	<i>DM 25.5 mil. [10]</i> DM 25.5 mil. [14]	—
Geothermal	\$3.47 mil. [2] DM 14.3 mil. [10] <i>\$30-40 mil. [11]</i>	\$4.94 mil. [2] DM 16.7 mil. [10] <i>\$30-40 mil. [11]</i>	DM 17 mil. [10] <i>\$30-40 mil. [11]</i>	\$30-40 mil. [11]
Ocean	0 [3]	0 [3]	0 [3]	0 [3]
Biomass	\$1.79 mil. [2] <i>\$6.2 mil. [3]</i>	\$3.5 mil. [2] <i>DM 20 mil. [14]</i>	—	—

Table B.8 Italian Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
Italy	493	500	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	55.0	40.9	—	—
Solar PV	15.3	13.8	—	17.2
as % of total	28	34	—	—
as % of GDP	0.0031	0.0028	—	—
Solar thermal	—	—	—	—
as % of total	—	—	—	—
as % of GDP	—	—	—	—
Wind	5.8	5.8	5.8	—
as % of total	11	14	—	—
as % of GD	0.0012	0.0012	—	—
Geothermal	—	—	—	—
as % of total	—	—	—	—
as % of GD	—	—	—	—
Ocean	—	—	—	—
as % of total	—	—	—	—
as % of GD	—	—	—	—
Biomass	3.7	2.7	—	—
as % of total	7	7	—	—
as % of GDP	0.0008	0.0005	—	—

^a GDP – Gross Domestic Product

Table B.9 Italian Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$493 bil. [1]	\$500 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$51.48 mil. [2]	L 50.5 mil. [2]	—	—
Solar PV	\$55 mil. [16]	\$40.88 mil. [2]	—	Ffr 100 mil. [6]
Solar thermal	\$15.32 mil. [2]	\$13.8 mil. [2]	—	—
Wind	\$32.48 mil. [2]	\$24.42 mil. [2]	\$5.8 mil. [17] ^a	—
Geothermal	\$5.8 mil. [17] ^a	\$5.8 mil. [17] ^a	—	—
Ocean	—	—	—	—
Biomass	\$3.68 mil. [2]	\$2.66 mil. [2]	—	—

^a (\$43m - \$2.7m)/(7 yr) = \$5.8m/yr (refer to [17] and Footnote 41 in this report).

Table B.10 UK Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
UK	534	522	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	35.7	42.4	—	—
Solar PV	0.0	0.0	—	—
as % of total	0	0	—	—
as % of GDP	0.0000	0.0000	—	—
Solar thermal	3.7	4.1	—	—
as % of total	10	10	—	—
as % of GDP	0.0007	0.0008	—	—
Wind	9.9	14.4	—	—
as % of total	28	34	—	—
as % of GDP	0.0019	0.0028	—	—
Geothermal	4.6	3.5	—	—
as % of total	13	8	—	—
as % of GDP	0.0009	0.0007	—	—
Ocean	3.9	4.8	—	—
as % of total	11	11	—	—
as % of GDP	0.0007	0.0009	—	—
Biomass	4.1	5.0	—	—
as % of total	12	12	—	—
as % of GDP	0.0008	0.0010	—	—

^a GDP – Gross Domestic Product

Table B.11 UK Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$534 bil. [1]	\$522 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$26.18 mil. [2] £ 20 mil. [18]	\$31.75 mil. [2] £ 24 mil. [18]	—	—
Solar PV	0 [2]	0 [2]	—	—
Solar thermal	\$3.73 mil. [2]	\$4.06 mil. [2]	—	—
Wind	\$9.86 mil. [2]	\$14.38 mil. [2]	—	—
Geothermal	\$4.62 mil. [2]	\$3.53 mil. [2]	—	—
Ocean	\$3.91 mil. [2]	\$4.76 mil. [2]	—	—
Biomass	\$4.07 mil. [2]	\$5.03 mil. [2]	—	—

Table B.12 Japanese Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP^a (billions of dollars)				
Japan	1679	1754	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	96.3	103.4	101.8	121.9
Solar PV as % of total as % of GDP	50.5 52 0.0030	53.5 52 0.0031	48.1 47 —	51.7 42 —
Solar thermal as % of total as % of GDP	2.2 2 0.0001	3.6 3 0.0002	— — —	18.9 15 —
Wind as % of total as % of GDP	2.5 3 0.0001	3.0 3 0.0002	7.7 8 —	9.0 7 —
Geothermal as % of total as % of GDP	37.1 39 0.0022	38.6 37 0.0022	33.1 33 —	37.6 31 —
Ocean as % of total as % of GDP	0.7 1 0.0000	0.8 1 0.0000	0.1 0 —	0.2 0 —
Biomass as % of total as % of GDP	5.4 6 0.0003	4.0 4 0.0002	0.2 0 —	0.2 0 —

^a GDP – Gross Domestic Product

Table B.13 Japanese Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$1679 bil. [1]	\$1754 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$96.34 mil. [2]	\$103.42 mil. [2]	¥ 12.9 bil. [22]	¥ 13.3 bil. [22]
Solar PV	¥ 7.32 bil. [19]	¥ 52.1 mil. [2] ¥ 6.4 bil. [20] \$53.5 mil. [21]	¥ 6.1 bil. [20] ^a ¥ 5.6 bil. [23]	Ffr 300 mil. [6]
Solar thermal	\$2.19 mil. [2]	\$3.59 mil. [2]	—	\$18.9 mil. [3]
Wind	\$2.53 mil. [2]	\$4.01 mil. [2] ¥ 410 mil. [20]	¥ 860 mil. [20] ¥ 982 mil. [22] \$7.7 mil. [24]	¥ 979 mil. [22]
Geothermal	\$37.14 mil. [2]	\$38.94 mil. [2] ¥ 5.2 bil. [20]	¥ 4.9 bil. [20, 22] ¥ 4.2 bil. [25]	¥ 4.6 bil. [22] ¥ 4.1 bil. [25]
Ocean	\$0.7 mil. [2]	\$0.77 mil. [2]	¥ 17 mil. [22]	¥ 17 mil. [22]
Biomass	\$5.38 mil. [2]	\$4.02 mil. [2]	¥ 25 mil. [22]	¥ 27 mil. [22]

^a - Pertains to "Solar Power," with no distinction between Solar PV and Solar Thermal indicated.

Table B.14 US Budgets for “New Energy” Technology – Estimates.

Year	1990	1991	1992	1993
GDP* (billions of dollars)				
US	4555	4496	—	—
R&D BUDGETS (millions of dollars)				
TOTAL	108.7	150.1	178.5	189.4
Solar PV as % of total as % of GDP	35.0 32 0.0008	47.1 31 0.0010	60.0 34 —	66.0 35 —
Solar thermal as % of total as % of GDP	21.1 19 0.0005	22.5 15 0.0005	28.8 16 —	27.0 14 —
Wind as % of total as % of GDP	9.1 8 0.0002	11.5 8 0.0003	21.3 12 —	24.0 13 —
Geothermal as % of total as % of GDP	19.2 18 0.0004	29.2 19 0.0006	27.2 15 —	23.0 12 —
Ocean as % of total as % of GDP	3.9 4 0.0001	2.7 2 0.0001	2.0 1 —	1.0 0 —
Biomass as % of total as % of GDP	20.4 19 0.0004	37.0 25 0.0008	39.0 22 —	48.4 26 —

* GDP – Gross Domestic Product

Table B.15 US Budgets for “New Energy” Technology – Sources.

Year	1990	1991	1992	1993
GDP	\$4555.0 bil. [1]	\$4496.0 bil. [1]	—	—
R&D BUDGETS				
TOTAL	\$108.7 mil. [2]	\$150.1 mil. [2]	\$178.5 mil. [26] \$240.1 mil. [27]	\$248.1 mil. [27] \$257.3 mil. [29] \$189.4 mil. [30]
Solar PV	\$34.99 mil. [2]	\$47.1 mil. [2]	\$59.995 mil. [27] \$60.4 mil. [28]	\$63.735 mil. [27] \$65.5 mil. [28] \$66 mil. [29]
Solar thermal	\$21.11 mil. [2]	\$22.54 mil. [2]	\$28.775 mil. [27] \$29.1 mil. [28]	\$26.264 mil. [27] \$27.0 mil. [28] \$27 mil. [29]
Wind	\$9.14 mil. [2]	\$11.52 mil. [2]	\$21.282 mil. [27]	\$23.368 mil. [27] \$24 mil. [29]
Geothermal	\$19.18 mil. [2]	\$29.25 mil. [2]	\$27.170 mil. [27]	\$22.812 mil. [27] \$23 mil. [29]
Ocean	\$3.88 mil. [2]	\$2.72 mil. [2]	\$1.970 mil. [27]	\$0.947 mil. [27] \$1 mil. [29]
Biomass	\$20.4 mil. [2]	\$36.99 mil. [2]	\$38.981 mil. [27]	\$47.125 mil. [27] \$48.4 mil. [29]

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