United Nations E/C.14/2000/9

Economic and Social Council

Distr.: General
23 June 2000

Original: English

Committee on Energy and Natural Resources for Development
Second session
14-25 August 2000
Item 10 (b) of the provisional agenda*
Review of salient trends and issues on energy development and use in the context of sustainable development: renewable sources of energy, with emphasis on solar energy

Renewable sources of energy, with emphasis on solar energy

Report of the Secretary-General

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* E/C.14/2000/1.

I. Background and introduction

1. Although the source of all renewable energy is solar energy, a distinction is often made between direct solar energy and its indirect forms, such as hydro, wind, biomass, ocean waves and thermal gradients. The present report summarizes the current status and relevant technical, economic, social, and environmental issues pertaining to the development and application of the direct form of solar energy, as well as policy options for stimulating its wider-scale utilization.

2. The real importance of solar energy in providing a sustainable supply goes far beyond its present contribution. It is the most widely distributed resource; its technical potential for power generation, even at present levels of technology, is many times that of other renewable sources. At present, the total contribution of the "new renewables" to world energy consumption is only about 2 per cent. The bulk of this can be accounted for by power generation based on wind, geothermal and biomass sources and by the use of biomass-derived gaseous and liquid fuels. No clear estimate of the contribution of direct solar energy to the world energy supply is available, but it is probably not more than 0.1 per cent.

3. The prospects for solar energy's providing many modern energy services in the medium and long terms are excellent. In order for it to be a major contributor to the global energy supply, there are still many issues, such as conversion technology, cost, land requirement, and storage aspects, that will have to be dealt with in a comprehensive manner. Nevertheless, there are several applications for which solar energy is an attractive and viable option even today; the list is expected to grow in future. With further technological developments, improved economics and greater user acceptance supported by suitable fiscal and policy measures, solar energy could become a major energy provider by 2050. In certain developing-country situations, the impact could be felt even sooner.

II. Solar energy resource

4. At the aggregate level, the solar energy resource base is very large (the solar energy intercepted by earth is 5.5 million exajoules (EJ)/year) compared with total global energy consumption (435 EJ/year). Even if a small fraction of this is converted into useful energy, its magnitude could be over 100 times the present level of energy consumption.

5. Solar radiation data is available for thousands of locations all over the world, often compiled over several decades. Numerous handbooks and atlases for many countries and regions have been published. The World Radiation Data Centre maintained for the World Meteorological Organization (WMO) by the A. I. Voeikov Main Geophysical Laboratory in Saint Petersburg, Russian Federation, together with the National Renewable Energy Laboratory of the United States of America, offers an on-line archive of solar radiation data from over 1,000 sites throughout the world from 1964 to 1993. The archive includes data on direct and diffuse solar radiation and sunshine duration.

6. It is possible to calculate the energy density, that is to say, the amount of energy available per unit area and per unit time for most places on earth using the available data, and software has been developed for this purpose. Nevertheless, there are areas in Africa and South America that are not adequately covered by data-

collection centres. Furthermore, it is advisable to obtain precise data at a particular location for an extended period of time if large power projects are to be undertaken at that location.

7. The practical utilization of solar energy requires the transfer of the heat to a liquid or gas (the solar thermal route) or direct conversion of sunlight into electricity (the photovoltaic (PV) route). The amount of usable energy that can be obtained through these routes and the applications that can be served depend not only on the efficiencies of these technologies but also on certain factors inherent in the nature of the resource itself.[1] The following are the main factors:

(a) Time variation: the solar flux at a given point varies hourly, monthly and seasonally from a minimum of 0.2 kilowatt (kW)/square metre (m^2) to a maximum at the surface of about 1 kW/m^2 necessitating the use of storage;

(b) Geographical variation: the yearly insolation (that is to say, energy density) varies from about 800 kilowatt hours (kWh)/m^2 in northern Scandinavia and Canada to about 2,500 kWh/m^2 in the North African desert, implying differences in performance of solar devices at different locations;

(c) Weather conditions: the annual average sky clearness is in the range of 80-90 per cent in sunny belts and only 40-50 per cent in Europe and Japan. Low sky clearness necessitates additional storage or larger system sizes.

8. Several factors suggest an increased role for solar energy in the world energy scene:

(a) Solar energy is more dependable and available at far more locations than any other energy source. Global variations in annual insolation levels are less than for wind energy. Also, for a given site, the yearly fluctuation in solar energy is small compared with that of wind energy and hydropower resources;

(b) The contribution of solar energy can actually come from millions of small and medium-sized systems all over the world, rather than from a few hundred or a few thousand large systems. In addition, using land where it is available, solar systems can also be installed on rooftops and along highways;

(c) PV systems are ideally suited for small, decentralized power supply to meet the lighting, drinking water, health, education and entertainment needs in large areas not yet served by conventional electricity grids. This can translate into electricity benefits (or at least initial electrification) for up to 2 billion additional consumers. Such coverage of the energy supply system is in fact viewed as an essential feature of energy for sustainable development.

III. The photovoltaic route: status of technology and utilization

9. Solar PV technology enables the direct conversion of sunlight into electricity without any moving parts, noise or pollution. Conversion is achieved through a device known as a solar cell. Solar cells are devices that are made from certain semiconducting materials that have the right optical and electronic properties to enable them to absorb solar radiation and generate a current. In actual practice, a

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[1] United Nations Development Programme, *Energy After Rio: Prospects and Challenges* (UNDP, 1997).

number of solar cells are interconnected and encapsulated to form a module. Modules come in various sizes, and voltage and power ratings, and constitute the building block of a solar PV system.

10. During the past 40 years, solar cells have remained the preferred and most reliable power source for satellites. In addition to silicon, other materials, notably gallium arsenide, have been used for this purpose. While silicon cells had been quickly adapted for terrestrial applications and the costs brought down by a factor of 10-20 during the 1970s and 1980s, the cost of gallium arsenide cells remained too high for terrestrial applications. The search began, however, for alternative materials and techniques, notably in the thin-film form. Among the materials that have been found promising are amorphous silicon (a-Si), polycrystalline silicon films, cadmium telluride (CdTe) and copper indium diselenide ($CuInSe_2$) (referred to commercially as CIS, or CIGS when gallium is also added). While a-Si has been in commercial production since the early 1980s, the other materials have witnessed major improvements in efficiencies and manufacturing processes during the 1990s. The efficiency records set by different research groups for these materials over the past two decades are shown in the figure.

Figure
Efficiencies of thin-film solar cells

11. Typically, commercial solar cells/modules have efficiencies that are about one half of those achieved in the laboratory (usually for a smaller cell size). Data for selected materials/technologies are given in table 1.

Table 1

Status of some important solar cells and module technologies

Technology	*Best laboratory cell efficiency (percentage)*	*Typical efficiency of commercial modules*[a] *(percentage)*
Single crystal silicon	24.7	13-15
Multi-crystalline silicon	19.8	12-14
Polycrystalline silicon films	116.6	(8-11)
Amorphous silicon	13.5	6-9
Copper indium/gallium diselenide	18.8	(8-11)
Cadmium telluride	16.0	(7-10)
Concentrator cells	33 (tandem) 28 (single)	-

Sources: M. A. Green and others, “Solar efficiency tables (Version 12)”, *Progress in Photovoltaics: Research and Applications,* vol. 7 (1998), pp. 31-37; and the Photovoltaic Solar Conference (PVSEC)-11 Conference information.

[a] Figures in parentheses referring to pilot production or first commercial production.

12. The module efficiency figures in the table are for the flat-plate type. Concentrator modules normally employ high-efficiency cells and are mounted on structures that track the sun so that the concentrated beam always falls on the cells; flat-plate modules, on the other hand, may or may not employ tracking arrangements.

13. World PV production has been increasing at impressive rates during the past decade as indicated in table 2. Growth over the last three years has been particularly impressive, with global production at the end of 1999 having reached 200 MW. Single-crystal and multi-crystalline silicon cells accounted for over 80 per cent of this production. Production for the different cell technologies is given in table 3. In a number of countries beyond Europe, Japan and the United States of America, production has been confined to modules only, using cells imported from Europe or the United States of America. Exceptions in this regard are Australia, Brazil, China, India, Mexico and South Africa.[2] The size and configuration of PV systems vary with the application. The commonest applications are lighting, water pumping, and rooftop or ground-based power systems that feed electricity to the grid. Many applications over a broad range are considered commercially viable, in other words, users buy PV systems in preference to available alternatives on the grounds of economics or convenience. These include telecommunications, railway signalling, broadcasting, remote-area power, recreational vehicles and military applications, as

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[2] G. L. Morrison and B. D. Wood, “Packaged solar water heating technology: twenty years of progress”, World Solar Energy Congress, Jerusalem (1999).

well as consumer products such as calculators and watches. Distribution among the various applications for the 1990s is given in table 4.

Table 2

World photovoltaic module production, 1990-1999

(MW)

Year	*United States*	*Japan*	*Europe*	*Rest of the world*	*Total*
1990	14.8	16.8	10.2	4.7	46.5
1991	17.1	19.9	13.4	5	55.4
1992	18.1	18.8	16.4	4.6	57.9
1993	22.44	16.7	16.55	4.4	60.09
1994	25.64	16.5	21.7	5.6	69.44
1995	34.75	16.4	20.1	6.35	77.6
1996	38.85	21.2	18.8	9.75	88.6
1997	51.0	35.0	30.4	9.4	125.8
1998	53.7	49.0	31.8	18.7	153.2
1999	64.6	80.0	36.4	20.5	201.5

Sources: *PV News,* vol. 19, No. 2 (February 2000), and yearly February editions.

Table 3

1999 world cell/module production by cell technology

Technology	*Module production (MW)*	*Percentage of total*
Single-crystal silicon	73.2	36.3
Multi-crystalline silicon	88.4	43.9
Amorphous silicon	23.9	11.9
Crystalline silicon concentrators	0.5	0.25
Ribbon silicon	4.2	2.1
CdTe	1.2	0.6
Polycrystalline silicon thin films	2.0	1.0
a-Si on silicon wafers	8.1	4.0
	201.5	**100.00**

Sources: PV News, vol. 19, No. 2 (February 2000); and yearly February editions.

Table 4

World module shipments by market sector

(MW)

Market sector	*1990*	*1993*	*1996*	*1997*	*1998*
Consumer products	16	18	22	26	30
United States off-grid residential	3	5	8	9	10
World off-grid rural	6	8	15	19	24
Communications/signal	14	18	23	28	31
PV/diesel commercial	7	10	12	16	20
Grid-connected	1	2	7	27	36
Central power	1	2	2	2	2
Total	**48**	**63**	**89**	**127**	**153**

Source: Paul Maycock, "Economic PV: a shift in thinking", *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

14. Nearly 40 MW of the modules shipped in 1998 were used to power small electronic devices with PV modules of less than five watts (W).[3] Besides millions of calculators and watches powered by energy from indoor light, there are 20 million battery trickle chargers and 300,000 electric fence chargers, and 2 million garden lights, 200,000 auto ventilators, and 100,000 pith helmets and caps. It is estimated that over 400,000 homes in developing countries have a minimum PV system that provides power for lights and in some cases also a television set.[4]

15. The cumulative world production of terrestrial PV products over the past quarter century is estimated to have been between 1,100 MW and 1,200 MW. Assuming that 1,000 MW of this is currently installed and in operation, and assuming further that each kW of PV modules generates an average of 1,200 kWh per year of usable energy, the PV systems installed so far have the capacity to generate 1.2 billion kWh/year. This may save some 12 million tons of carbon dioxide CO_2 per year. Both numbers are insignificant in the present world energy scenario.

16. The intense research and development (R&D) activities in the field of photovoltaics have a bearing not only on their economics, but also on new applications, market development and user acceptance. The R&D efforts cover new materials and production techniques as well as improvements in the balance-of-system (BOS) components. For example, impressive improvements have been reported on organic dye solar cells.[5] A research group in Switzerland has established links with industrial organizations in a few countries with a view to commercializing this technology. Another recent effort relates to the development of alternating current (ac) modules, which possess built-in inverters so that the modules deliver readily usable ac power. These modules can be useful in roof-mounted installations

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[3] Paul Maycock, "Economic PV: a shift in thinking", *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

[4] Ibid.

[5] D. Meissner, "Plastic solar cells", *Photon International*, No. 2 (1999), pp. 34-37.

and potentially also in power plants. Field testing of such modules is currently under way at many locations in the United States of America.[6]

17. In most small PV systems, storage batteries constitute the second most expensive item after the modules. Lead-acid batteries continue to be the most commonly used storage devices for PV energy. During the past 15 years, lead-acid batteries with low maintenance and longer life have been developed. Such “solar batteries” are now available in several countries. Another variant of the lead-acid battery is a sealed version that is totally maintenance-free. Such batteries are popular in portable systems as well as in locations that are difficult to access. They are, however, more expensive than low-maintenance batteries and may not have an equally long life cycle. In certain low-power applications, the nickel cadmium battery, which is relatively inexpensive, finds use but only on a limited scale. Further research is needed to develop alternative electrical energy storage systems that can reduce the cost of storage.

18. The control electronics associated with PV systems, such as charge controllers and inverters, requires special attention. Many PV system failures (in addition to lack of battery maintenance) are often traced to the unsatisfactory performance of these components in actual practice. However, significant improvements in power electronics during the past decade have led to a range of reliable, high-quality and compact inverters. These inverters offer direct current (dc)-to-ac conversion efficiencies in excess of 90 per cent. Inverters can also be made grid-synchronous for use in PV systems that are linked to the electricity grid. A special type of inverter is used to operate ac pumps directly from the PV array. Large-volume production has led to significant reduction in the cost of the electronics.

IV. The thermal route: status of technology and utilization

19. The solar thermal route, which utilizes the heat in solar energy, is in some ways less sophisticated than the PV route. While the processes and applications are different, this technology also has the same advantages of silent and pollution-free operation and system modularity. Like the module in a PV system, a collector is the building block of a solar thermal system.

A. Solar water heating

20. The commonest use of solar thermal technology is in heating water. This is now considered to be a mature technology as well as one that is commercially viable. There is therefore no significant government funding for technology development or for promoting wider use. Certain policy measures have, however, been employed in some countries to encourage the use of solar water heaters.

21. Data on the worldwide production and use of flat-plate collectors are not compiled on a systematic basis as is the case for PV modules. Table 5 shows the number of solar domestic water heaters (SDWH) and the glazed collector area

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[6] *CADDET Newsletter*, No. 1/00 (2000). (*Note*: CADDET: Centre for the Analysis and Dissemination of Demonstrated Energy Technologies.)

produced annually for some countries with reference to 1994, as published in a 1999 report.[7]

Table 5
Solar domestic water heater (SDWH) markets in 1994

Country	*Total SDWH in use (thousands)*	*Total glazed collector area installed (thousands of m^2)*	*Glazed collector area produced annually (thousands of m^2)*
Australia	350	1 400	140
Austria		400	125
Canada	12		
China		1 500	500
Cyprus		600	30
Denmark	14	74	8
France		260	18
Germany		685	140
Greece		2 000	120
Israel		2 800	300
Japan	3 800	7 000	
Korea, Republic of	8.7		50
Netherlands	10	49	9
Portugal		200	13
Spain		118	12
Sweden		71	20
Switzerland	9.3	131	6
United Kingdom	45	108	7.2
United States	1 200	4 000	70

Source: G. L. Morrison and B. D. Wood, "Packaged solar water heating technology: twenty years of progress", World Solar Energy Congress, Jerusalem (1999).

22. It can be seen that Japan has the highest production and total number of installations among all countries. Progress in European countries has also been remarkable. The industry in the United States of America, which installed such systems in thousands of homes during the 1970s and early 1980s, suffered a setback with the withdrawal of tax benefits. Solar systems are being used for district heating[8] as well as in stand-alone "combisystems", which provide residential hot water and space heating.[9]

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[7] G. L. Morrison and B. D. Wood, "Packaged solar water heating technology: twenty years of progress", World Solar Energy Congress, Jerusalem (1999).

[8] J. Dalenbaeck, "Thinking Big: large-scale solar heating in Europe", *Renewable Energy World*, vol. 2, No. 4 (July 1999), pp. 86-91.

[9] W. Weiss, "Solar Combisystems: thinking big for a sustainable energy future", *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 84-91.

23. According to another study covering most major user countries,[10] the total collector area installed by 1994 in the world amounted to 25.4 million m^2 with sales in 1994 amounting to 2.287 million m^2, of which the European Union (EU) accounted for about 5.46 million m^2, Japan 6.04 million m^2, the United States of America 5.2 million m^2 and Israel 2.8 million m^2. According to a recent estimate by the European Solar Industry Federation, sales of solar collectors in Europe in 1998 were of the order of 1 million m^2 and the total installed collector area in EU reached over 8 million m^2.[11] These systems are estimated to save 1.4 million tons of CO_2 annually.

B. District heating

24. Interest in large-scale solar water heating as a means of district heating has been increasing steadily in Europe. Such plants mainly serve residential areas. Some use large seasonal storage systems while others work in conjunction with biomass heating.[12] There are about 45 systems with a collector area of 500 m^2 or more, aggregating to 77,742 m^2. The oldest plant still in operation dates from 1983 and is located in Sweden. Sweden remains the leading country with 15 plants accounting for more than 35 per cent of the total installed collector area. The largest plant is in Denmark with a collector area of 9,040 m^2. It has been estimated that, in favourable cases, investment costs may come down to euro 250/m^2 of collector area, resulting in a solar heating cost of euro 0.06/kWh.

C. Solar cooking

25. It is estimated that about one half of the world's cooking is performed using firewood as the fuel. In certain regions of the world, cooking energy requirements place great pressure on biomass resources; the burning of biomass in traditional stoves also causes problems to users. Considering that the regions that depend on biomass for cooking also have significant levels of solar radiation, it would appear that solar cooking can have a beneficial impact in these regions. A number of cooker designs are available. The two most common are the box-type cooker, which is essentially a flat-plate collector in which two to four vessels containing the food to be cooked are placed in the box; and the small parabolic reflector, which concentrates the solar radiation onto a vessel placed in the focal region. A simple cooker of corrugated cardboard with one side pasted with a reflecting film has also been designed as a low-cost alternative. All these cookers are suitable for single-family use. Such cooking devices have certain limitations in regard to the type of preparations that can be made and the time required for the cooking. As a result, solar cookers can only supplement but not totally replace conventional fuels. A home that uses a solar cooker regularly can save between one third and one half of the conventional fuel that is otherwise used for cooking. The payback period is usually two to three years. Cookers with electrical back-up are also available.

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[10] *Opportunities for Large Solar Purchase of Active Solar Systems* (Harwell, United Kingdom, IEA ACDDET Centre for Renewable Energy, December 1998).

[11] R. Berkmann, "Promoting solar thermal: comparison and evaluation of experiences", *Renewable Energy World*, vol. 2, No. 4 (July 1999), pp. 93-95.

[12] *Technical Bulletin No. 120*, (Harwell, United Kingdom, IEA CADDET Centre for Renewable Energy, 1999).

26. Large concentrating cookers can also be used to cook meals for 30-40 persons twice a day. The world's largest solar cooking system has been functioning since February 1999 at Taleti in the Indian State of Rajasthan. The system employs 84 parabolic concentrators, each of 9 m^2 aperture area. Receivers placed at the focus of the concentrators are connected in series. Steam is generated in the system and is used for cooking food and boiling milk in the kitchen of the Brahmakumaris organization. The system can normally prepare meals for 10,000 persons twice a day. The consumption of diesel fuel otherwise used in the boiler system of the kitchen has been drastically reduced through use of the solar systems.

27. China and India are among several countries that have been promoting the use of solar cookers. About 450,000 box-type solar cookers have been distributed in India. A subsidy was made available initially for solar cookers for over 12 years. The subsidy was discontinued in 1994, although the Government continues to promote solar cookers through other measures.

D. Solar thermal power generation

28. A number of experimental projects have been undertaken all over the world since the 1970s to evaluate all three types of collector in concentrating systems and demonstrate their use for power generation. About 400 MW of such systems have been installed so far, the largest collection of which are located in California, United States of America, with an aggregate of about 350 MW. These power plants employ parabolic trough collectors. Some systems heat oil which in turn is used to generate steam; other systems employ natural gas as the secondary fuel. The California plants were completed in the late 1980s and early 1990s. Although technically successful, no more plants of this kind have been built, as they did not prove to be competitive in the absence of tax benefits and other fiscal incentives. A 140 MW solar thermal combined cycle power plant, employing parabolic trough collectors and naphtha as the supplementary fuel, has just been approved for installation in Mathania in Rajasthan, India. Besides funding from the national and State Governments in India, the project is receiving substantial assistance from the Global Environment Facility (GEF) and Kreditanstalt für Wiederaufbau (KfW) of Germany.

29. Dish systems can be used either with a Stirling engine or with a steam engine. Such systems have been tried in Australia, the United States of America and Spain, among other countries. The typical power output of a dish is in the range of 10-50 kW. Such systems have been projected as being suitable for meeting village and small community power needs. Further technical improvements and series production will be necessary to bring down the costs and improve reliability.

30. The largest project employing the solar tower or central receiver principle is a 10 MW system known as Solar Two in Barstow, California. The system uses molten salt as the heat transfer fluid. The relative economics of this type of system compared with the dish and parabolic trough systems have yet to be fully established. More demonstration and pilot projects based on all three collector technologies appear to be necessary.

31. At least two other approaches to solar thermal power generation have been tried: the solar pond and the solar chimney. Experimental pond projects were constructed in Israel and California, United States of America, during the 1980s. The ponds are no longer operational, as the economics are not favourable compared

with those of fossil fuel-based generation. The solar chimney employs the principle of the draught created by hot air rising up a very tall chimney surrounded by a large area covered with transparent material. Wind turbines placed at the base of the chimney generate electricity. Higher-power systems require taller chimneys and larger areas to heat the air. There is no operating power plant based on this concept at this time, although a small system was installed and evaluated in Spain during the 1980s.

E. Other solar thermal applications

32. Solar thermal energy can be used directly as heat for drying and for water desalination. Much research has been done on such systems all over the world. Solar drying systems have to be designed, keeping in mind the product to be dried, its initial and final moisture contents, the rate of drying required for the product and the geographical location. Because of these conditions, it is not possible to evolve standard designs for mass production and installation. Several successful installations have, however, been designed and built for specific agricultural products including tea, spices, vegetables and flowers. Solar drying may also be a feasible option in the confectionery, food processing, chemical and pharmaceutical industries.

33. Different designs of solar stills have been developed in many countries to distil water. While technically the systems are suitable in areas with brackish water, the economics are not yet favourable. Small stills, however, seem to be useful in providing distilled water for batteries in remote and unelectrified areas.

34. Solar thermal energy can also be used for water pumping, air conditioning and refrigeration. Such systems, however, are technically more complicated and less reliable compared with PV-based systems. There are also no clear economic advantages for such applications.

F. Solar buildings

35. A major area of activity all over the world relates to the use of solar energy in buildings. In recent years, there has been growing interest in solar passive architecture and in integrating solar PV systems in buildings. The design and construction of “solar buildings” are emerging as a new discipline in architecture and building construction.

36. Solar passive architecture is basically climate-responsive building design. The height and orientation of a building can be fixed in a manner that allows maximum use of solar light during the daytime. The size and placement of windows, overhangs and skylights can also determine the amount of solar heat that is allowed inside the building. A properly designed solar building can reduce the heating load in winter and the air-conditioning load in summer. The use of appropriate building materials, external cladding and insulating materials for walls can contribute further to reduction in the energy demand in buildings. Demonstrations have shown that new buildings can be 40 per cent more efficient and even the refurbishing of old

buildings can reduce energy consumption by 25 per cent in most Western European countries.[13]

37. It is not inconceivable that a building can be designed with appropriate architectural features and further fitted with active solar thermal and PV systems so that dependence on external energy inputs, especially for electricity and water, is nearly zero. Such experimental solar houses have been built by enthusiasts and by way of demonstration. Considering that buildings consume about 20 per cent of the total energy in many countries, the impact of this effort could be significant in the future.

V. Solar industry and international trade

38. As solar energy applications began to appear in the 1970s, the organized manufacture of solar collectors, PV modules and systems started in a few countries. Actually, there were a few manufacturers of solar thermal products even before the oil price increase of 1973. During the 1980s, commercial-scale manufacture spread to several countries on all continents.

A. Solar PV manufacturing

39. The PV sector attracted investments by large multinational companies, including a few oil companies. There are three clear stages or levels of manufacture in this sector: solar cells, PV modules and systems. The investments required to set up manufacturing facilities are highest for cells, followed by modules, and lowest for system assembly. The same order is perceived in respect of complexity of technology.

40. Solar cell manufacture has gone through many changes and improvements during the last two decades. The size of silicon cells increased and diffusion, contact formation and other process stages were refined. Thin-film solar cells required the development of wholly new processing techniques. Even today, thin-film production is based largely on custom-built equipment. An important trend is the progressive increase in automation. The “glass in-panel out” concept has resulted in manufacturing lines in which cells and modules are fabricated in an integrated fashion. The roll-to-roll deposition of some types of thin-film cells is also an example of automated production.

41. While efficiency improvements and larger throughputs can reduce the cost of the product, they often push up the cost of the capital equipment. Economies of scale are then needed to make production viable. For a production capacity of 1-2 MW of crystalline silicon cells, an investment of about US$ 2 million-US$ 3 million per MW is needed. At the 10 MW level, the cost per MW drops to one half. In the case of thin films, a 1 MW plant may cost as much as US$ 6 million-US$ 8 million, but a 10 MW plant may require only US$ 30 million. This trend is already known in the semiconductor and electronics industries.

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[13] UNDP, Department of Economic and Social Affairs of the United Nations Secretariat and World Energy Council, *World Energy Assessment* (forthcoming).

42. The patterns of capital requirement and technological complexity have practically established the kind of manufacturing activity that can take place in a country. While industrialized countries can afford to set up increasingly larger plants that make solar cells, most developing countries have to be content with the assembly of systems and, in some cases, the manufacture of modules. Because of the size of their domestic markets, India and China have been able to develop and sustain solar cell manufacture.

43. The above pattern also reflects the cost of labour at different stages of PV production. Module production is more labour-intensive compared with cell production, and therefore multinational manufacturers sometimes find it cheaper to shift some stages of their manufacturing activities to developing countries. Manufacture and assembly of systems are also cheaper in developing countries that have some infrastructure in the battery and electronics industries.

44. Historically, the United States of America has had a 35-45 per cent share of the global PV module production. A major increase in PV manufacturing capacity is under way in Europe at this time.[14] By the end of this year, Europe will have a production capacity of 100 MW. Production in Japan and the non-European and North American regions increased significantly in the last two years.[15] In spite of these trends, United States of America industry hopes to retain a 40 per cent share of global module shipments between 2000 and 2020.[16]

45. Most of the global trade in photovoltaics also emanates from the three main producing regions: the United States of America, Europe and Japan. About 30 per cent of the United States of America production is used domestically, and the rest is exported. With the ongoing big programmes in Japan and Germany, much of the trade is within these three regions. The European Commission has targeted production of 1,000 MW under the Campaign for Take-off, of which 650 MW will be used within the EU countries and 350 MW exported.[17] Shell Solar plans to install 50,000 solar home systems in South Africa and 100,000 in China, using cells imported from their production facilities in Europe. Other major global exporters include Siemens, BP Solarex, Photowatt, Kyocera, Sanyo, Helios, and Astropower. Exports of Indian-made cells and modules have also been increasing steadily; exports during 1999-2000 amounted to about 6 MW.

46. Growth in PV markets has also led to growth in trade relating to BOS components such as batteries and lamps. Compact fluorescent lamps used widely in systems are manufactured only in a handful of countries and exported everywhere. Sealed maintenance-free batteries, special low-maintenance batteries and nickel-cadmium batteries are also made in a limited number of countries. These items need large volumes to justify manufacture. Countries that do not have large domestic

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[14] W. Palz, “PV for the new century: status and prospects for PV in Europe”, *Renewable Energy World*, vol. 3, No. 2, (2000), pp. 24-37.

[15] *PV News*, vol. 19, No. 2 (February 2000), and yearly February additions.

[16] G. E. Cohen, D. W. Kearney and G. J. Kolb, *Final Report on the Operation and Maintenance Improvement Programme for Concentrating Solar Power Plants*, Sandia National Laboratories (1999).

[17] W. Palz, “PV for the new century: status and prospects for PV in Europe”, *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 24-37.

markets have to rely on imports. As in the case of solar cells and modules, access to technology also determines the feasibility of local manufacture.

B. Solar thermal manufacturing

47. Manufacturing activity in the solar thermal sector can also be divided into three stages: (a) manufacture of the selectively coated absorber material, which requires relatively advanced technology and controlled conditions; (b) manufacture of the collectors which basically requires fabrication work; and (c) assembly of complete systems such as water heaters by adding a storage tank, supporting structures and piping. Here again, the first stage is carried out only in a few countries, with other countries importing the selectively coated material. Collectors can be and are being made by dozens of companies worldwide. In India also, there are over 40 companies that make collectors according to the national standard. System assembly is often a small enterprise- or dealer-level activity. Several hundred such companies are operating in many countries. The United States of America, Japan, Australia, Germany, Austria and Israel are among the leading manufacturing countries for solar collectors. There are no large companies as in the PV field. As a result, only a few companies are selling outside their region.

VI. Constraints on and barriers to solar energy utilization

48. The development and utilization of renewable energy technologies have faced numerous constraints and barriers during the past quarter-century. Some of the barriers have been reduced but others still remain to a significant extent. The barriers are of all types: technical, infrastructure, finance, human resources and awareness. Actions have been initiated both by Governments and by international agencies to mitigate them, but much more remains to be done.

A. Limitations imposed by resource characteristics

49. Solar energy is perceived as an intermittent energy source. This is not an insurmountable constraint, as proper design of systems and development of more efficient and economical storage systems can offer solutions. The diffuse nature of the energy source also means that large areas of land are required for large-scale power generation. Concentration technologies can help (and in any case are required for generation of high temperatures), but also may increase system cost. In urban areas, adequate space may not be available for water heating in large apartment buildings, hospitals or hotels, where there is also the problem of the availability of shadow-free space.

B. High capital cost

50. This is perhaps the biggest barrier to the large-scale use of solar and other renewable energy sources. It may be argued that the life-cycle cost of the energy from solar energy systems is lower compared with the cost of a conventional fuel-based system. However, the fact remains that the high initial cost is a major barrier. Innovative financing can help to mitigate this problem.

51. The user of a renewable energy system is also at a disadvantage compared with the user of a fossil fuel-based system. Unlike the latter who invests only in the device that uses the energy, the former must invest in the energy generator as well as the appliance. This problem is felt most acutely when one compares electrified villages with unelectrified ones, where the residents are asked to pay for the cost of electrification including the generation system. The inequality appears even more glaring considering the fact that people living in unelectrified areas generally have significantly lower incomes.

C. Insufficient awareness

52. The diffusion of renewable energy sources continues to be hampered by lack of awareness, both in industrialized and in developing countries. Even in a country such as Australia, "the public is not well informed as to how solar water heaters work".[18] Many consumers do not understand the difference between solar thermal collectors and PV panels. In many developing countries, most people are not aware of the type of applications that can be served by solar energy and also about the availability of various solar products. Continued promotional campaigns and demonstrations financed by Governments, manufacturers and non-governmental organizations are clearly required. In many countries, extension work relating to health care, agriculture and education is carried out through agencies and departments set up for this purpose. It is rare to find such a workforce for renewable energy. One of the options that could be considered would be to utilize the machinery of other extension services that exists; this, however, would require some training and awareness-raising among extension workers.

53. Inadequate attention to system design, manufacture, installation, operation and maintenance either individually or in combination can be the cause of systems' not working according to expectations or failing frequently. This situation led to a certain loss of credibility for renewable energy technologies. While such problems do arise with any new technology or industry, this problem, when coupled with the high initial cost and need to maintain a back-up, deters many potential users from investing in renewable energy systems.

D. Lack of manufacturing infrastructure

54. Lack of adequate local manufacturing capacity is a major barrier to wider-scale use of solar energy. While some countries might still choose to undertake only system integration, the diffusion of solar technologies can be rendered more effective if manufacturing capability in respect of PV modules and solar collectors is more widely developed. Thus, the development of requisite skills among small enterprises for carrying out proper assembly and installation is also an important consideration. The problems associated with access to technology, lack of capital, lack of trained personnel and relatively weak general infrastructure in many developing countries inhibit the establishment of local manufacturing capacity.

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[18] *Report of the Photovoltaic Industry Roadmap Workshop* (Columbia, Maryland, Energetics, Inc., 1999).

E. Paucity of human resources and skills

55. The paucity of trained personnel can slow down field programmes and also lead to a host of problems ranging from faulty installation to poor maintenance, underutilization and total failure of systems. Failure of many solar thermal and PV systems can be traced to poor quality of plumbers and electricians. It is not enough to construct PV modules or solar collectors with a life of 20 years or more; it is equally important to have other reliable components, install the system correctly and maintain it properly. The general belief that solar energy systems require no maintenance is not correct; they require some minimum maintenance which can be provided only by personnel with the requisite skills.

56. There are numerous efforts in many countries to organize training programmes for renewable energy technicians. However, it is also noticed that most trained personnel cannot make a living entirely by repairing, say, solar systems. As long as the concentration of solar systems in a particular area is below a critical level, it remains difficult to retain trained manpower to service the systems. Manufacturers as well as other promotional agencies need to devise ways of overcoming this barrier.

F. Policy

57. A national policy framework that provides direct or indirect support for renewables is critical to their development. Lack of political will, inadequate awareness among decision makers, and economic factors have resulted in many countries’ still lacking support mechanisms for renewable energy sources. The policy framework has to provide the financial or other incentives needed to level the playing field for renewables with respect to conventional energy sources.

VII. Economics of solar energy and prospects for future growth

A. Economics of photovoltaic systems

58. The number of applications for which PV is already “economic” is growing steadily and such applications account for about 70 per cent of global module shipments. The cost of PV power from stand-alone systems varies between US$ 0.30 and about US$ 0.80 per kWh, depending on the system configuration, location, type of battery and other parameters. This is roughly 6-10 times the price of conventional electricity in most countries. While this would be unacceptable in electrified regions, it can still be economic for isolated households and remote-area power. (Power from dry batteries can be 500 to 1,000 times as expensive as grid electricity, yet millions of batteries are used every year because they can be employed conveniently for small portable applications.)

59. Among the earliest applications that were considered economic were communications and signalling systems. Communication networks require reliable power on a variety of locations, many of them in forest or hilly areas. PV systems ranging from 500 W to 10 kW have been used the world over for providing power to microwave repeaters, cellular transmitters, radio and television broadcasting. Smaller power systems are being used in emergency call boxes, rural telephones and

other equipment. Over 150,000 systems were installed by the Indian Department of Telecommunications for providing wireless telephone connections in rural areas where grid supply was non-existent or unreliable. Each remote telephone unit is powered by a 70 W module. Such small power demands cannot be supplied economically by gasoline generators or other sources. PV power systems are also being used widely for off-grid uses such as recreation vehicles, boats and navigation equipment. Consumer items such as calculators and portable radios have long been powered by solar cells. Electric fencing in rural and forest areas is another application where the small power required is provided cost-effectively by PV.

60. There are two major applications where the economics of PV power are being studied closely: rural electrification and grid-connected power. The former is important in the context of providing electricity services to the estimated 2 billion people in developing countries living in unelectrified areas. Here, the economics of PV power has to take into account: (a) the cost of PV power either from a small power plant in a village or from a cluster of villages calculated on a life-cycle basis, taking into account also the cost of replacement of batteries and other equipment during the lifetime of the system; (b) the alternative cost of generating power from fossil fuels or large hydropower in a distant location; (c) the cost of laying a transmission line from the nearest point where the grid is already available; (d) the cost of installing a transformer and other equipment in the village to distribute the conventional power; and (e) the transmission and distribution power losses.

61. The above costs obviously vary from country to country and depend on the local geographical conditions. The competitiveness of PV systems also depends on the load in the village, which in turn depends on the number of households and the anticipated requirement in each household. In India, a comparative analysis that has taken into account all these factors shows that the PV option can be cheaper for a capacity of about 3 kW at distances beyond 3 kilometres (km) from the existing grid in hilly and forest regions, and beyond 6 km in the plains.

62. Grid-connected PV power is usually cheaper than power from stand-alone systems because storage is not necessary in grid-connected systems. Nevertheless, no PV power plant feeding power to the grid can at present compete with fossil fuel-based generation or even with other renewable energy systems based on wind or biomass. With power costs of about US$ 0.20/kWh and even higher ones for smaller rooftop systems, most such projects cannot be considered commercially. Practically, all large central power plants and rooftop systems are financed or subsidized through government programmes.

63. The key to lower costs for PV power is obviously the cost of PV modules. It is widely anticipated that the price of PV modules will come down to one third or one fourth of their present levels through large-volume production, automated plants and the introduction of new technologies. A number of studies and projections have been made regarding future costs. For example, a European Commission-sponsored study in 1996 projected that a 500 MW-per-year plant using the best available crystalline silicon technologies could produce modules at a cost of euro 0.91/W. However, a recent projection by Bayer Solar of Germany, a leading producer of silicon, indicates a module price of about US$ 2.50/W in the year 2010.[19] A study by Arthur D. Little Enterprises indicates that direct manufacturing costs could fall to US$

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[19] H. D. Block and G. Wagner, 16th European Photovoltaic Solar Energy Conference, Glasgow (May 2000).

1.45/W for single crystal silicon and US$ 1.15/W for multi-crystalline silicon modules in the next 10 years.[20] This study also projects manufacturing costs of $1.40/W for amorphous silicon, $1.00/W for CIGS and $0.95/W for CdTe modules in the next 10 years. A recent study by Fraunhofer Management of Germany on thin-film photovoltaics indicates that PV systems in the 2.3 kW range based on thin-film technologies are not expected to become competitive with crystalline silicon-based systems until about 2008.[21] PV Energy Systems, a United States of America firm, projects PV module prices of about US$ 2/W based on crystalline silicon technologies and US$ 1.25/W based on thin-film technologies by the year 2010.[22]

64. In the past, such optimistic projections were also made and such projections have sustained many corporate PV programmes. However, some current projections appear to be more realistic. It appears feasible that thin-film modules will become available at prices ranging between US$ 1.25/W and US$ 1.50/W by the end of this decade. Besides the module prices, reductions are also expected in BOS and overall turnkey system costs. According to Japanese projections, the turnkey system cost could come down to 310 yen (¥)/W beyond 2005 with the cost of power ranging between ¥20 and ¥29/kWh.[23] This would still not be competitive with power generation from large fossil fuel plants. The era of solar PV power from large-scale grid-connected systems may arrive around 2020.

B. Economics of solar thermal systems

65. Low-temperature thermal systems for water heating have already achieved economic competitiveness in many countries. This explains the rapid growth in the installation of such solar water heaters for domestic purposes in Europe, the Middle East and Japan. Their economics are seen mainly in terms of savings in electricity bills. In Israel, compared with an electric heater, a solar water heater costing US$ 500 is estimated to result in a net saving of $58 per year.[24] In most parts of India, the cost of a domestic water heater is recovered in three years through reduction in the electricity bill.

66. The same, however, cannot be said in respect of industrial water heating systems where solar energy has to compete against coal, oil and gas. The payback times can stretch to five to six years which may or may not be attractive to commercial enterprises. Such systems are popular in countries that provide tax benefits and/or low-interest loans.

67. Solar thermal energy is generally not competitive for applications that can be powered by medium-grade heat such as cooling, water pumping and cooking. It is even less so for grid-connected power generation. Practically all solar thermal power plants built so far have relied on either tax benefits or direct government funding.

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[20] L. Frantzis and others, 16th European Photovoltaic Solar Energy Conference, Glasgow (May 2000).

[21] *NCPV Hotline* (22 February 2000).

[22] Paul Maycock, “Economic PV: a shift in thinking”, *Renewable Energy World*, vol. 2, No. 5 (September 1999), pp. 73-76.

[23] International Energy Agency, *A Preliminary Analysis of Very Large-Scale Photovoltaic Power Generation Systems*, report IEA-PVPS VI-5 (1999).

[24] Joseph Nowarski, “Solar Israel: a practical and legislative model”, *Renewable Energy World*, vol. 3, No. 2 (2000), pp. 92-99.

Commercially viable solar thermal power generation must await improvements in concentration technologies and large-scale production of components. The capital cost of parabolic trough plants are expected to fall from US$ 3,000/kW-US$ 3,500/kW in the near term to US$ 2,000/kW-US$ 2,500/kW in the long term.[25] Likewise, the capital cost of central receiver systems could come down to US$ 1,600/kW-US$ 1,900/kW in the long term. At that stage, the levelized energy cost could drop to US$ 0.05/kWh-US$ 0.06/kWh. There are hopes that this might become possible in the period 2010-2020.

C. Prospects for future growth

68. There are indications that current growth rates for PV and thermal systems will continue in the coming 10-20 years. The main reasons for this optimism are: (a) efforts by industrialized countries to meet their commitments on CO_2 reduction under the Kyoto Protocol[26] to the United Nations Framework Convention on Climate Change;[27] (b) improved economics in relation to conventional energy systems through technology development and large-volume production; (c) improvement in the reliability and performance of solar energy systems which may reduce attitude barriers; and (d) growing international recognition of the need to provide basic energy services to the nearly 2 billion people in developing countries who require them.

69. In the area of PV, United States of America industry has prepared a roadmap for growth.[28] According to different scenarios, based on different growth rates, worldwide annual PV module shipments could increase to between 1.5 gigowatts (GW) and 15 GW by 2020. Assuming a 25 per cent growth rate, cumulative worldwide shipments could rise from about 1,000 MW at present to about 85 GW. Such growth rates, however, appear unrealistic. If cumulative shipments were to double every four years on average, 32 GW would be reached by the year 2020. A number of actions would be required on the part of Governments and manufacturers to sustain even these growth rates.

70. In the area of solar thermal technology, the potential, at least in Organisation for Economic Cooperation and Development (OECD) countries, has been projected at between 0.5 m^2 and 1 m^2 of solar collectors per inhabitant.[29] The lower figure represents warmer climates and the higher figure is for the climates of northern and central Europe. Countries like Israel and Cyprus have already achieved this. On this basis, the ultimate potential in Europe would be about 200 million m^2.

71. Considering that no significant reductions in cost can be expected for solar water heaters, market growth will depend mainly on the relative cost of conventional energy. Assuming that about 1 billion people will use an average of 0.5 m^2 of solar collector area by 2020, the cumulative installation will reach 500 million m^2 by that

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[25] UNDP, Department of Economic and Social Affairs of the United Nations Secretariat and WEC, *World Energy Assessment* (forthcoming).

[26] FCCC/CP/1997/7/Add.1, decision 1/CP.3, annex.

[27] A/AC.237/18 (Part II)/Add.1 and Corr.1, annex I.

[28] *Report of the Photovoltaic Industry Roadmap Workshop* (Columbia, Maryland, Energetics, Inc., 1999).

[29] *Opportunities for Large-Scale Purchase of Active Solar Systems* (Harwell, United Kingdom, IEA CADDET Centre for Renewable Energy, December 1998).

time. These installations can contribute to savings in other forms of energy: oil, gas and coal.

72. There will also be a sizeable growth in solar thermal power generation. A generating capacity of 6,000 to 8,000 MW seems possible. On account of such growth in PV and thermal technologies, the overall contribution to world energy supply from solar energy could grow by a factor of 20-30 from the present level of about 0.02 per cent. This would lead to corresponding benefits from reduction in CO_2 emissions.

73. The above projections would appear to indicate that direct forms of solar energy will not make a significant contribution to the world energy supply during the next two decades. Some believe that solar energy can have an impact on the world energy scene only if an economic way is found to produce hydrogen from solar energy. Hydrogen is not a primary energy source but rather a versatile energy carrier that can be stored and transported. It can be used as a fuel for transportation — a major consumer of energy. It can also be used in engines for static motive power and for power generation. This aspect of solar energy utilization is not covered in this report because most work in this field is still experimental with no breakthroughs achieved so far. Moreover, much work still needs to be done on safe methods for handling hydrogen. Environment-driven policy measures could easily increase the contribution of solar energy in the world energy supply by a factor two to three times that projected for 2020 and even more in later decades.

VIII. Issues and approaches concerning the utilization of solar energy for rural areas

74. Energy for cooking is a major problem in rural areas, where the use of solar energy for cooking presents both opportunities and problems. Simple box-type cookers and small concentrators are not difficult to use. However, they suffer from problems of high initial cost and limitations in use. Box cookers take considerable time and cannot be used for frying. Dish-type cookers are faster but may require the user to stand in the sun. More sophisticated cooking systems would be even more costly. However, there are some advantages to solar cooking as well as substantial savings in conventional fuels that can be realized through large-scale use of solar cookers. The impact of solar cookers on rural energy is likely to be limited owing to their inherent constraints.

75. Lighting is another basic need in rural homes. Most unelectrified homes use kerosene or other oils for lighting. Hundreds of millions of lanterns in the world use these fuels. Studies have shown that electric lighting is not only far superior and safer, but also more economical compared with kerosene lighting.

76. Among the renewables, solar PV technology scores over other options, as it can offer small systems for each household separately (an option not available with the other technologies) or a “central” power plant in the village coupled to a small distribution system. Solar systems have no moving parts, are noiseless and require minimal maintenance. It is therefore not surprising that much of the discussion on decentralized rural electrification has focused around the solar PV option (the solar thermal option is not considered, as small power systems are still not mature).

77. Considering all aspects, it does appear feasible that solar energy can be used effectively to provide at least one form of energy — electricity — to the rural areas of the world. The impact of large-scale programmes can, however, be significant in terms of the number of people who benefit and the contribution that solar energy can make to improvements in the standard of living of people in some of the most impoverished regions of the world. Concomitant benefits include improved health care, education, communications, and access to information.

78. The above discussion covers only the minimum needs that can be met from solar electricity. There are other requirements in rural areas that also need to be addressed including water pumping for drinking water and agriculture, water treatment, drying of agricultural produce and refrigeration. Water pumping has long been a major PV application. Large-scale use of PV systems for water pumping may be feasible only if the module costs come down by a factor of two to three. This may happen within a decade. Solar drying has a role in localized situations, but the necessity of having different dryer designs and sizes for different crops as well as the seasonal utilization of these systems is an obstacle to their large-scale use. Refrigeration is again confined to applications such as vaccine preservation which cannot always be evaluated on the basis of economic criteria.

IX. Policies and actions for wider use of solar energy

Policies and enabling environment

79. The need for Governments to establish clear policies for energy for sustainable development, including the promotion of renewable energy technologies, has been highlighted in the past. Governments could take steps ranging from a national energy policy statement to legislative measures and the introduction of an appropriate fiscal regime. If a clear niche was identified for the use of solar energy and other renewable energy sources in the national energy mix, it would help mobilize investments and focus national efforts. This has to be supplemented by the establishment or identification of appropriate institutions and implementation of supporting measures relating to human resources, commercialization and general rural development.

Financial incentives

80. Direct capital subsidies are often not favoured as a long-term strategy to promote renewable energy. The contention is that such subsidies are not sustainable in the long run and ultimately hamper market growth. Therefore, phasing out subsidies for both conventional and renewable energy is an option to be considered seriously. In the short term, some form of subsidy for the poor appears to be necessary for the growth of renewable energy markets. Other forms of incentives include tax credits, exemptions from duties and preferential pricing for electricity from renewable energy sources. These are being applied in various ways in many countries. The most recent development is the German Renewable Energy Law of 2000 which allows a price as high as deutsche mark (DM) 0.99 for electricity from PV.

Economic and legislative measures

81. Legislative measures can achieve certain goals that are in the public interest even if they are justified purely on financial grounds. As a move towards sustainable development, countries could consider enacting laws that would, for instance, require all new buildings to incorporate energy-efficient features and install solar water heaters if hot water is necessary in the buildings. Appropriate laws relating to emission controls from diesel or gasoline generators encourage greater use of PV systems. Other laws could even require utilities to generate a certain minimum percentage of power from renewables and industries to meet a part of their energy requirements from these sources. Economic measure can also provide for easy financing for renewable energy projects and manufacturing activities.

Intensification of R&D

82. The slowing down of the research effort during the 1980s has perhaps delayed some promising technologies in reaching maturity. There is general concern that, even now, R&D in support of sustainable energy development is not adequate. This will require a commitment on the part of Governments and large companies to deploy financial and manpower resources for accelerating research efforts. Among areas that need to be studied further are materials, designs, component development, system aspects and manufacturing technologies. There is a need to enhance the current level of research funding by a factor of two to three during the next five years. The benefits of such acceleration will be seen in the decade that follows.

Technology diffusion and transfer

83. The wider use of available technologies requires the diffusion of technologies on a global scale and establishment of local manufacturing facilities. The need is particularly great for developing countries that do not have adequate intrinsic technological strength. The training of manpower is an essential prerequisite. The undertaking of a large number of demonstration and pilot projects in developing countries is another way to promote diffusion of solar technologies. There is scope for considerable international cooperation in this aspect.

Commercialization and entrepreneur development

84. Large multinational corporations alone cannot reach out to all parts of the world and supply products. Entrepreneurs are needed not only to act as dealers but also to undertake local assembly and manufacture. This also promotes employment and can be viewed as an indirect benefit of decentralized energy development. Those who are able to establish energy service companies and operate small power plants for local people form an important class of entrepreneurs. If they were offered financial assistance to install and manage such systems, individual households would not need to invest in the generation component of solar energy systems, and solar energy would become more affordable to millions of people.

Financing

85. The financing needs mentioned above will have to be effectively met by existing financial institutions or by establishing new institutions. A change in the mindset of banks and financiers will be necessary to promote lending for renewable projects. Equally important is the need to establish retail financing networks or

microcredit arrangements. Despite a few good examples, more needs to be done in this area.

International cooperation

86. There is significant scope for international cooperation in achieving many of the objectives mentioned above. What is needed first of all is a clear assignment of priorities by donor countries and international organizations to sustainable energy programmes. From this will flow projects that can support training, capacity-building, awareness-promotion and actual utilization activities. However, not all activities involve a donor-recipient relationship. There is already a good measure of cooperation among the International Energy Agency (IEA) and EU member countries. This needs to be strengthened and the benefits also made available to developing countries. Technical cooperation among developing countries is another concept that has been mentioned often in international forums but has received scant financial support. The value of such cooperation in the renewable energy sector can be very high. Some of the international funding in this sector should be earmarked for technical cooperation among developing countries.