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NEW & ADVANCED MATERIALS 1996/1 and 1996/2

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SPECIAL ARTICLE
Solar Cell Materials, Technologies, Applications and the Impact on Developing Countries
by M.R.L.N. Murthy

RECENT ACHIEVEMENTS

TRENDS IN RESEARCH & DEVELOPMENT

INTERNATIONAL & NATIONAL PROGRAMMES

POTENTIAL MARKETS

PUBLICATIONS

CALENDAR OF EVENTS

UNIDO NEWS

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TO OUR READERS

Technology is now at the core of competitive strategies of successful industrial firms. The new and rapidly evolving generic technologies, such as biotechnology, new materials and information technologies, offer many opportunities and challenges for broad competitive strategies. They engender entirely new products, services, markets and businesses. Their impact is trans-sectoral, radically improving the competitiveness of products, processes and services of firms in a large number of traditional industrial sub-sectors. New materials improve product specifications and lower production costs in engineering and chemical industries; biotechnologies save energy and raw materials in chemical, pharmaceuticals and food processing, while the pervasive applications of information technologies allow companies in all industrial sectors to re-engineer critical processes, improve overall efficiency and raise productivity across functional areas. Monitoring and access to information is now a key to competitiveness.

Experience in newly industrialized countries shows that access to reliable technical information can be instrumental in allowing manufacturers to leap whole periods of technological development and adopt state-of-the-art systems directly - without needing to undertake a painful and costly development phase. Up-to-date economic information and analysis of global economic trends and the prevailing industrial situation in other countries is likewise indispensable - and the gateway to identifying industrial needs, opportunities, constraints and priorities of the country and region concerned. Monitoring technological advances and economic analysis provide the basis for the formulation and effective implementation of appropriate industrial programmes and projects by both public and private entities.

One of the objectives of UNIDO is to carry out a set of coherent activities at the national, regional and international levels, to help developing countries at different stages of development to acquire, apply and develop and manage technologies against a global background of technological change. Investment and technology play a vital role in the industrial growth of developing countries, as well as their gradual integration into the international economy. There is a need for a wide-ranging investment and technology approach that will not only attract and retain the inflows of investment and technology, but also make the optimum use of them for the domestic economy. UNIDO's wealth of experience in industrialization, combined with its worldwide network of contacts makes the Organization an ideal partner to assist developing countries in building up their investment and technology partnerships. The Organization is a focal point of industrial technology; it is a global source of industrial information; and it is an honest broker for industrial cooperation.

Through this new series of publications on emerging technologies in developing countries, which supersedes the ***Industrial Technology Monitors and the Technology Trends Series,*** UNIDO plans to sensitize industry and governments to the need for and requirements of technology monitoring and assessment in the areas of new an emerging technologies. We plan to introduce ***"Industrial Opportunities"***, whereby you, the reader can offer technologies to other readers, or request technologies. Feel free to contact us for more information.

Vladimir Kojarnovitch
Technical Editor

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1. SPECIAL ARTICLE

SOLAR CELL MATERIALS, TECHNOLOGIES, APPLICATIONS AND THE IMPACT ON DEVELOPING COUNTRIES

by

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I. Introduction

Concerns for ecological aspects are overwhelming compared to materials as the world heads towards the twenty-first century. With the widening gap between electricity demand and generation, especially in developing and newly industrialized countries, there is a noticeable increase of activities in power generation which would result in staggering amounts of air pollution if the world continues to depend on oil and fossil fuels. Developing clean energy sources has thus become an important task to arrest gas emissions and to protect ecological cycles of bio-systems on the Earth.(1)

It is fortuitous that solar energy technology has reached maturity at a time when mankind needs it most. What was once regarded good enough for promising power to satellites has come down for terrestrial application. Photovoltaics (PV), the technology to directly convert sunlight (solar radiation) into electrical energy has significant advantages as a generator of electricity.

1. Clean and inexhaustible source: solar photovoltaic conversion systems tap an inexhaustible resource which is free and available anywhere in the world, even in space. The amount of solar energy incident on earth (~1.5 x 10^{18} kwh/year) is about 10,000 times larger than the current annual energy consumption of the entire world.
2. Maintenance-free operation: It has no mechanical moving parts and needs no lubrication. The simplicity of operation and low maintenance costs make the life-cycle costs of PV systems much lower than that of other traditional options. PV needs no transportable fuels and can thus be set up in any remote, or normally inaccessible areas.
3. Modularity and reliability: Suitable for standalone systems from a fraction of a watt to MW operations. System power can be increased modularily. PV is known for reliable operations over many years. A solar cell consists of semiconductor modules which can be mass produced like transistors and ICs. A modular increase in production scales with an expanding market size results in cost reductions. Thus, PV is poised for a phased growth into large market sectors.
4. Decentralized operations: PV power generators can be deployed as sizeable captive power sources or small standalone systems dealing with distribution networks and transmission losses.
5. Clean energy: solar energy is environmentally benign. A gegawatt hour of electricity generated by PV instead of burning coal, prevents as much as 1,052 tons of CO_2 being emitted into the Earth's atmosphere. PV is known not to produce any pollution in the form of ash, waste or even noise.

Despite several advantages in photovoltaic generation as mentioned above, substantial R&D efforts were made only in the 1970s after the oil crisis. It was only during the 1980s that substantial growth in PV technologies based on crystal silicon and amorphous silicon was witnessed. The technology push however, could not attract the market resulting in a limited application area, such as remote power sources, for example powering light houses, and telemetering power sources located in far-flung areas. The big barrier impeding large scale production is the high price of solar cells, which was more than $60/W during the seventies dropping to $10/W in the 1980s. However, recent advances in technology over the last 10 years have resulted in solar cells with higher efficiencies, scaled-up production plants, and coupled with efforts at government level in various countries, the module cost has come down to $4 to $5/W in a firm bid for large-scale purchase. The present scenario is good with PV reaching rooftops in urban areas and being connected to grids, apart from a variety of applications in the rural sector.

In the mid-1990s, solar PV power generation is receiving greater attention because of a growing concern for ecological aspects, optimal energy utilization, life-cycle costs and thus prompting the large-scale usage of solar energy. Realizing the importance and the need for renewable energy, international financial and institutions such as the World Bank and the Global Environment Facility have initiated programmes for the widespread utilization of solar energy in several developing countries.

This article reviews recent advances in solar photovoltaic technologies, and the expected technological innovations following the discovery of new materials and an in-depth analysis of the techno-economics of the PV industry from the view point of large scale terrestrial applications. Key issues are achieving utility power applications in near future due to module cost reductions, the role of international organizations such as UN bodies, World Bank etc., in promoting solar energy in developing countries, potential markets and funding mechanisms for PV market development, and finally the impact of PV on developing countries.

II. Solar energy materials

The amount of solar irradiation in outer space is 1,353 W/m^2, on the Earth's surface it is reduced to 1,000 W/m^2 due to absorption and the scattering effect of the Earth's atmosphere.

The ability of certain semiconductor materials to directly convert light (photons) into electrical energy is the basis of solar cell or photovoltaic cell. Solar cells, the primary component of photovoltaic equipment have been the focal point for research and a variety of materials and a multiplicity of fabrication techniques were developed to achieve higher conversion efficiencies.

Solar cell

A typical solar cell consists of a p-n (or p-i-n) junction formed in a semiconductor material. When light impinges on the solar cell, the quantum energy contained in the photons is absorbed in the material resulting in the liberation of "electrons" and "holes", which move freely in the material. In the presence of concentration gradients and an internal electric field that exists across the p-n junction, the charge carriers diffuse and drift before they recombine and neutralize. The metal electrodes located on the top and bottom surfaces of the solar cell collect the charge carriers enabling an electric current to be driven through an external circuit. However, not all the light impinging on the solar cell generates charge carriers, nor do all the charge carriers generated reach the electrodes to contribute towards the current flow. Thus, there is a conversion efficiency factor which is governed by the reflectivity of the surface, absorption by the material, rate of generation and recombination of electrons, the energy band structure of the semiconductor material used, etc. R&D efforts taking place throughout the world are mainly aiming to increase this efficiency factor by employing advanced and innovative materials and techniques. Solar cell operation is illustrated in figure 1.

Solar cell technologies

Although the interaction of light with matter has been known for a long time, no practical devices were developed until the 1950s. The first devices could be traced back to the fabrication of a solar cell based on crystal silicon in 1954 and gallium arsenide in 1956 and found applications in powering satellites. Efforts to increase the conversion efficiency and the search for new cell materials and cell structures have been made, however, the impetus for accelerated R&D efforts and production oriented technologies came with the oil crisis in 1973. Crystalline silicon PV cells were recognized as useful in remote standalone applications (for small loads), and amorphous silicon cells in consumer electronic products, such as watches and calculators, marked the beginning of PV cells being deployed in terrestrial applications. Industries have commercialized the technologies, and with scaled-up productions, demonstration plants of up to a few hundred kilowatt rating were established.

Parallel efforts for increasing cell efficiency led to the search for other semiconducting materials such as Cd Te, Cu In Se_2. Also several new materials such as multi-crystalline silicon, ribbon and sheet and spheral silicon have been developed resulting in a cost reduction. Over the past 15 years several solar cell technologies have been developed in USA, Japan and European laboratories and they can be broadly classified as shown in figure 2.

Single crystal technology

With the advent of the Czochralski process of growing large silicon crystals (100 mm diameter and 1.0 ~ 1.5 m long crystal ingots), single crystal technology has been the mainstay for large-scale solar cell production by photovoltaic industries.

The fabrication of a solar cell and module involves three stages: firstly the fabrication of a single crystal silicon wafer; secondly, the fabrication of single crystal silicon photovoltaic cell, and finally the fabrication of a photovoltaic module.

Fabrication of single crystal silicon wafer

The first step is the preparation of metallurgical grade silicon by mixing silica (SiO_2) with carbon (coal or charcoal) and deoxidized in an arc furnace. The resulting silicon (97-98 per cent purity) is processed by the trichlorosilane method to produce high purity poly silicon. The Czochralski method (CZ) or float zone (FZ) method is employed to grow single crystals. The major percentage of crystal silicon for photovoltaic use is produced by the CZ process. Silicon crystal production is a well established industry in many countries.

The specifications of the crystal ingots required for photovoltaics are less stringent than those of crystals required by the semiconductor industry producing integrated circuits. The heads and tails of the semiconductor grade silicon crystal are used to produce solar grade crystal ingots.

The crystal ingots are sliced by either an ID saw to slice wafers in the range of 300 to 450 microns, or a wire saw to get thin wafers in the range of 120-200 microns.

Multi-crystalline technology

Fabrication of a multi-crystalline solar cell is generally on the same lines as that of crystal silicon technology, but with some modifications introduced to counter the problems faced by grain boundaries, stresses, impurities etc., in cast silicon process technologies, which are reviewed elsewhere in this article.

Multi-crystalline silicon

Multi-crystalline material at the industrial level has been produced specially for photovoltaic applications for the last 10 years, but in limited quantities. While Wacker Chemi and Solarex Companies are some of the companies which started producing multi-crystalline material by the casting process over the last eight years; other companies, such as Crystal Systems, IBM, Photowatt, OTC, Polyx, Crystalox, have come up with silicon cast ingots employing various techniques, namely a heat exchanger method, directional solidifaction cold crucible induction casting etc. Several ingots produced are in the range of 80-120 kg materials, generally with square cross sections of 44 x 44 cm or 55 x 55 cm and the throughputs are continually improving.

Slicing

Both crystalline and multi-crystalline ingots are sliced employing an ID saw. However, during the last five years, wire saws have been developed which reduce the Kerf loss to a great extent, to as much as 120 microns compared to the best values of 300 microns when sliced by an ID saw. Another innovation in slicing technology is the Fixed Abrasive Slicing Technique (FAST) which was recently developed by Crystal Systems. FAST utilizes a multi-wire blade pack with each wire held in a frame with equal spacing and tension, and slicing is achieved by reciprocating the blade pack in a slicer head.

The major process techniques developed, as well as the slicing methods employed, together with results on capacities of ingot growth time, size, life times, diffusion lengths and cell efficiencies have been detailed in table 1. Shown in figure 3 are silicon crystal growth machines, crystal ingots, cast silicon ingots, round and square wafers and solar cells.

Ribbon and sheet technologies

Ribbon silicon crystal growth was envisaged mainly to reduce the wastage of precious silicon crystal which occurs during the slicing process (in the order of 30-40 per cent). A variety of techniques were developed to grow ribbons or sheets of crystal silicon.

Mobil Solar Energy Corporation employ a graphite or ceramic die (shaping the guide material) which has a thin slit through the centre lowered into molten silicon. The silicon is drawn up through capillary action. A seed crystal touching the melt at the top is slowly withdrawn upwards resulting in ribbon crystal growth. Mobil produces nanogon wafers where they get nine ribbon crystals in one run.

Westinghouse Corporation uses the dendritic web method. Unlike the dye used in the EFG process this method employs two dendrites—elongated starter crystals are lowered into the silicon. As they are drawn up a sheet of crystal silicon is formed between them.

Hoxan Corporation from Japan has developed a novel process called the spin cast method to make 10 x 10 cm silicon wafers. A specified amount of molten silicon is allowed to fall from a quartz funnel onto a graphite mould with a 10 x 10 cm cross-sectional cavity. The mould is spun as the silicon melt is dropped to form a 10 x 10 cm silicon wafer. The silicon solar cells fabricated using the spin cast wafers have shown conversion efficiencies in excess of 10 per cent.

Fabrication of solar cells

The solar cell is the most important element of the photovoltaic device and the crucial part is diffusion to create the P-N junction. After the initial etching and texturing process steps on the silicon wafer, a thin layer of phosphorous doped silicon is brought into contact with a layer of boron doped silicon in the diffusion process to create the P-N junction. Minute quantities of boron and phosphorous (one part in a million) are used as dopants. Electrode printing is done using Ag pastes and fixed for the electrode formation and then solder coated.

After the cell is given its metallic contacts, the front surface is provided with an anti-reflective coating. Since Si is highly reflective, throwing back 35 per cent of light that strikes it, the cells are coated with a thin layer of silicon monoxide or titanium dioxide to counter the reflection.

Amorphous silicon cell

Amorphous silicon has a high optical absorption coefficient, which means most of the sunlight falling on it is absorbed after passing through a very short distance—less than a micrometer in hydrogenated amorphous silicon compared to 50 times that distance in crystalline silicon for the same amount of light to be absorbed. Another advantage is the ease with which it can be deposited over large areas, as well as on curved substrate surfaces. The material and energy requirements are low.

Amorphous silicon solar cell fabrication steps

The basic structure of the A-Si Solar Cell consists of thin layers of P-I-N materials sandwiched between a transparent top contact and metallized bottom contact deposited onto a glass superstrate. The basic fabrication steps are:

- Deposition of TCO layer on glass using APCVD process;
- Patterning of oxide layer by laser scribe;
- Deposition of P-I-N layer by PECVD process;
- Patterning of P-I-N layer by laser scribe;
- Metallization by vacuum evaporation or screen printing;
- Patterning of metallized layer by laser scribe or screen printing; and
- Encapsulation.

Semiconductor-based thin film technologies other than silicon

CIS, Cds, CdTe are some of the compounds that are promising materials for the conversion of sunlight into electricity in view of their high absorption coefficient for sunlight, relatively stable cells without the problem of degradation like A-Si cells and also because of the simpler technologies required.

A typical thin film solar cell is made of Glass/Mo/CIS/Cds/ZnO with the CIS layer of a few microns thickness and a thin CdS layer of about 500A° to act as a window. The Mo layer acts as the back contact material for CIS, and ZnO layers on CdS services as the top contact.

Fabrication steps for CIS solar cell

- Vacuum evaporation of Mo (0.5-2.0μ) and (0.45μ) as stacked layers using evaporation process;
- Selenised under H_2Se atmosphere around 400° C forming Cu In Se_2;
- Deposition of CdS through vacuum deposition;
- Deposition of ZnO over CdS by R.F. sputtering or MOCVD; and
- Encapsulation with EVA.

Schematic diagrams of the various photovoltaic cell structures are shown in figure 4a and the flow charts for manufacturing process steps of crystalline Si cells and Amorphous Si cells are shown in figure 4b.

Concentrator techniques

By increasing the amount of sunlight impinging on the solar cell it is possible to decrease the more expensive semiconductor material used in solar cells. Optical concentration systems of lenses and mirrors to focus sunlight are fabricated to achieve 100 to 1,000 sun concentration.

- A parabolic trough reflector focusing sunlight on a string of cells and the reflector is rotated to follow the sun;
- Linear fresnel lens focusing sunlight on the row of cells and the whole device turns to track the sun; and
- Point focusing by fresnel lens to concentrate sunlight on a single cell and using a two-axis tracking to follow the sun.

Other arrangements include a multiple junction tandem cell wherein three or four cells of different materials are stacked one above the other; the top cell is activated by higher energy photons, the next cell down converting photons of lesser energy and the bottom-most cell activated by further lower energy photons. This cell can achieve very high efficiencies and is economically viable with the use of thin films. Experts believe that this could be the first photovoltaic technology to be cost effective for utility scale powerplant applications.

Concentrator cells represent approximately one-third of the cost of a typical concentrator collector and the cell efficiency is the dominant factor concerning collector performance.(9) A review of concentrator cell technology is presented by King.(10)

Solar cells are made using a number of materials dominated by silicon and they are designed as dictated by the parameters required for achieving high efficiency.

Criteria for high efficiency cells include low resistivity, long lifetime, reduction of surface recombination velocity, band gap narrowing energy loss mechanisms such as photon losses, carrier losses and power losses contributing to the degradation of cell efficiency. Some of the best results recorded on cell efficiencies on A-Si based technologies are presented in table 2.

For a complete review of the various techniques employed for attaining high efficiency and R&D efforts by several laboratories and industries refer to "Solar Cells and their applications" UNIDO Advances in Materials Technology Monitor. (Issue No. 31, March 1993)

Recent achievements and trends in photovoltaic developments

Recent progress in solar cell research all over the world indicates the coming of the thin film age. Tremendous progress in amorphous silicon technology, and also in Cd Te and CIS thin film processing and even polycrystalline silicon films, has been taking place.

Silicon film technologies

1. *Amorphous silicon solar cell*

Remarkable advances have been made in the technology of wide gap windows, heterojunction graded band profiling, doping, super lattice, BSF treatment and also stacked alloys. Some of the recent developments are presented below (11 to 19).

- Band profiling triple junction stacked cell with 12.4 per cent efficiency (Sharp Corporation);
- A - Si/ A - Si/ A - Si Ge stacked solar cell with 13.7 per cent efficiency (ECD - Sovonics);
- Heterojunction with intrinsic thin layer (HIT) with an efficiency of 21 per cent (SANYO);
- μc - Si C/Poly - Si heterojunction solar cell with 17.2 per cent efficiency with simple fabrication process (Osaka University).

2. *Thin film polycrystalline silicon solar cell*

In view of the high cost of mono silicon material (400 μm per wafer) and the wastage associated with slicing the crystal (Kerf loss) R&D efforts have been undertaken to develop polycrystalline silicon material for solar cells, satisfying the cell criteria such as light trapping, planar films with single crystal grains, a minority carrier diffusion length twice the thickness, benign grain boundaries, a substrate providing mechanical support.

Notable, among others, is the Astro Power Company which has developed a silicon - film TM solar cell with 50 μ film (expected to increase to 14 per cent in near future) which has a substrate providing mechanical support. The entire process is amenable for low-cost production.

3. *Compound semiconductor thin films*

Substantial progress has been made in the development of Cd Te Technology and Copper Indium Diselenide (CIS) technologies, especially over the last two years. Notable among them are:

- Total area efficiency of 17.7 per cent has been achieved for a thin film Cu In Ga Se2 (CIGS) solar cell fabricated by NREL;
- Total area efficiency of 12.4 per cent for CIS fabricated by ISET;
- Aperture area efficiency of 13.0 per cent for CIGS mini module fabricated by Solarex, Siemens and Showa companies;
- 9.1 per cent efficient, 6,728 - cm^2 area Cd Technology module by Solar Cell Inc.

Since the World Conference on Photovoltaic Energy Conversion in December 1994, several groups have focused their efforts on Cd Te, CIS and specifically CIGS films, producing excellent results as shown in table 3.

PV modules and systems

The photovoltaic module is the basic building block of the standalone photovoltaic system and is the smallest complete, environmentally protected assembly of solar cells designed to generate D.C power.(27) A single solar cell provides small amounts of power: typically a 100 cm^2 cell gives about 3.0 A and 0.5 V in full sunlight. A large number of cells, generally 30 to 40 in number, form a photovoltaic module resulting in useful levels of power. The generic elements of a module encapsulation system are shown in figure 5 along with layer designation and the function performed by each layer. The "superstrate" uses the top surface, such as toughened glass, to provide strength for the cells and light to shine on the cells, and substrate to provide the mechanical support. The cells are encapsulated to protect the mechanical support. The cells are encapsulated to protect them from environmental stresses such as wind, hail, differential expansion and humidity and to maintain at least a 20-year lifetime. The various steps involved in a typical module assembly are given in table 4, the PV module assembly process steps are shown in figure 6. After soldering and interconnecting the electrodes, the stringed cells are sandwiched between a tempered glass ad sheets of EVA for mechanical bonding and encapsulation. These are followed by cushioning sheets of glass fibres and are of mylar, which provides the dielectric insulation. Finally the modules backing is applied in the form of a Tedler/aluminum foil/Teldler laminate to seal the unit against moisture. The module is placed in a lamination chamber to evacuate all the air from the module and heat sealing the layers and integral unit. Figure 7 shows the standard photovoltaic modules with single crystal silicon round and square cut cells, polycrystalline silicon module and thin film modules. Each photovoltaic module has its own unique current/voltage relationship (I-V) curve determined by a I-V tracer. The majority of the photovoltaic modules available in the market today are designed to charge 12 V batteries and deliver in the range of 15.5 to 17.0 VDC under standard operating conditions.

Photovoltaic module system

The photovoltaic module is the chief constituent of the photovoltaic system designed for any of the following applications: domestic lighting, irrigation and water pumps, small clinics, microwave relay stations, railway signals, road signs, as well as large photovoltaic systems connected to the grid. The photovoltaic module and array (made of several photovoltaic modules) should be compatible with the balance of system (BOS).

BOS consists of the batteries, inverter, charge controller, voltage stabilizer, safeguard controls and structural support.

Schematic diagrams for BOS for various configurations are shown in figure 8. This schematic diagram of a basic DC standalone system, shows how the photovoltaic array is connected directly to load with storage (b), the same as in (a), except the array is connected to load via a voltage regulator, which is an indispensable component if the photovoltaic system is left unattended (c), an inverter is introduced to connect to the A.C load (d). In this system power from the grid is substantial as an auxiliary source of electricity enabling a supplement to the systems output when needed and sold back to the utility when photovoltaic arrays' power is in excess. (Please refer to the report on standalone photovoltaic systems, "A handbook of recommended design practices by Photovoltaic Design Assistance Center", Sandia National Laboratories, Albuquerque, New Mexico, USA)

III. Photovoltaic applications

Solar cell technology provides a clean energy, without any moving parts, with minimal maintenance, with abundant and free fuel and also delivers power in a wide range from fractional watt to megawatts.

The first applications for solar cells were in space, during the 1960s, followed by hand-held calculators with the advent of amorphous silicon technology and terrestrial applications with crystal silicon technology. During the 1990s photovoltaic powered cars have been demonstrated.

Although the initial applications of photovoltaics have been limited to remote areas, deserts, mountainous areas due to the high cost of commercial electricity in these areas, the applications for household use in villages and even urban homes are increasing as photovoltaic production costs decrease.

Listed below are some of the examples of photovoltaic applications indicating the typical power requirements:

In view of the increasing pollution all over the world people are now aware of the need to reduce CO_2 and are planning to use photovoltaic energy in urban areas as well.

In the USA, Japan and Europe several rooftops are powered by photovoltaics for residential power requirements. Recently Sanyo Company announced that they would be developing A-Si technology suitable for use on curved tiles, traditionally used in Japan. Germany has started a thousand-roof project. These are pointers for widespread photovoltaic applications even in urban locations in the near future.

Developing countries such as India, Brazil and China are increasing their photovoltaic productions to cater for their rural power requirements.

In developed countries several photovoltaic power plants, in the range of 100KW to 5MW exist and there are proposals for utility grid connection. Semitransparent A-SiC solar cells and see-through type solar cells have new areas of application such as sun-roofs in motor cars and decorated windows in buildings.

The application of solar cells range from powering household equipment to connection to the utility grid; photovoltaic also has the potential to contribute to solving global environmental issues in the near feature.

System	Description	Required photovoltaic cell output (peak power)
Lighting	Indoor lighting in villages, isolated areas, street lights, outdoor signs, tower lights, etc.	15W ~ 60W
Household equipment	Electrical home appliances, fluorescent lamps, refrigerators, drinking water pumps, radio, TV etc. can be powered even in areas where commercial electricity is not available.	40W ~ 2KW
Cathodic Protection	Protecting petroleum pipelines, gas pipes and telephone cables from corrosion.	500W
Land Transportation Control	Railway signals, unmanned railway crossings, road signs, barrier flashes and guide boards.	20 to 100W
Wireless and microwave relay stations	Microwave or UHF relay stations, TV broadcast stations serving remote areas.	60W to 3kw
Small clinics	Supplies lighting, refrigerator for storing medicines, powering other medical equipment especially in developing countries.	300W to 1 KW
Irrigation and Water Pumps	Irrigation pumps as well as drinking water pumps on a large scale in many developing countries.	1 KW - 4 KW

IV. Techno-economic aspects of photovoltaic industry

Photovoltaic technology is a relatively mature technology. Photovoltaic costs have dropped ten-fold in the last 20 years as shown in figure 9. Current prices of $4.0 to $5.0 still remain, except for applications of low load and off-grid applications.

Cost reductions, development of niche markets, efforts by Governments and international bodies for sustainable energy should bring in the necessary critical market volume. Then, photovoltaic with its several plus points added to comparable costs of other energies, would have exponential growth.

Cost reductions could be attained through improvements in technology, process and economics of scale.

Scaling up manufacturing process

Solar cells consist of semiconductor modules and can easily be mass produced like transistors and ICs. For photovoltaic technology, especially thin films are highly amenable for mass production. For example, an amorphous silicon plant of 2 MW capacity costs about $12.5 million, while an 80 MW capacity plant requires an investment of $81 million and the production cost is expected to be $1.25/Wp. The scaling-up production VS module cost is shown in figure 10. At this price, the market expansion would have an exponential growth which is indicated in figure 11.

Photovoltaic processing technologies and its effect on module cost

As of today crystal silicon technology amounts to 35 per cent of the total photovoltaic production despite the high material cost. Employing process developments to reduce the wastage in crystal growth, slicing (kerfloss) and also reducing the thickness of the wafers from 400 μ to 250 μ, could result in price reductions of up to $2.5/Wp by the year 2000.

Multicrystalline silicon technology, which holds about 28 per cent of photovoltaic production, also suffers from high material cost. High throughputs, larger casting ingot production and also using cheaper silicon is expected to cut down costs, but, because of lower cell efficiency produced, compared to a single crystal, the cost is expected be around the same value, $2.5/Wp.

Amorphous silicon technology which achieves higher stable conversion efficiencies (10 per cent as of now), and is also suitable for mass production, is expected to reach a price level of $1.0/Wp by the year 2000.

Cost break-up per peak watt of silicon (~ 400 μ) VS thin film based modules at a plant capacity of 3 MW per annum is shown in table 5, indicating that thin film based modules would be less costly.

CIS and CdTe thin film technologies have grown remarkably well during the last two years and a few MW size plants are being set. With their higher efficiencies and suitability for mass production, and requiring less capital investment as compared to amorphous silicon plants, CdTe and CIS based module costs are expected to plummet to less than $1.0/Wp by the year 2000.

The cost digression as a result of mass production of solar modules can also be estimated from an extrapolation of the real cost transitions in the past 20 years. Figure 12 shows the actual costs of photovoltaic modules (without BOS), of a size of module varying from < 1kwp to > 1MWp.

Energy payback period (EPP)

Electrical energy generated by a photovoltaic module depends upon the values of conversion efficiency and the average insulation level at the given site. The EPP is the quotient of the invested energy in fabricating photovoltaic module and the energy generated by the module in one year. Some figures are available on the energy payback period, particularly with the rooftop photovoltaic modules of 2 to 3 KWp capacity. During 1994, a joint cooperation programme of the house building industry and solar module manufacturers to develop photovoltaic roofing house was initiated under the New Sunshine Project in Japan. The EPP for a 3 KWp rooftop photovoltaic power house and a solar roofing house, calculated on crystal silicon-based and amorphous silicon-based solar cells are given in table 6. EPP is much less for amorphous silicon-based rooftops.

Comparing several factors, such as material costs, suitability for mass production and energy payback period, "Thin Film" technologies look as though they have an edge over crystal silicon technology for large-scale production from the viability and economic considerations. This will be particularly true when world-wide photovoltaic module production per year crosses the 250 MW threshold, for lack of feed stock silicon, unless solar grade silicon manufacturing plants are commissioned.

Scale of merit

The present annual world photovoltaic production is around 90 MW with a sharp growth expected from 1997 (plans for commissioning photovoltaic plants to the tune of 270 MW exist), and it is expected to cross the 400 MW of photovoltaic production per year threshold by the year 2000. One of thin film technologies, with a share of the 100 MW annual production, could achieve substantial cost reductions due to the scale of merit.

An increase in mass production scales with an expanding market size, induces cost reductions by their large-scale merit. Figure 13 shows cost reductions of the solar cell module in the last 10 years for various photovoltaic technologies. The scale of merit refers to the percentage of unit cost after the mass production scale is increased by one order of magnitude. The results indicate a scale of merit of about 30 per cent for crystal silicon solar cells and a 25 per cent scale of merit for the amorphous silicon solar cell because the production processes of thin film are better matched to mass production.

Governmental and institutional promotionary role in photovoltaic industry

The development of photovoltaic technology in major photovoltaic producing countries has depended on (1) government support (2) R&D efforts (3) developing markets for sustainable energy growth and public awareness of the new technology for terrestrial applications.

USA: The Department of Energy (DOE) plays the main promotional role by stressing the major end usage of photovoltaic for utilities in national programmes, coordinates various funding programmes on R&D, standardization, advanced materials technology development, demonstration of pilot projects, BOS systems through national institutions, such as NREL and SNL.

Japan: The Ministry of International Trade and Industry (MITI) promotes photovoltaic as a possible source of power supply by coordinating with agencies such as AIST, ETL, NEDO etc. The programmes are oriented more to bringing photovoltaic products to the market and developing process techniques suitable for mass production.

Recently Japan has introduced new government regulations for the promotion of photovoltaic systems by: (a) tax reduction for private industry investment for photovoltaics, including photovoltaic air-conditioners (big loads) (b) 2/3 subsidy for photovoltaic system facility installation cost fee and data acquisition (c) 1/2 subsidy for residential photovoltaic system installation costs, and a variety of incentives to achieve economic viability for photovoltaic systems.

Europe: Europe has multinational projects such as the EUREKA and JOULE programmes for promoting R&D as well as for demonstration projects. Germany, Switzerland and Italy have strong photovoltaic programmes. Germany has started a 1,000 rooftop photovoltaic systems programme and has programmes to increase terrestrial photovoltaic applications in a big way, mainly from environmental considerations.

Switzerland has a programme targeting 50 MW by the year 2000, with a strong commitment to integration in buildings. Italy has already established a 3.3 MW plant, the single largest plant in Europe, shown in figure 14, and several photovoltaic industrial projects.

The photovoltaic promotional activities taken up by various Governments help in overcoming some of the institutional and market barriers for photovoltaic propagation such as investment, subsidies, transaction costs, customer awareness etc. Based on the technical data on cell efficiencies, development of new technologies, system life time, production costs, production scale and the promotional measures taken by several Governments for the propagation of photovoltaics; Prof. Hamakawa (28) proposed a scenario of technical milestones, achievements both in terms of conversion efficiency and costs of photovoltaic modules and BOS, and finally the levelized electricity costs along with DOE estimated figures during the 5th International PVSEC as presented in table 7. The predictions fell short by two years and the levelized electricity cost of $0.18/kwh and $0.07/kwh are expected to be achieved in 1997 and 2002 respectively.

Potential markets for photovoltaics

The zero-emission technology of photovoltaics has enormous potential to reach various cross sections in developing countries.

Rural and off-grid markets

Two billion people in developing countries still lack adequate energy for economic growth and basic needs. Four-hundred to 500 million households in rural areas have no access to a grid connection, or which may not be available within the next two or three decades. Grid extension is very expensive varying between $5,000 to $10,000 per a mile of extension, depending on the location.

Solar house system (SHS)

An estimated 100 W per house to provide three lights, a fan and a radio or a TV, with the minimum domestic electrical needs known, solar house system (SHS), as shown in figure 15, in the rural areas mentioned above, would require 40,000 MW; a staggering power need which cannot be met in the near future by the conventional grid. Thus, it provides a very good potential market for photovoltaics especially because it is a standalone system and a low load application.

ASTAE, the World Bank and GTZ (Germany) have carried out work on these programmes.

Drinking water and irrigation pumps

Almost one billion people in the developing world lack access to safe drinking water supplies. Together with drinking water pumps, the irrigation pumps for agriculture in the developing countries alone use about 50 million diesel pumps, each consuming one ton of oil per annum. This represents a huge market for photovoltaics as a least-cost option, if life cost cycle (LCC) is taken into account.

Health clinics, community centres

Another potential market in the rural areas, which are not electrified, is a health clinic and community centre for education and entertainment. Health clinics, as shown in figure 16, having a refrigerator to keep life-saving medicines, essential medical electronic gadgets, lights, fan, communication equipment and water pumps etc., is an indispensable minimum to cater to the basic health needs of several hundreds of thousands of villages. Similarly, community centres are a gathering place in the village and could be well utilized for education information and entertainment purposes. It could also be used for adult education programmes, such as is practised in developing countries like India.

A community centre with a few lights, a fan, TV & VCR requires 1/2 KW coupled with the power requirement of about 1 kw or so for a health clinic for approximately 500,000 villages is 750 MW. These are the facilities for which photovoltaics are certainly the least costly option in developing countries.

Photovoltaic hybrid systems

This forms a very important and potential market for photovoltaics for several medium-range power applications. Because of high price of diesel fuel in developing countries, photovoltaic powered systems are known to be cost-effective in the long run. Shown in figure 17 is a comparison of 60 KW systems run by photovoltaics and diesel, indicating that photovoltaic is cheaper over a period of 20 years. However, in view of the capital costs for a photovoltaic system, a photovoltaic-diesel-hybrid system proves economically and technically advantageous with loads between 50 to 250 KWh/day. Hybrid systems presently enable a trade-off of capital and operating costs as shown in figure 18, providing a more optimal solution.

Several units exist, with a 25 KW photovoltaic array along with 30 KVa diesel set delivering a load of 200 kwh a day in an island north of the Australian mainland, and 4 KWp photovoltaic and 12 KVa powering an emergency communication system in Florida. This indicates the great potential of photovoltaics in both developed and developing nations.

Application in small island countries

In several island countries in the Pacific and Asian countries, needs such as water desalination plants, low power-consuming industries, cottage industries, fishing industry (requiring refrigeration for transport), and inter-island communications, are best served with photovoltaics, and this forms another big potential market.

Hybrid systems, including photovoltaic micro hydro systems, where photovoltaics are used to pump water back for reuse, and as a storage media, are some of the applications increasing the photovoltaic market potential.

Solar roofs

In several developed countries such as Japan, USA, Germany etc. solar roof programmes have been initiated. Typically the solar roofs are of the capacity 2 to 3 KW and, over the last two years, photovoltaic has made inroads in building and construction activities in view of the aesthetic considerations, as well as the suitability of geometric integration of photovoltaic modules into roofs like shingles and wall curtains and into larger buildings and facades. Figure 19 shows 13.14 KW photovoltaic modules incorporated in the architecture of a building. Figure 20 shows a Japanese house with a solar roof delivering 2 to 3 KW of power. Figures 21 to 24 show the penetration of photovoltaics in building construction and highways.

This promises to be another potential market for photovoltaics in the urban areas of developed countries. With cost reduction, the potential market for solar roofs would be huge.

Funding mechanisms

While it is cost effective on a life-cycle basis, photovoltaic still has a high front-end capital investment. Given the scenario of the dispersed basis of individual photovoltaic customers located in rural and remote areas, it has been difficult to mobilize the financing requirements from commercial or private sources.

Low customer density in a given service territory makes sales, installation, service and finally payment collection generally an expensive and unmanageable operation. This is the experience of GTZ, which for 10 years has been involved in the dissemination of photovoltaic systems for rural households in developing countries.

Recognizing the need in developing countries for renewable energy technologies, the World Bank through ESMAP (Energy Sector Management Assistance Programme) in cooperation with the US DOE and other international organizations, launched FINESSE (Financing Energy Services for the Small Scale Energy users). The objective of FINESSE is to identify and promote ways to provide economically viable and affordable alternative energy services in the developing world. It encourages non-governmental organizations to assist in establishing and operating mini utilities to provide power to local communities. Donor funding is channelled to the NGO through commercial lending sources. Funding is provided directly to voluntary organizations with government approval. In most instances it could operate as a revolving fund.

Solar house system (SHS)

The SHS is considered as a least costly economic option for rural lighting and for a power supply. However, there are several financial barriers that limit the purchase of SHSs for rural households such as import duties, subsidies on kerosene, costs associated with establishing a retail and service network and high front-end costs requiring financing.

An SH system needs to import BOS which attracts high tariff in several developing countries. In Sri Lanka duties add up to about $2.50/Wp, India levies a 45 per cent duty on photovoltaic equipment. Duty on imported batteries vary from 50 to 100 per cent depending on the country.

In the early stage of market development, the investment required for sales, training and servicing are very high for a minimum quantum, as can be seen from an example in Indonesia where a SHS in West Java (annual sales are in thousands of systems) is 50 per cent cheaper than in Lampung where SH system sales are in hundreds per year.

It is expected that support from Government, by promotional campaigns of SHS for rural households, tax credits at the retail or wholesale level, training and technical assistance to help establish retail and service networks, could facilitate the necessary financial viability of SHS.

The high initial purchase price represents the biggest barrier for rural populations in developing countries where annual incomes are at the lowest level. While 5 per cent of the rural householders can afford cash payments for SHS system or even other gadgets, 95 per cent do need funding.

Financing models

Broadly, four funding models have emerged, energy service companies (ESCO), leasing, consumer financing and cash sales.

ESCO sells the energy service while retaining ownership of the hardware. Typically ESCO procures the SHS in bulk from distributors or the international market. ESCO personnel install the SHS and service the power generating components. The monthly cost charged to the customer can also be reduced by spreading the cost of the photovoltaic system over the lifetime of the system.

In the leasing arrangement the intermediary retains ownership of some or all of the SHS and provides it to the customer under specified terms and conditions.

In the consumer financing model the suppliers sell directly to consumers who can obtain financing from local banks or dealers. The summary of the various financing scheme characteristics are shown in table 8. The finance terms vary substantially from country to country and depend on the cost of financing, degree of risk to the lender and loan processing and administration costs.

GEF Green Carrot Project (29)

The Green Carrot Program of GEF is mainly to accelerate the commercialization, market penetration and financial viability of photovoltaic technology in developing countries. It has set up a $60 million fund providing $5-20 million rewards for a few companies to expand commercial applications. GEF has identified, among others, energy service companies or leasing companies operating either independently or combined in a country addressing markets in water pumping, development of photovoltaic/diesel hybrid systems in association with renewable energy vendors.

GEF also identified funding for increased technology transfer to further the developing countries' capabilities in the photovoltaic market and in manufacturing and the introduction of new financing mechanisms.

The awards could be used as a base capital to attract further financing for significant manufacturing scale-ups. Several photovoltaic manufacturing companies in developing countries find it very difficult, in view of the limited market, to scale up their product or establish cost-effective technologies for lack of funds as local interest rates are very high (20 per cent or more). Now Ex-Im banks of several developed countries have initiated programmes to give loans at LIBOR level interest rates to encourage eco-friendly technologies. This can bring economic viability for many photovoltaic industries in developing countries.

V. Impact of photovoltaics on developing countries

Despite enormous investments in rural electrification, two billion people which is about half the population of the developing world, continue to live without adequate power supplies or no power at all. Even in those countries which implemented rural electrification, only a few serve more than 20 per cent of their rural population.

In rural areas, the electrification programme is problematic as line extensions are unreliable and are characterized by low loading ratios and high losses.

There is also a growing awareness of the pollution caused by the use of fossil fuels and oil together with the environmental degradation in developing countries. The rapid industrialization taking place in this world is known to worsen the situation.

These emerging realities are now motivating leaders in developing countries to realize that renewable energy in rural areas, and energy efficiency in urban areas, can play a vital role in satisfying developing countries' energy needs while helping to mitigate environmental pressures.

It has been realized that photovoltaic energy is best suited for several low load applications, such as solar house systems especially in the rural sector.

Currently, the photovoltaic power generation is 9 to 10 MW in developing countries, which is about 10 per cent of the world photovoltaic production.

India, Brazil and China are some of the countries which have well-established photovoltaic industries, having experienced significant growth over the last eight years.

India: India is a forerunner in photovoltaic industrialization in developing countries with a cumulative photovoltaic module production of about 30 MW over the last eight years. The Ministry of Power and Non-Conventional Energy Sources, established 10 years ago, is responsible for setting up photovoltaic industries, supporting R&D efforts and establishing the Indian Renewable Energy Development Agency (IREDA) with the mandate to promote, develop and finance renewable energy technologies.

India, with two companies in the public sector and two in the private sector, has a total capacity of 6 MW per annum, based on crystal silicon technology with photovoltaic module shipments of the order of 3 to 4 MW. There is a poly silicon plant with 25 tons per annum capacity and a silicon wafer facility producing more than one million wafers per annum. A 1/2 MW amorphous silicon plant was commissioned five years ago and a production plant for manufacturing CdTe modules is currently in progress.

Currently, there are about 15 companies with varying capacities to assemble photovoltaic modules. Most of these companies manufacture photovoltaic modules as well as the BOS required for various applications such as street lights, water pumping, portable lanterns and solar house systems.

Photovoltaic production got a big boost in 1993 with the Indian Government's decision to power rural telephone exchanges by photovoltaics (70 w per unit) and started tendering on average 3 to 4 MW per year, reaching 7 MW this year.

India is likely to have 9 to 10 MW market from 1997. However, this is insignificant compared to its potential for photovoltaics and the need to provide energy to rural households.

India uses about 15 million diesel pump sets (each consuming 1 ton oil/year) for irrigation. Phasing out the diesel pumps and replacing them with photovoltaic powered pumps, setting up photovoltaic powered village clinics, community centres and SHS units for rural houses is the challenging potential for solar energy utilization in India.

Brazil: The scenario in Brazil is not very different. The photovoltaic potential is comparable to India. Brazil too has established photovoltaic industries for solar cell, module and systems and exports more than a million silicon wafers.

China: China has 7 photovoltaic plants with a production capacity of 4.5 MW and manufactures solar cells of 3.0 MW per year. Two plants manufacture crystal silicon and wafers. China has a programme to use photovoltaic for households in rural, nomadic districts and isolated islands. They have a target of providing photovoltaic electricity to six million of the present 120 million people who have no access to electricity.

Indonesia: In South-East Asia, Indonesia has made tremendous progress by embarking on a project to electrify 1 million houses with 50 W capacity SHS units amounting to 50 MW.

Zimbabwe, with a $7 million grant from GEF, is setting up domestic lighting systems.

Several Pacific islands have installed photovoltaic powered gadgets, including photovoltaic diesel hybrid systems. Photovoltaic powered refrigerators (to keep life-saving medicines and vaccines) are being used in several African countries. Figures 28 to 35 show some of the applications employed in various developing countries, showing the impact of photovoltaics.

Recognizing the need for use of photovoltaic power in developing countries the World Bank has taken a solar initiative and is providing funds for the dissemination and propagation of photovoltaic energy applications (30, 31).

The GEF, with its target of arresting gas emissions, provides grants to develop photovoltaic industries and markets in developing countries.

UN bodies, such as UNIDO (United Nations Industrial Development Organization), plays an important role in forming vital linkages between various nations for the transfer of know-how and technologies from developed countries to developing countries. It has programmes such as COSERA, for promoting and augmenting solar energy applications and market surveys by providing forums for countries in various locations for interaction, providing expert advice for technology promotion, as well as feasibility studies for photovoltaic projects in developing countries.

A number of large-scale photovoltaic power systems are planned world-wide: During 1996 large scale plans for photovoltaic plants totalling 280 MW have been proposed. These are: 50 MW plant in India, 4 MW in Hawaii, 10 MW plant in California, three plants 100 MW, 70 MW and 50 MW in different locations of Nevada. Such large sized mass-production plants would result in cost reductions and attract market pull.

VI. Conclusions

The report has reviewed solar cell materials, technologies for production of various materials for cell fabrication, current techniques employed for fabricating crystal silicon, amorphous silicon and other semiconductor thin films and recent achievements in developing high efficiency solar cells. While C-Si and A-Si efficiencies have improved substantially it is clear that thin films Cd technology and CIS have become strong contenders for the low-cost manufacture of photovoltaic cells. With the development of efficient polycrystalline Si thin films, and the initiation of mass production of CdTe and CIS thin films, a \$2/Wp goal looks to be realistic very soon. A detailed description of photovoltaic module assembly operations have been presented, in view of the increased activity for photovoltaic module and system operation in developing countries.

The techno-economic aspects of the photovoltaic power generation have been discussed taking into account the technology push and the desirable market pull which is gaining momentum. The potential and niche markets for photovoltaics, the funding mechanisms that are operating in developing countries as well as the photovoltaic industrial growth in several countries have been presented.

Several Governments, realizing the need for renewable energies, especially photovoltaics in the rural areas, have initiated projects such as solar house systems (SHS) and graduated from low load applications to medium load power applications such as water pumping. Having taken the solar initiative, the World Bank and GEF are actively participating in establishing photovoltaic power units in the rural areas of developing countries by introducing a variety of funding programmes and financial schemes.

Solar rooftop projects are becoming popular in several countries such as Japan, USA, Germany and Switzerland, thus disproving the myth that solar energy is only good for the rural sector.

1996 looks to be the start of a period of rapid growth for the photovoltaic industry world-wide, with the announcement of plans to set up photovoltaic plants in the order of 280 MW.

With the development of high efficiency solar cells, also suitable for mass productions and scaled up manufacturing plants in the offing, production costs would plummet to \$2/Wp by 2000. This would have a remarkable impact on developing countries and accelerate the growth of photovoltaic industry.

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Table 1
Multi-crystalline ingot growth techniques, ingot size throughputs, lifetimes, diffusion lengths and cell efficiencies.

Name	SEMIX	-	-	-	EUROSIL	SILSO	BAYSIX	POLIX
Company	**Solarex**	**Crystal Systems**	**Sumitomo Sitix**	**Kyocera**	**Eurosolare**	**Wacker**	**Bayer**	**Photo-watt**
Method	Casting	DS	DS	Casting	DS	Casting	Casting	DS
Crucible/Coating Mould/coating Re-use	Silica/prop. Silica/prop. no	prop./Si_3N_4 --	C/Si_3N_4 nx	silica C/prop. nx	silica/Si_3N_4 -- no	silica/- C/prop nx	silica/- silica/Si_3N_4 nx	C/liquid enc.-- nx
Heater	C	C	RF	RC/C	C → RF	RF/C	RF	RF
Ingot Size [mm^3] [kg]	240x240x 200 30	550x550x 150 100	330x330x 200 50	330x330x 250 62	550x550x 210 150	440x440x2 80 125	220x330x 250 40	410x410x 130 60
Growth Rate [mm/min] [kg/h]	prop.	10			0.1 - 0.2 6	0.4 - 0.6 12		
Throughput [kg/h] [kwh/kg]	prop.	2-3 10			3 15	10-15		
Impurities Precipitates	C/O SiC	C/O/N	C/O/N		C/O/N	C/O/N SiC_2 Si_3N_4	C/O/N	
Lifetime[μSec] Diff.length[μm]	100	$\leq$ 300			180	10-20	200	
Solar Cell eff[%]/ Size [cm^3]	15.8.130 16.9/1	15.3/100 16.3/42 17/1	16.4/225 17.2/100 17.8/4	15/225	14/100 16.7/4	15.6/100 15.8/4	16.4/100	16.2/4

Table 2
Summary of some top efficiency records in thin film Solar Cells and modules (As of Sept. 1994)

		Voc(V)	Jsc (mA/cm²)	F.F. (%)	ñ (%)	A(cm²)	Institute	Remarks
a-Si Single Junction Small Area Cells More Than 12% Efficiency		0.967	17.7	70.3	12.0	0.033	Osaka Univ.	p μc-SiC (ECR)
		0.891	19.13	70.0	12.0	1.0	Solarex	
		0.927	18.4	70.5	12.0	1.0	Fuji-Elect.	BF3 Pulse CVD
		0.90	18.9	72.0	12.3	0.09	TIT	8-doped player
		0.923	18.4	72.5	12.3	1.0	Fuji-Elect.	Pulse CVD; p-a SiC:H
		0.899	18.8	74.0	12.5	1.0	Fuji-Elect.	p a-SiO:H/a-Si:H/n a-Si:H
		0.885	19.13	74.7	12.65	1.0	SEL	Reverse Bias Annealing
		0.887	19.4	74.1	12.7	1.0	Sanyo	Superchamber
		0.909	19.8	73.3	13.2	1.0	Mitsui-Toatsu	a-C/a-Si ML/a-SiC/a-Si
a-Si Sub-Modules (M) More Than 10%		12.53/M	130.1/A	73.5	12.0	10 x 10	Sanyo	TCO improvement
		2.409/M	611.6/A	68.6	10.1	10 x 10	Mitsubishi	a-Si/a-Si/a-SiGe
		53.9/M	328/A	71.4	10.05	30 x 40	Fuji-Elect.	a-Si/a-Si, a-SiO player
a-Si Basis Stacked Solar Cells		1.75	8.16	7.2	10.2	1.0	Solarex	a-SiC/a-Si
		1.80	9.03	74.1	12.0	1.0	Fuji	a-Si/a-Si
		2.29	7.90	68.5	12.4	1.0	Sharp	a-SiC/a-SiGe/a-SiGe
	2	2.32	7.30	73.0	12.4		Sumitomo	a-SiC/a-Si/a-SiGe
	T	2.55	7.66	70.1	13.7	1.0	ECD/Sovonics	a-Si/a-Si/a-SiGe
		1.48	16.2	63.0	15.0	0.033	Osaka Univ.	a-Si/c-Si
		2.4	6568/A	67.5	11.8	905.9	Canon/USSC	a-Si/a-SiGe/a-SiGe
		0.871	16.4	72.0	10.3		ARCO	a-Si/CulnSe2
	4	0.432	17.4	68.0	+5.3=15.6			
	T	0.917	10.4	76.0	7.25	0.033	Osaka Univ.	a-Si/poly-Si

Table 3
Module Performance of Semiconductor Thin Films CdTe and CIS.

Company	Material	Area (cm²)	ñ (%)	Power (W)
SCI	CdTe	6728	9.1*	61*
SSI**	CIS	3830	11.2	43.1
SSI**	CIS	3859	10.3*	39.7*
BP Solar***	CdTe	4540	8.4	38.2
SSI	CIS	3261	10.1*	35.7*
Golden Photon	CdTe	3528	7.7*	27.2*
SSI	CIS	938	11.1*	10.4*
Matsushita	CdTe	1200	8.7	10
BP Solar	CdTe	706	10.1	7.1
Golden Photon	CdTe	832	8.1*	6.8*
ISET	CIS	845	6.9*	5.8*
EPV	CIS	791	7.2	5.7
EPV	CIS	722	6*	4.3*

*NREL-measured; **Unencapsulated; ***Not monolithic

Table 4
Photovoltaic Module Assembly Process

Progress Flow Diagram		Description Of Process (Equipment Required)
1.	Cell Inspection	Measurement of Electrical Characteristics of each cell. (Solar Simulator: consisting of xenon lamp, an electron charge and a system which allows the characteristics of measured devices to be recorded).
2.	Interconnector Soldering	Manual soldering of interconnectors to the cell face. (Tables, soldering iron, teflon rubber, magnifying glass).
3.	Array Soldering	Cells are positioned and interconnectors are soldered at the back of each cell to form circuits. (Table, cell aligner jig, back side wiring tray)
4.	Reversing the Array	Array is inverted to the front face and after visual inspection EVA and glass is placed on it. (Table, reversing equipment)
5.	Reverse to Backside	Array with glass and EVA reversed to back side again, onto a background lit table. It is visually inspected for any dust and mis-soldering. Backside EVA and film is placed and aligned. (Backside lit table, magnifying glass)
6.	Laminate	The whole pile is placed in laminator for lamination. (Laminator)
7.	Shelving	Laminated array is placed in the shelf. (Racks)
8.	Curing	Laminated array is cured in the curing oven. (Oven, racks)
9.	Edge Cutting	Outward projected film and EVA is cut to the size of glass. (Cutting stand, heat cutter).
10.	Framing	Long and short aluminum frame battens are lined with rubber and framed onto the encapsulated array, on frame assembler (frame assembler, power screwdriver)
11.	Terminal Assembly	Terminals are soldered and terminal box is attached. (Soldering iron, table)
12.	Standardization tests	Measurement of electrical characteristics, data for standardization (simulator, I-V tracer, data printer)
13.	Final Inspection	Panel is compared with standard panels for performance test. Visually inspected and labeled. (Comparator tester, standard panels, simulator).

Table 5
Cost breakup per peak watt of silicon (400 μ) vs thin films photovoltaic modules at a plant capacity of 3 MW per annum. (All costs in US dollars)

Sr. No.	Particulars	Silicon (bulk)		Thin Films	
		Crystal silicon	Multicrystalline silicon	Amorphous silicon	CdTe & CIS
1.	Cell Material	$ 2.0	$ 1.8	$ 0.5	$ 0.5
2.	Cell Process	$ 1.25	$ 1.35	$ 1.5	$ 1.25
3.	Module Cost	$ 1.00	$ 1.00	$ 1.5	$ 1.00
		$ 4.25	**$ 4.15**	**$ 3.5**	**$ 2.75**

Table 6
Energy Payback Period (EPP) calculated for 3 KWp PV

Annual production (MW/y)	Rooftop PV			Solar cellar roofing house		
	10	30	100	10	30	100
1. c-Si						
output energy	9614	9240	7993	8327	7952	6706
EPP (years)	2.4	2.2	1.5	2.1	1.9	1.2
2. a-Si						
output energy	5675	5518	4355	4388	4230	3067
EPP (years)	2.1	1.6	1.1	1.6	1.2	0.7

Table 7
Conversion Efficiency Data, Technical & Financial Milestones

Target Year		1992	1997	2002
Solar cell/module efficiency (%)	Xstal-Si	18/15.5* (23.7)	20/18*	22/20
$100cm^2$ area level	Poly-Si [cast/sheet]	15.7/13.5 [15.7/12.3]	18/15.5 [18.14]	20/17.5
(Small area top data)	a-Si	10/8.7* (12.0)	12/10*	14/12
	stacked a-Si (4T/2T)	10.6/9.2 (16.8/15)	14/11	18/15
Production scale (MWP/year)		14.5	40	500
Module cost(¥/Wp)		650 ($4.5/Wp)	500* ($3.3/Wp)	100-200* ($1/Wp)
BOS cost (¥/Wp)		500 ($3.3/Wp)	350 ($2.3/Wp)	250 ($1.7/Wp)
System life (year)		20	22	25
Levelized Electricity Cost ($/kwh)		42** ($0.29/kwh)	27** ($0.18/kwh)	11** ($0.07/kwh)

* Sunshine Project Milestones.
** Module efficiency 10%, annual shine period 1200 hrs/year are assumed.

Table 8
Summary of Financing Scheme Characteristics

Financing	Financing Scheme			
Characteristic	ESCO	Leasing	Consumer	Cash Sales
Affordability	Highest	Moderate	Low	Lowest
Interest rate	Low	Medium	High	Not applicable
Repayment Period	Long	Medium	Short	Not applicable
Down Payment	Low	Moderate	High	Full cost at purchase
Loan security	SHS	SHS	SHS and/or other collateral	None
Credit risk to lender	Low	Moderate	High	Not applicable
Administration costs	High	Moderate	Moderate	Low
SHS ownership	Generation components by ESCO rest by user.	Eventually by user	Eventually by user	User

Figure 1

Solar Cell: Incoming units of light energy (photons) are absorbed by electrons within the silicon wafer creating -ve charges (electrons) which are attracted to the n-type silicon and +ve charges (holes) are attracted to the p-type. A photo current flows voltage develops and electricity is produced.

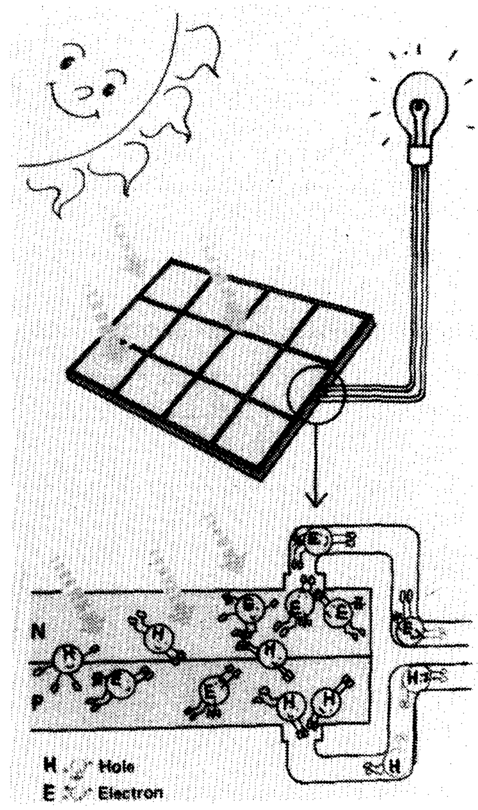


Figure 2

Solar Cell Technologies

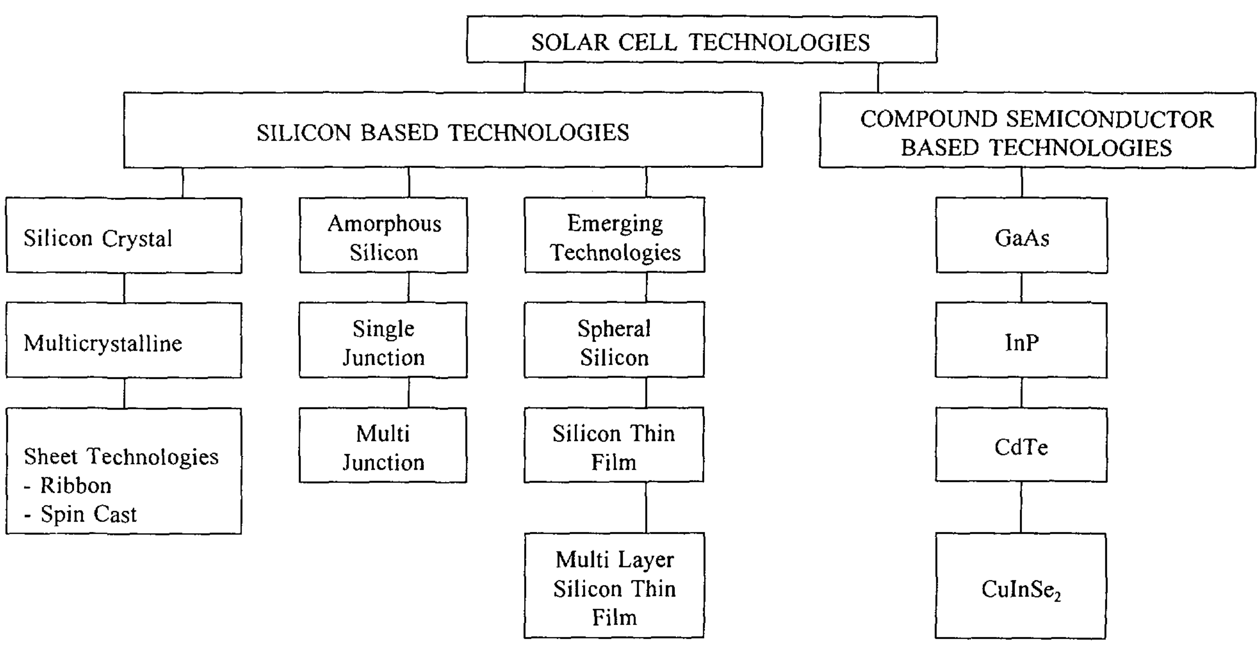


Figure 3 (a)

CZ Crystal growing machines (b) Silicon Crystal ingots & Cast Silicon ingots (c) Round and Square wafers after slicing and (d) Solar Cells.

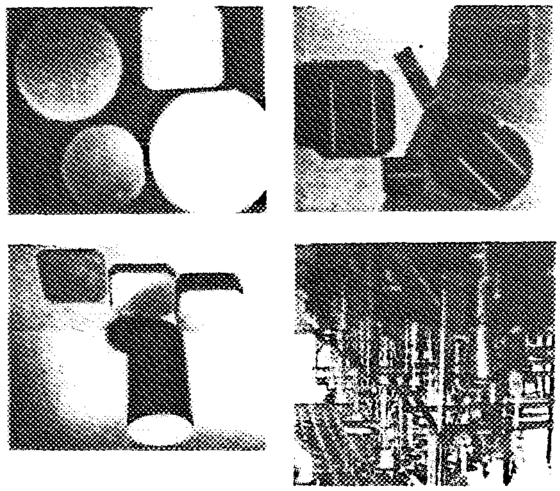


Figure 4 (a)

Schematic diagrams of Solar Cell structures.

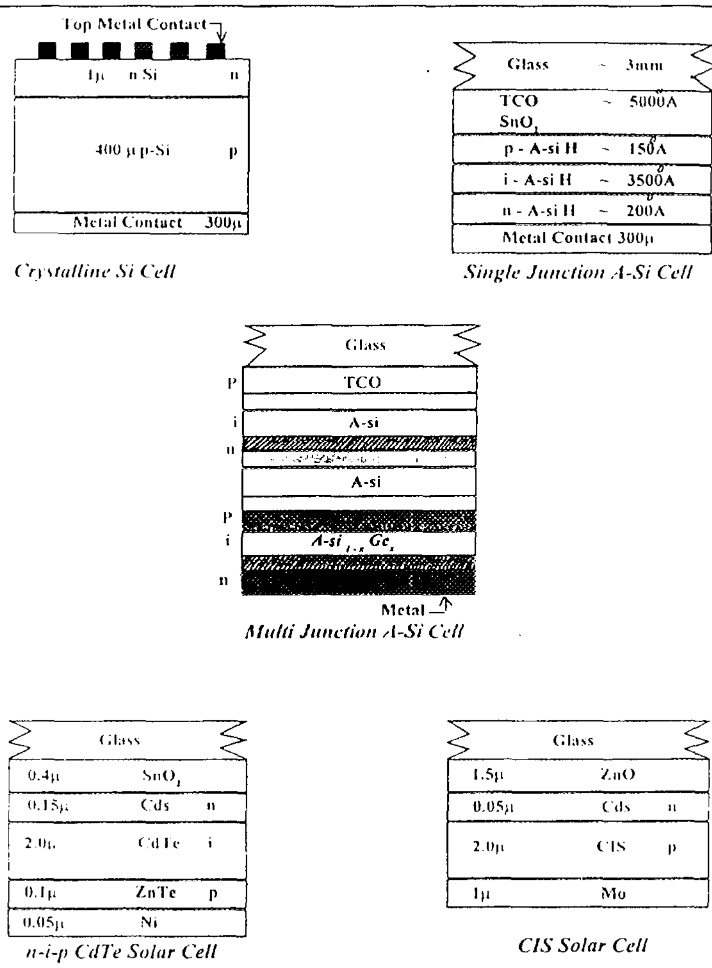


Figure 4 (b)
Manufacturing process steps of Solar Cell

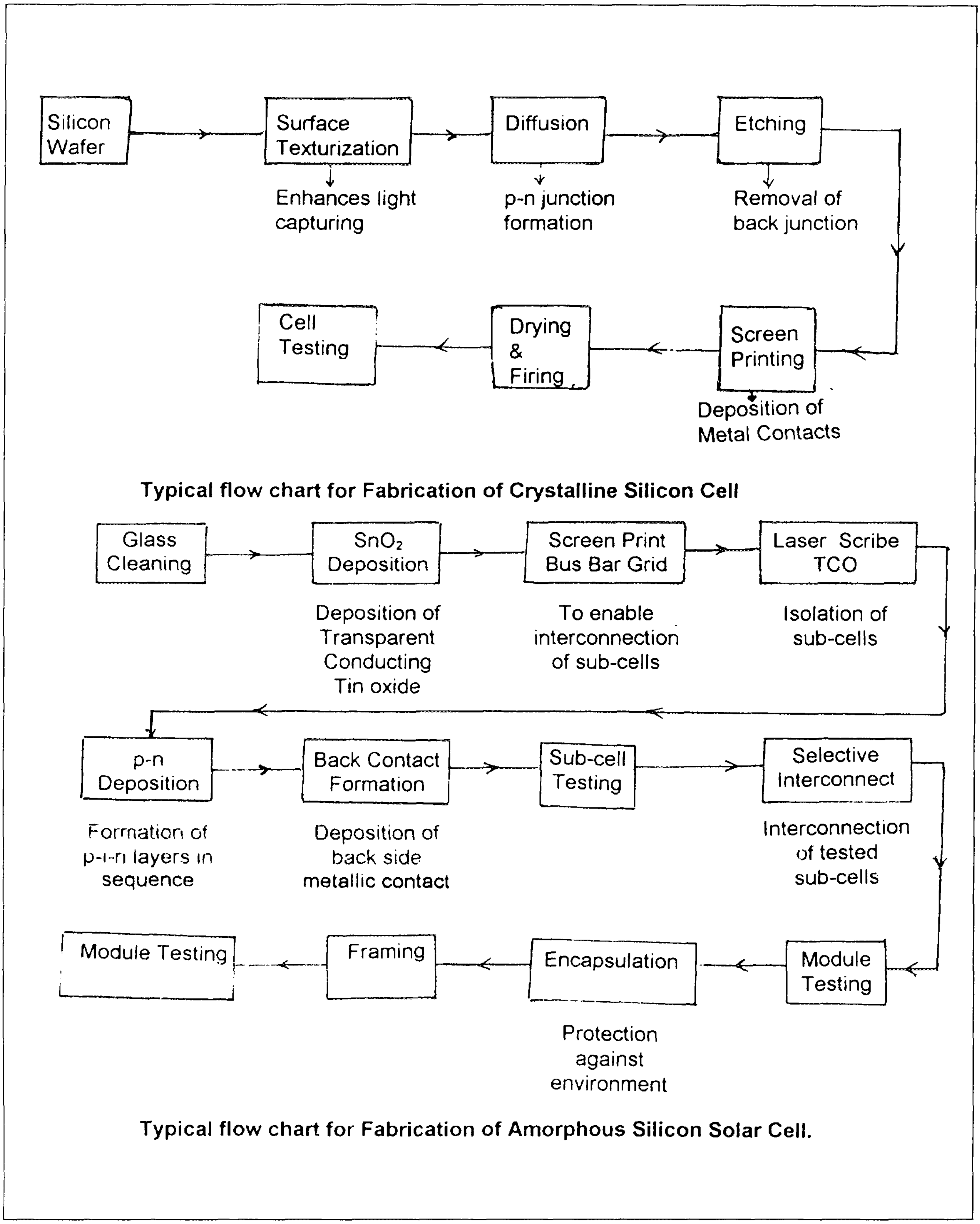


Figure 5
Generic elements of photovoltaic Module encapsulation system.

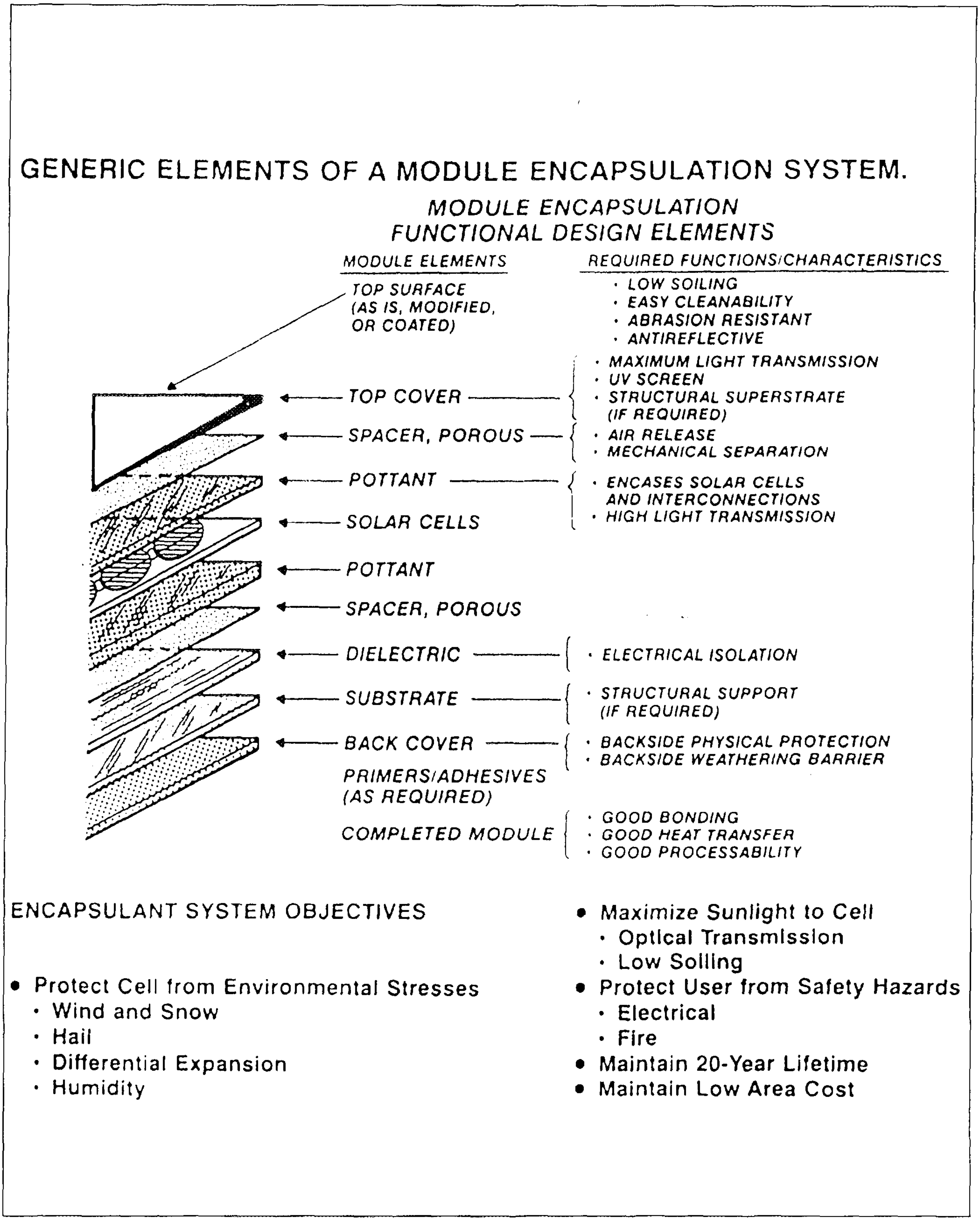


Figure 6
Assembly Process steps of photovoltaic module.

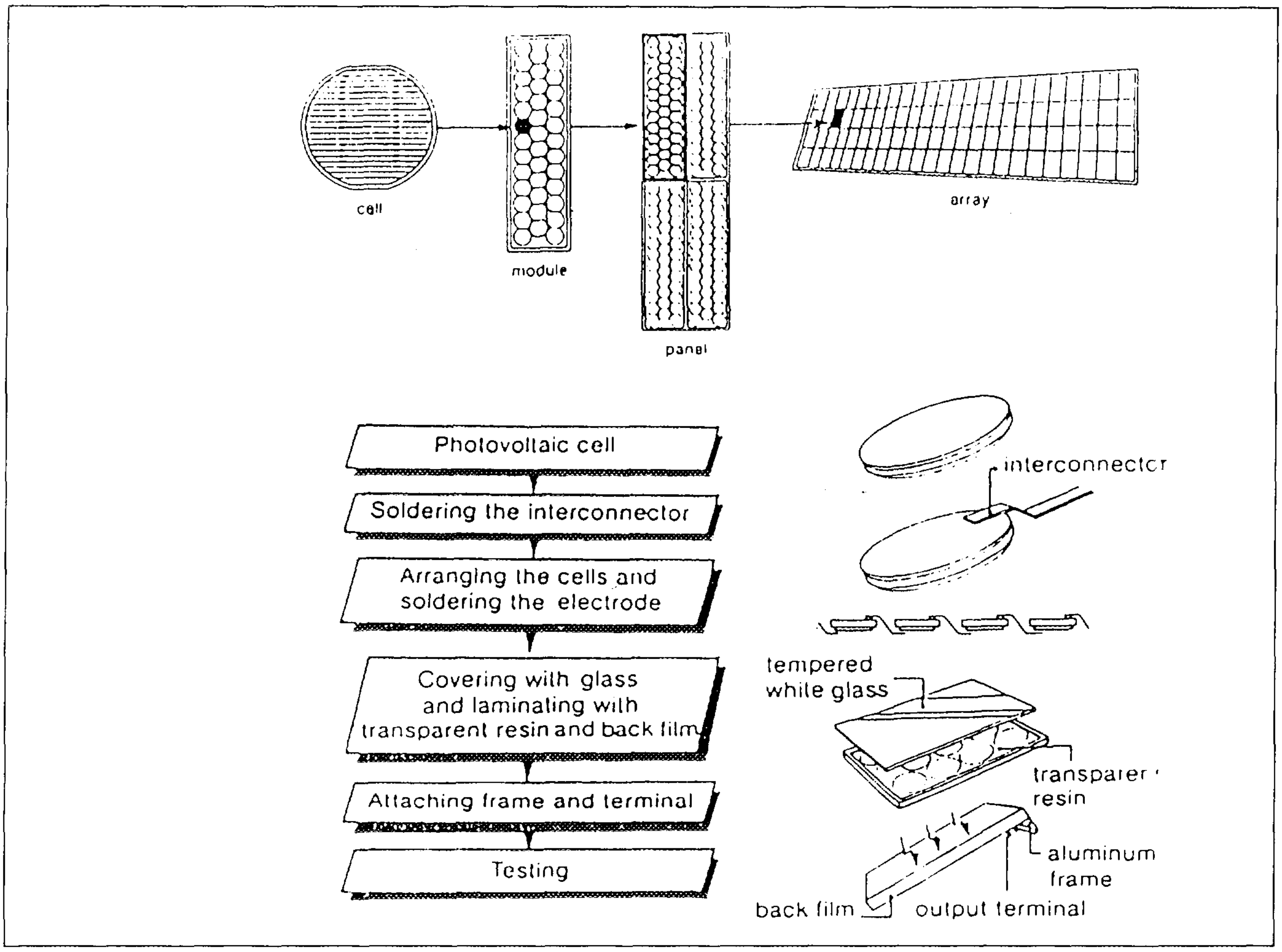


Figure 7
PV modules. Left to right - Single Crystal Silicon modules with round cells and square-cut cells, polycrystalline silicon module, thin film modules (rigid and flexible)

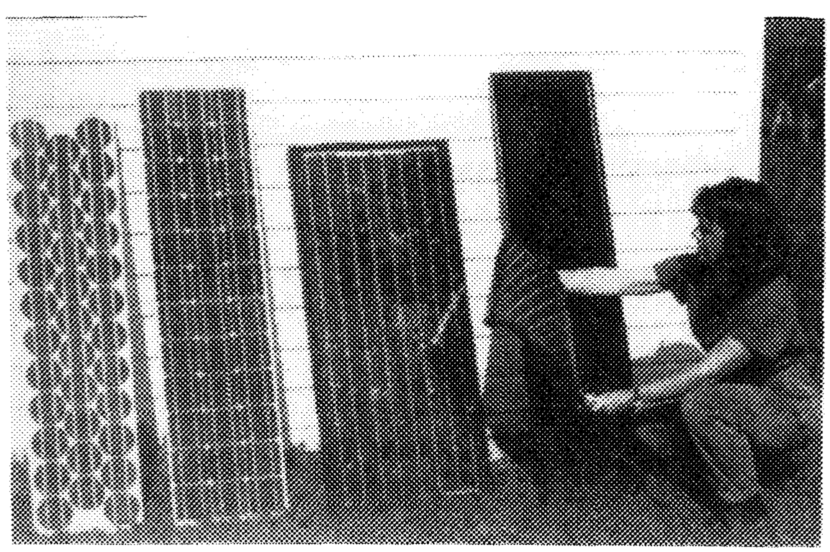


Figure 8

Block diagrams of pv system (a) D.C. standalone system - PV array connected directly to load (b) PV array connected to the load and battery via voltage regulator (c) system equipped with a voltage regulator, storage and inverter (d) system as in C and use of utility grid to supply backup power via a battery charger.

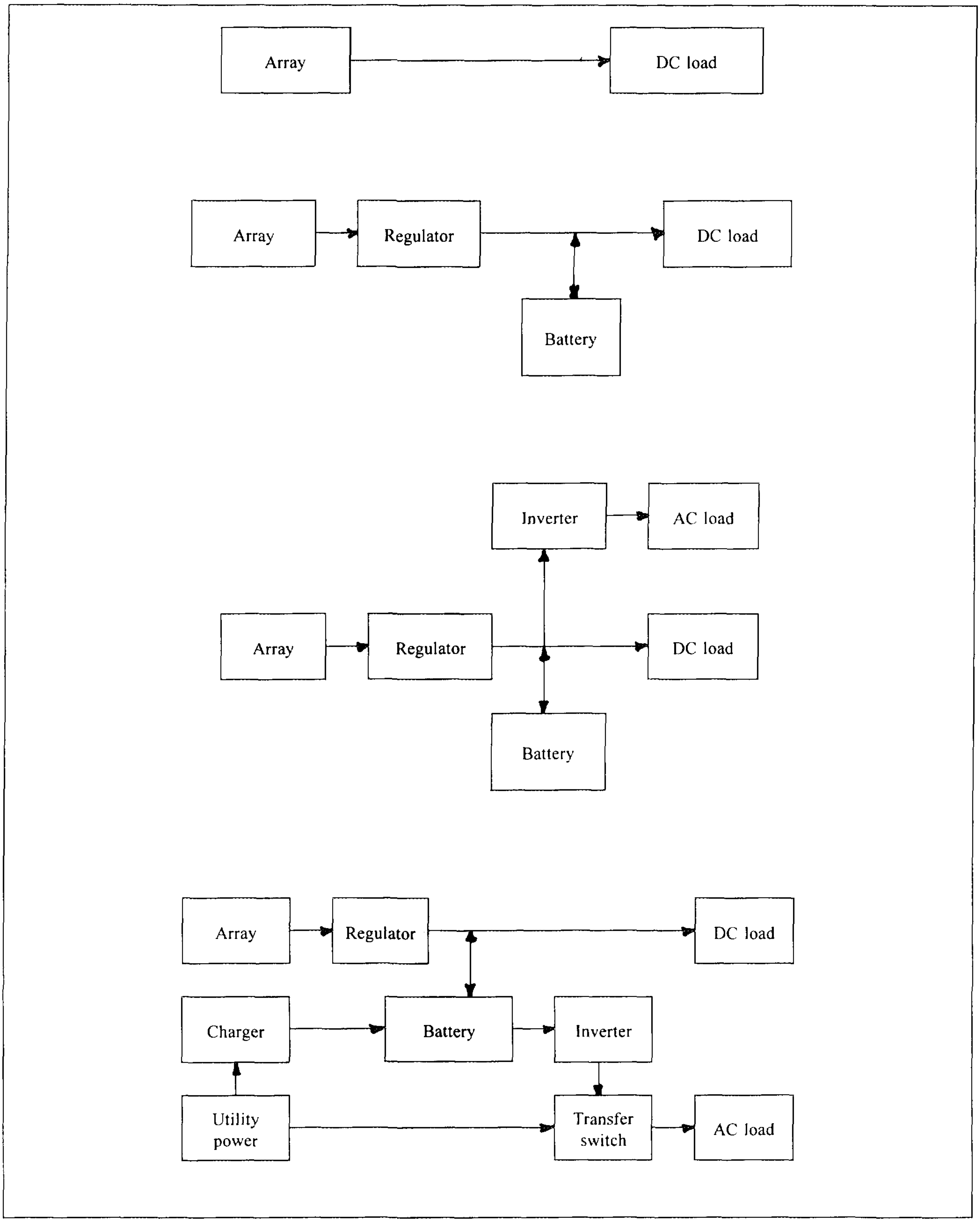


Figure 9
PV costs have dropped ten fold in twenty years.

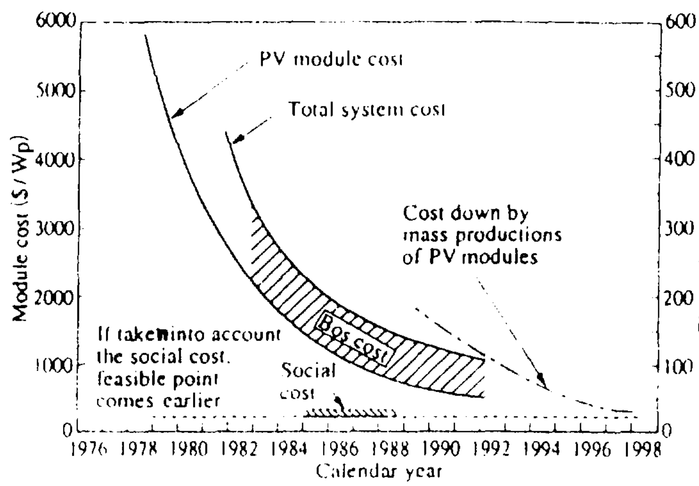


Figure 10
Scale up productions VS module cost.

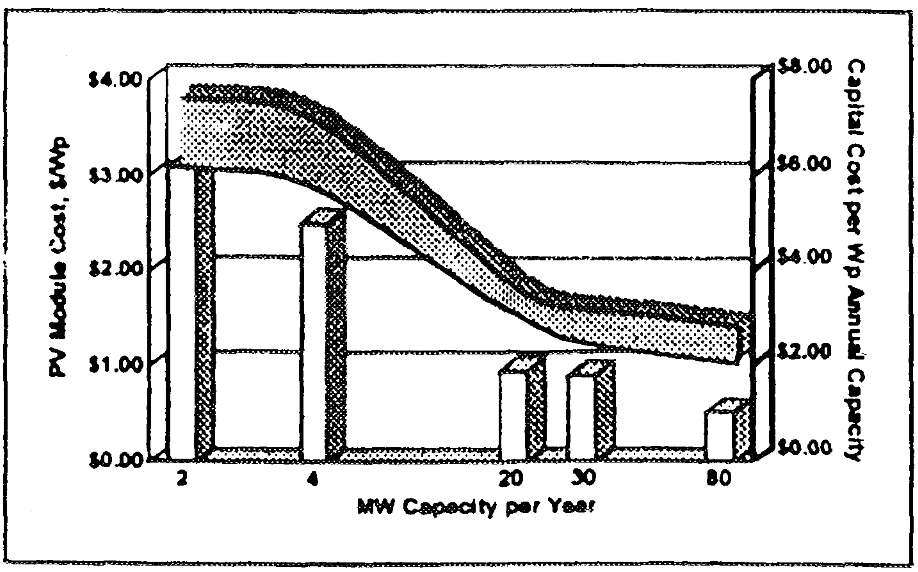


Figure 11
Module cost VS Market Growth.

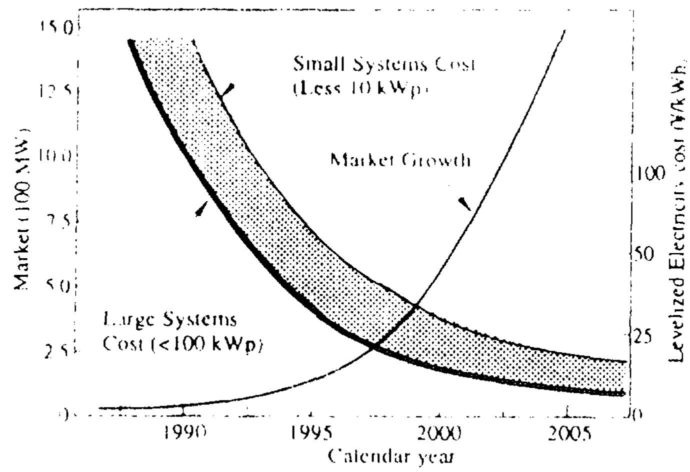


Figure 12
Actual costs of PV modules (without BOS) size of module varying from less than 1 KWp to more than 1 MWp.

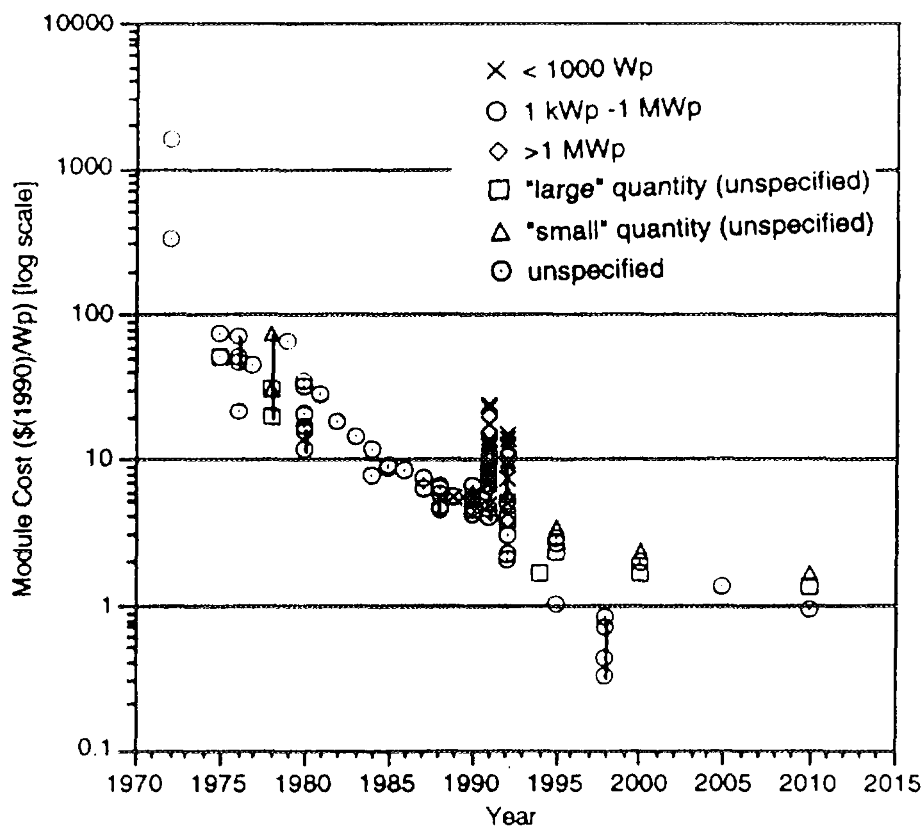


Figure 13

Cost reduction of PV modules based on various technologies indicating the scale of merit for a chosen technology.

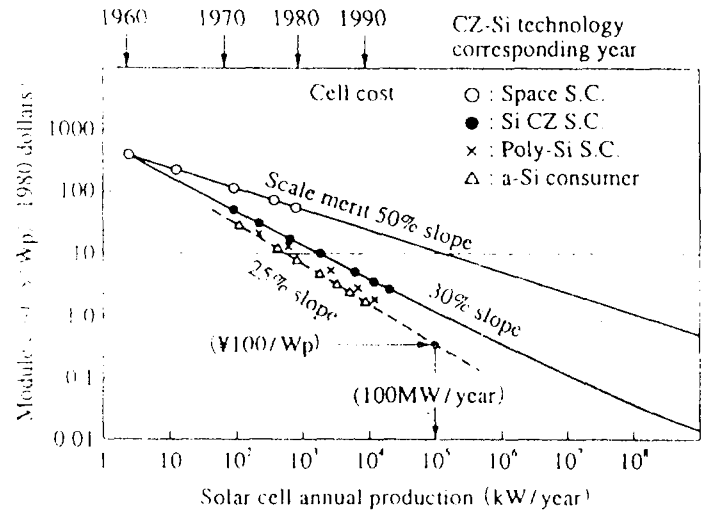


Figure 14

View of the 3.3 MW PV power station at Serre, Italy showing photovoltaic car parking in the foreground.

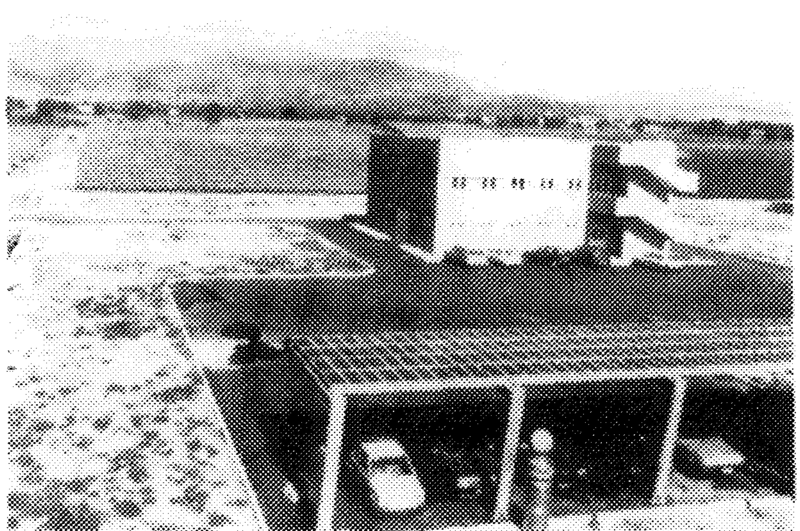


Figure 15

Schematic diagram showing the components of Solar House System (SHS):

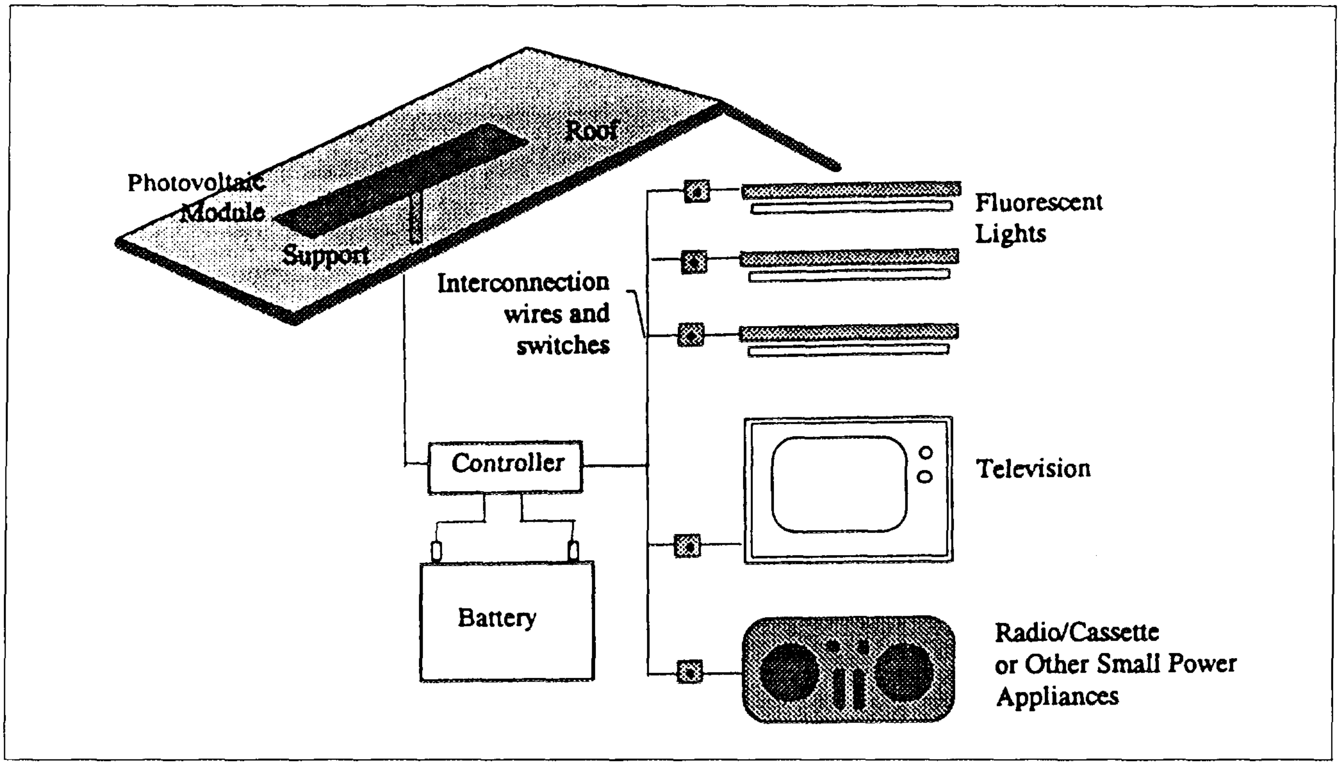


Figure 16

Picture of health clinic unit powered by PV with essential medical electronic gadgets, refrigerator to store life saving medicines and vaccines, lights, communication equipment, water pumps etc.

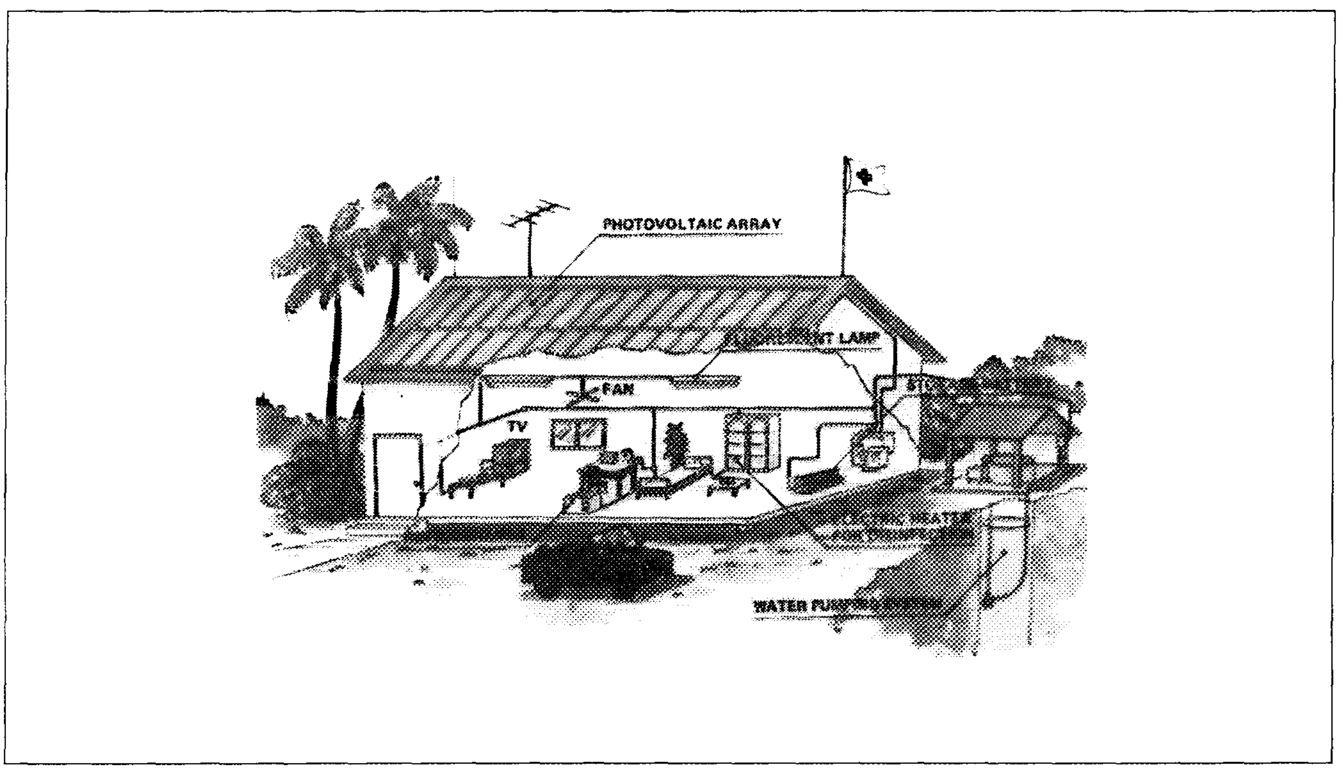
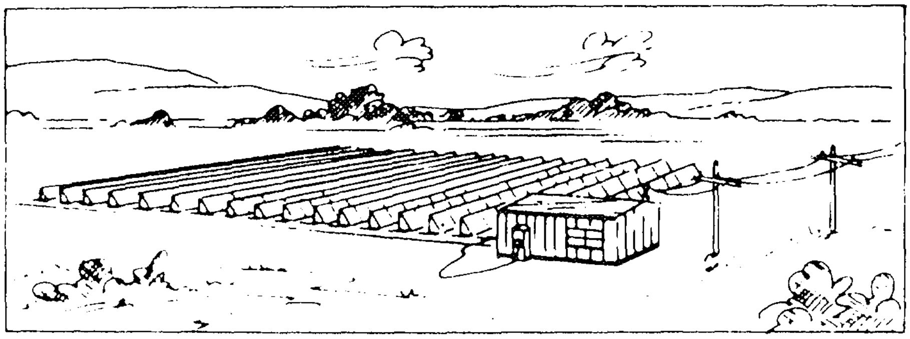


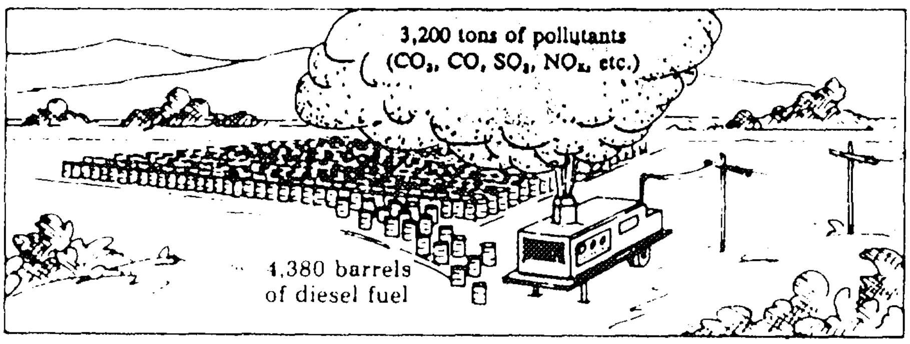
Figure 17

Comparison of photovoltaics with diesel electric for power generation in remote areas. Because of high price of diesel in developing countries, PV systems are competitive in many areas unlike diesel unit spewing 3200 tons of CO_2 and other pollutants, PV is a clean energy. Source: Paul Maycock.



60-kilowatt photovoltaic system
Lifetime: 20 years—131,400 kWh/yr
2,366 modules (97,000 cells)
½-acre array
20-year cost (1980 dollars)

Capital investment (land additional)	$600,000
Fuel	0
Total	$600,000



60-kilowatt diesel-electric generator
Lifetime: 20 years—131,400 kWh/yr
Diesel replacements: 10 @ $16,000 each
Fuel: 9,000 bbl (1,039 tons)
20-year cost (1980 dollars)

Capital investment	$160,000
Fuel (@ $3/gal)	$1,134,000
Total	$1,294,000

(operation and maintenance extra)

Figure 18

Photovoltaic - Diesel Hybrid System: Offers trade off of capital costs and operating costs for loads in the region 50 to 250 kwh / day.

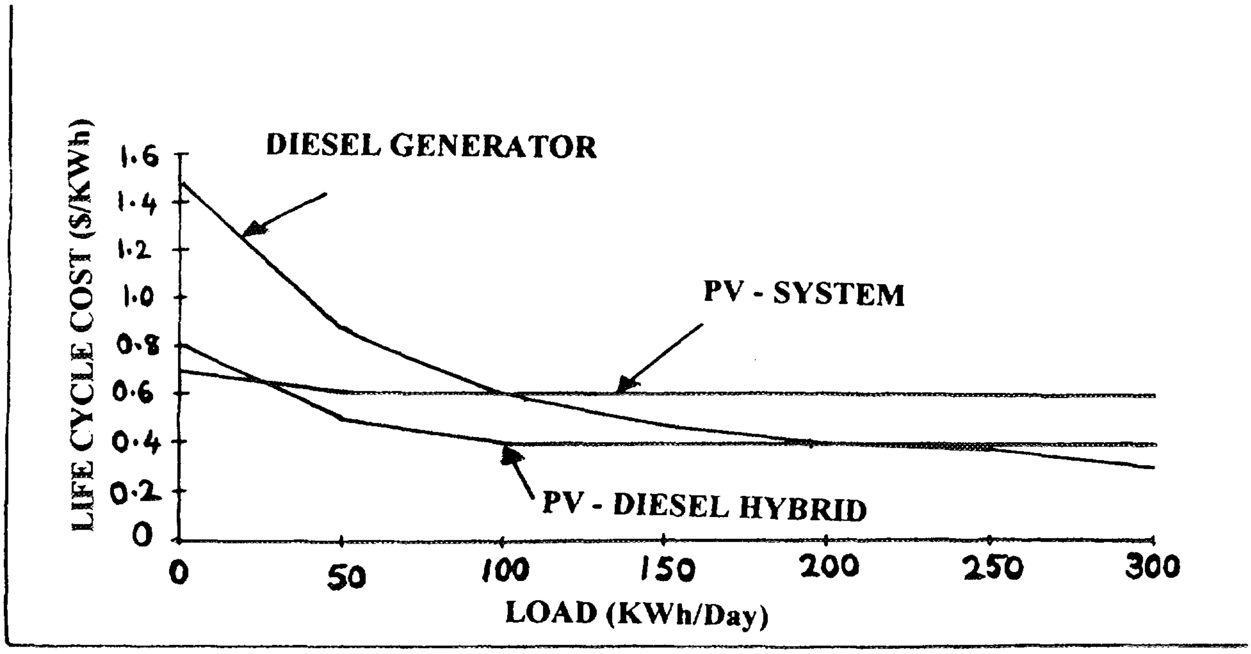


Figure 19

A Laboratory building at the ISPRA Research Institute in Germany with a 720 m² photovoltaic facade delivering a power of 13.166 kw.

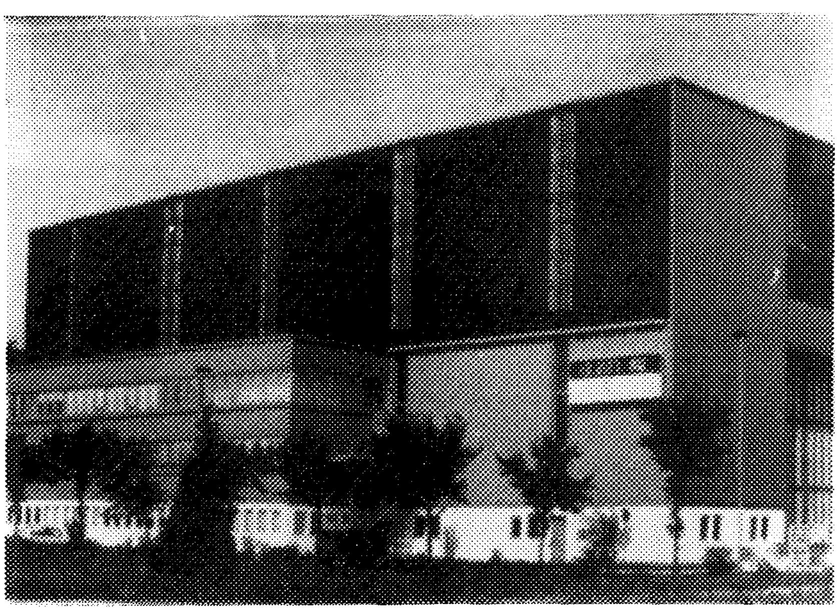


Figure 20

House with Solar Roof in Japan. Typically 2 to 3 kw photovoltaic powered roofs attracts 50% subsidy from Government.

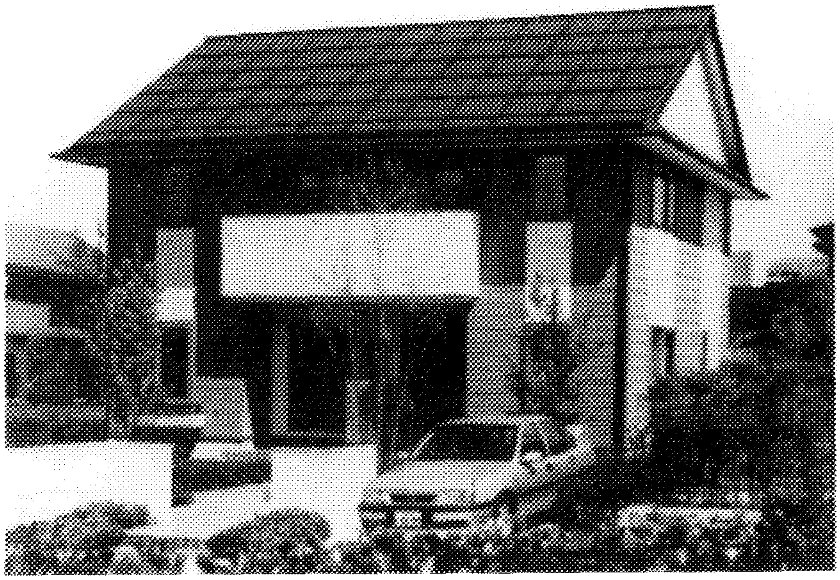


Figure 21

PV in buildings - some examples of roofing tiles and building walls in Japan also showing amorphous silicon solar cell roofing on typical Japanese home.

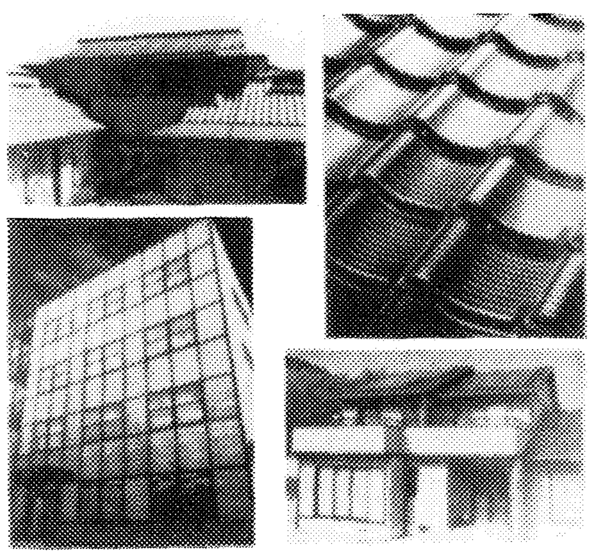


Figure 22
Picture showing several homes and office buildings with PV built in architecture in Europe & USA.

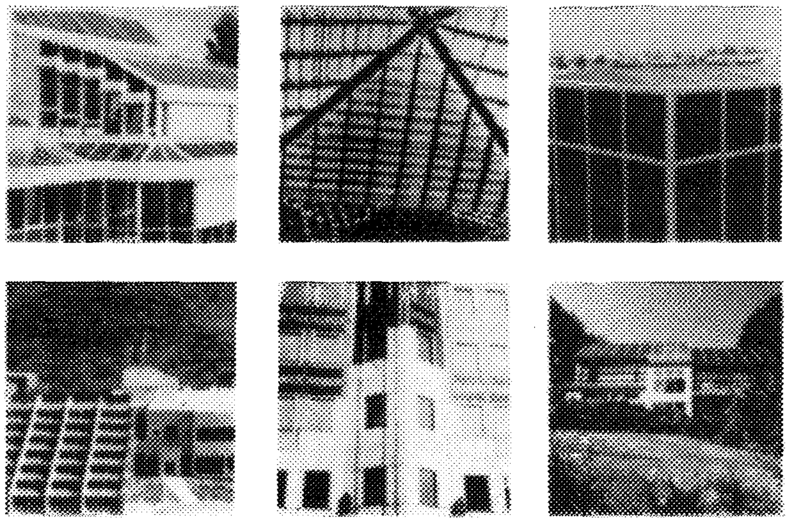


Figure 23
PV on highways. The first grid connected 100 KWp PV plant on sound barriers in Switzerland.

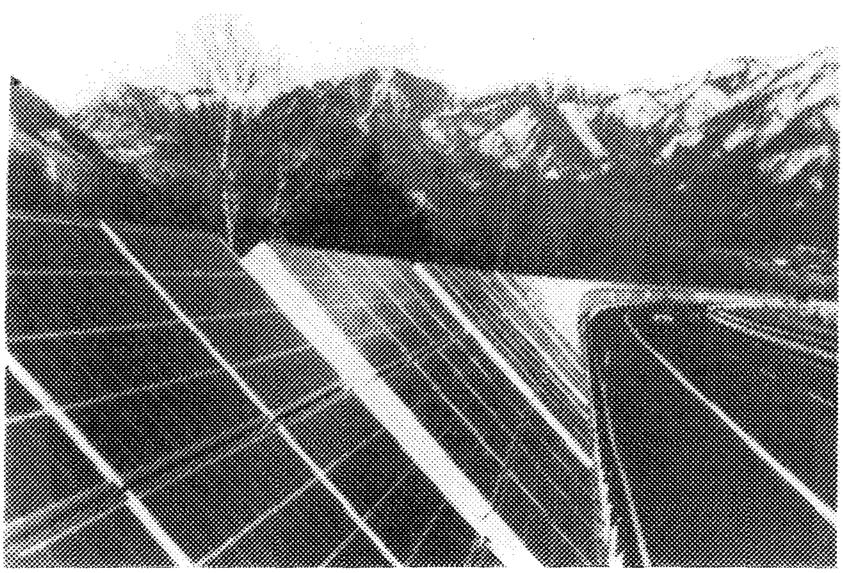


Figure 24

Picture showing prefabricated PV module systems for rooftop and can be installed very quickly.

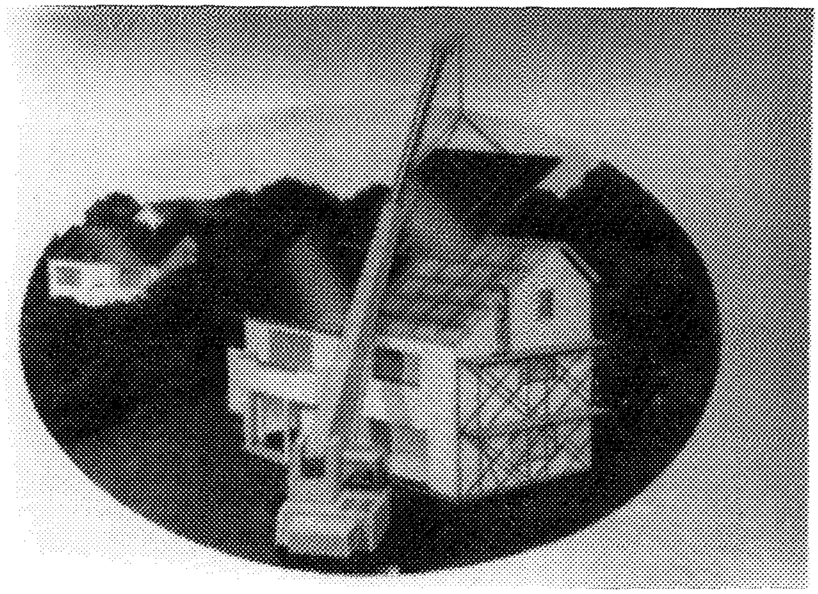


Figure 25

Plans are ahead in Japan and European countries to develop cars for short distances.

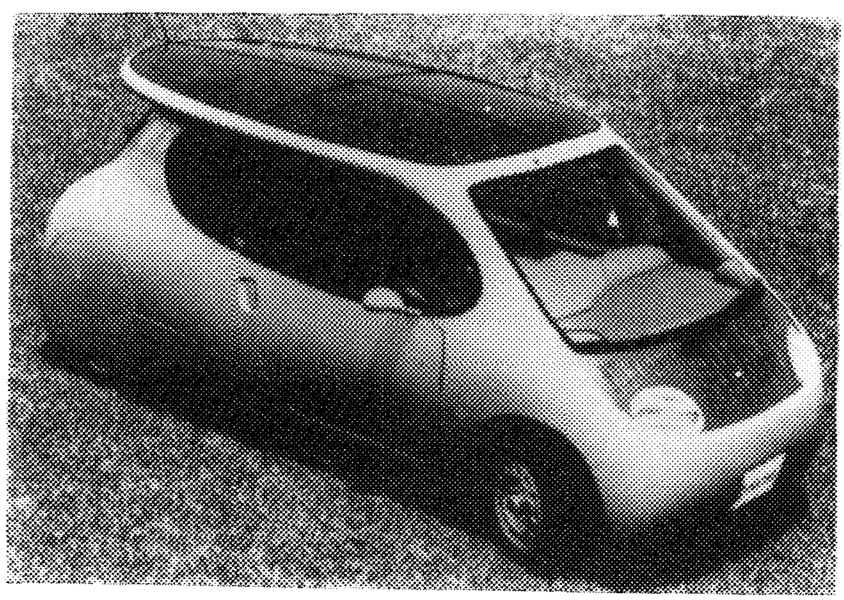


Figure 26

PV is part of a large hybrid power generation system including 234 PV modules, a 40 kw inverter, a diesel generator and wind turbines. This PV hybrid system is located in a village Xcalak, Mexico.

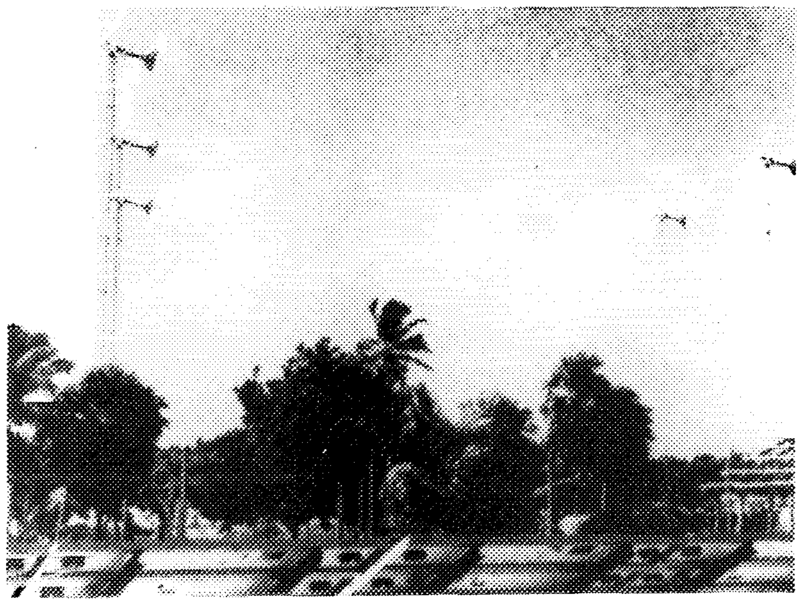


Figure 27

Interesting light effects produced inside a building by variation of distance between PV cells and amorphous silicon PV elements.

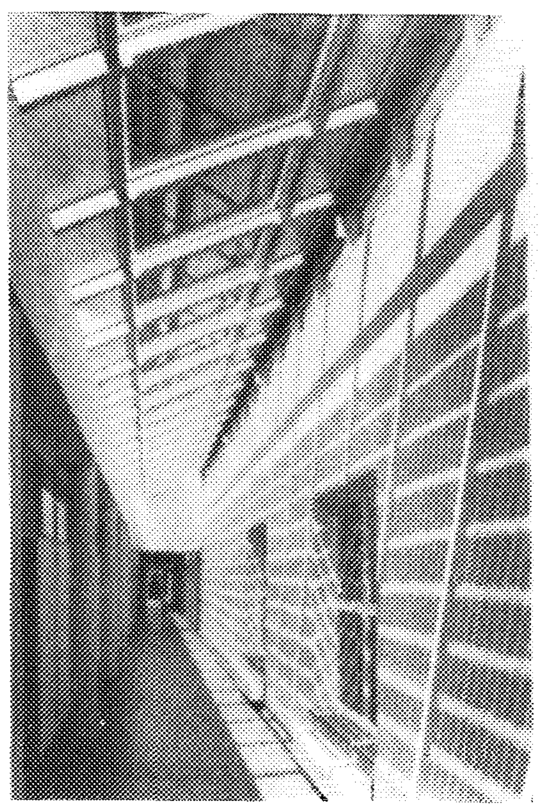


Figure 28

This couple is standing in front of their village's water pumping system powered by PV in Penjemu, Gambia. This is done in a program of luring city dwellers back to their old agriculture ways.

Figure 29

This picture demonstrates the versatility of PV systems in developing countries. Local mode of refrigerated transport used a PV powered refrigeration system mounted on a camel to keep the vaccines cool on the way to remote health clinic in Djibouti, Africa.

Figure 30

The country side community center: has a TV and VCR for entertainment, a direct reception TV system powered by PV and can receive the telecast directly from satellite and PV powered lights for organising training programmes and adult education. These kind of centers are established in India.

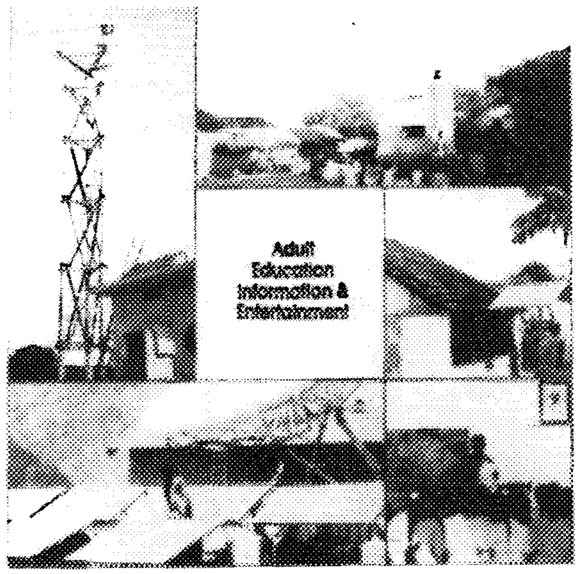


Figure 31

PV powered house of nomadic people in Mongolia.

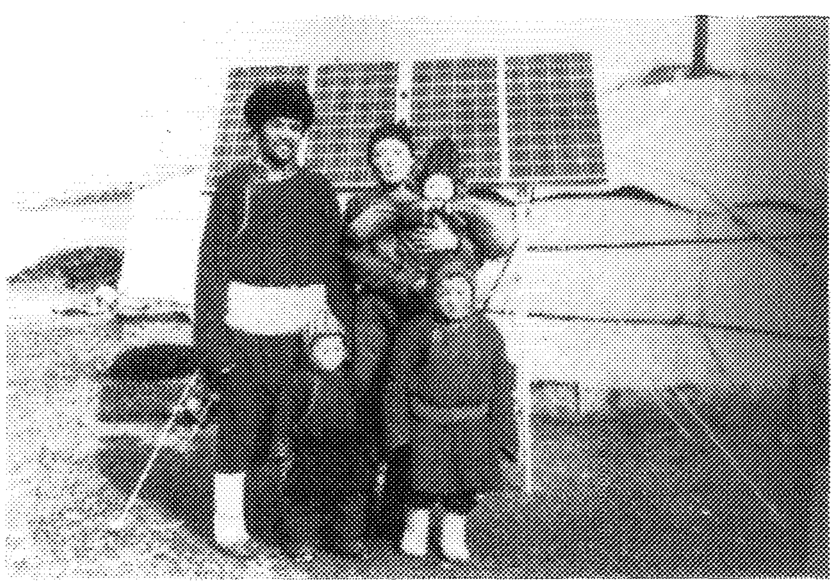


Figure 32

Installation of PV module system in rural area is easy. A Siriono Indian erects a PV array to power lights and charge batteries in an encampment in north eastern Bolivia.

Figure 33

Shown in picture is a street light and a SHS unit to cater the electrical needs of the house in a remote village in southern India.

Figure 34

Picture illustrates that PV powered light placed in best location for reading and provides better quality of light compared to kerosene or candles — SHS unit in Dominican Republic.

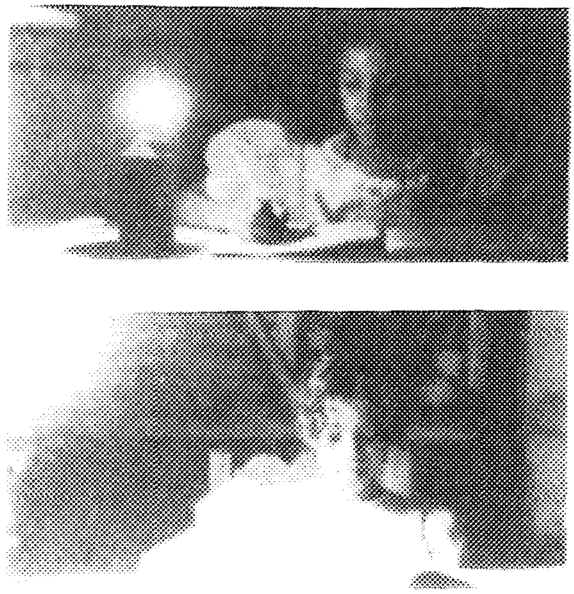
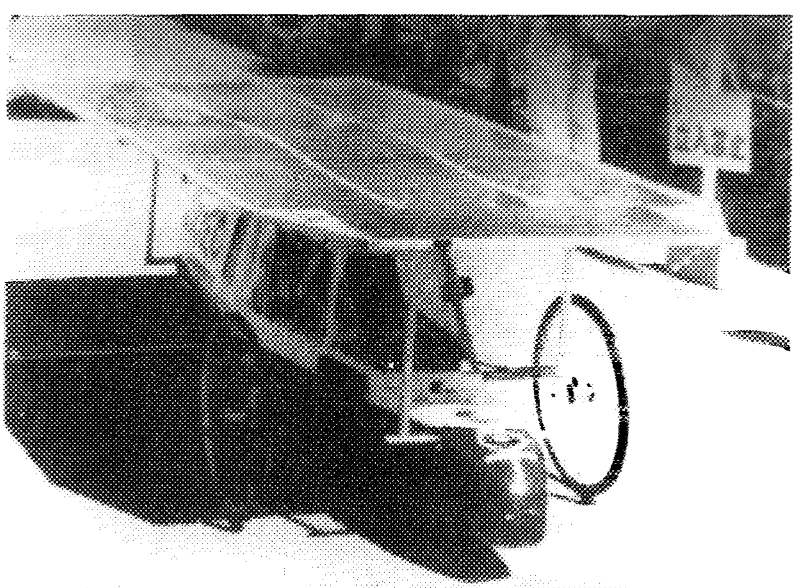


Figure 35

This PV powered vehicle participated in a car rally in Japan. With a few modifications. A PV powered three wheeler could be an ideal common man vehicle for 2 or 3 passengers in developing countries.



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Glossary

Ampere-hour (Amp-Hour or Ahr): A measure of electrical charge, equaling the quantity of electricity flowing in one hour past any point of a circuit. Battery Capacity is measured in amp-hours.

Array: A group of photovoltaic modules wired together to produce a specific amount of power. Array size can range from one to hundreds of modules, depending on how much power will be needed.

Balance of System (BOS): Parts of a photovoltaic system other than the photovoltaic array.

Cell (Photovoltaic): A semi-conductor device that converts light directly into de-electricity.

Charge Controller: A component of a photovoltaic system that controls the flow of current to and from the battery to protect the batteries from over-charge and over discharge. The charge controller may also indicate the system operational status.

Concentrator: A photovoltaic module which includes optical components, such as lenses, to direct and concentrate sunlight onto a solar cell of smaller area. Most concentrator arrays must directly face or track the sun.

Efficiency (of a solar cell or module): The ratio of electric energy produced to the amount of solar energy incident on the cell or module. Typical crystalline solar modules are about 10 per cent efficient - they convert about 10 per cent of the light energy they receive into electricity.

Grid-connected: A photovoltaic system that is connected to a centralized electrical power network.

Hybrid System: A power system consisting of two or more power generating subsystems (e.g. the combination of a wind turbine or diesel generator and a photovoltaic system).

Insolation: The amount of energy in sunlight reaching an area. Usually expressed in watts per square meter (W/m^2), but also expressed on a daily basis as watts per square meter per day ($W/m^2/day$).

Inverter: A device that converts direct current (dc) to alternating current (Acquisitions) electricity.

Irradiance: The solar power incident on a surface. Usually expressed in kilowatts per square meter. Irradiance multiplied by time equals insolation.

I-V Curve: The plot of the current versus voltage characteristics of a photovoltaic cell, module, or array. Three important points on the I-V curve are the open-circuit voltage, short-circuit current, and peak power operating point.

Kilowatt (kw): 1000 watts.

Kilowatt-hour (kwh): 1000 watt-hours. A typical residence in the United States consumes about 1000 kilowatt-hours each month at a price in the range of $0.6 to .15 per kilowatt-hour.

Life Cycle Cost (LCC) Analysis: A form of economic analysis to calculate the total expected costs of ownership over the life span of the system. LCC analysis allows a direct comparison of the costs of alternative energy systems, such as photovoltaics, fossil fuel generators, or extending utility power lines.

Load: In an electrical circuit, any device or appliance that uses power (such as a light bulb or water pump).

Module: A number of solar electric cells wired together to form a unit, usually in a sealed frame of convenient size for handling and assembling into arrays. Also called a "panel".

Peak Watts (WP): The maximum power (in watts) a solar array will produce on a clear, sunny day while the array is in full sunlight and operating at 25° C. Actual wattage at higher temperatures is usually somewhat lower.

Photovoltaic (PV) system: A complete set of interconnected components for converting sunlight into electricity by the photovoltaic process, including array, balance-of-system components, and the load.

Power: The rate at which energy is consumed or generated. Power is measured in watts or horsepower.

Silicon: A non-metallic element that, when specially treated, is sensitive to light and capable of transforming light into electricity. Silicon is the basic material of beach sand, and is the raw material used to manufacture most photovoltaic cells.

Standalone photovoltaic system: A solar electric system, commonly used in remote locations, that is not connected to the main electricity grid. Most standalone systems include some type of energy storage, such as batteries or pumped water.

Watt (W): A measure of electric power in a unit of time, equal to the rate of flow (amps) multiplied by the voltage of that flow (volts). One amp of current flowing at a potential of one volt produces one watt of power.

Watt-hour (Wh): A measure of electrical energy equal to the electrical power multiplied by the length of time (hours) the power is applied.

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B. RECENT ACHIEVEMENTS — INDUSTRIAL APPLICATIONS

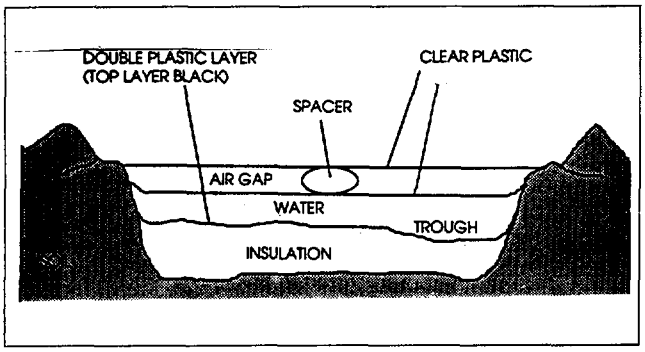
Solar puddle

A new water pasteurization technique

The lack of clean drinking water is a major health problem in the developing world. To reduce this health risk, ways of producing clean water at an affordable cost are needed, and people need to be educated about germs and sanitation, lest they accidentally recontaminate their clean drinking water.

If water is heated to 149° F (65° C) for about six minutes, all the germs, viruses and parasites that cause disease in humans, including cholera and hepatitis A and B, are killed. This process called pasteurization, is not the only way to decontaminate drinking water, but it is particularly easy to scale down.

The new device called a solar puddle, is essentially a puddle in a greenhouse. One form of the solar puddle is sketched in the figure, though many variations are possible, and described below.



The test device was "a family-size" unit, about 3 1/2 feet by 3 1/2 feet, but the puddle could be made larger or smaller. The pit is filled with 2 to 4 inches of solid insulation, using for instance wadded paper. Straw, grass, leaves or twigs could also be used. This layer of insulation should be made flat, except for a low spot in one corner of the puddle. A layer of clear plastic and then a layer of black plastic are placed over the insulation with the edges of the plastic extending up and out of the pit. Two layers are used in case one develops a small leak. It is possible to use inexpensive polyethylene, though special UV stabilized plastic would last longer. Some water was poured and the insulation flattened out so that the water depth is even to within about 1/2 inch throughout the puddle, except in the trough which should be about 1 inch deeper than the rest. More water is poured so that the average depth is 1 to 3 inches depending on how much sunshine is expected. A pasteurization indicator should go in this trough, since this is where the coolest water will collect. A layer of clear plastic is placed over the water, again with the edges extending beyond the edges of the pit. Form an insulating air gap by putting one or more spacers on top of the third layer of plastic (large wads of paper will do) and putting down a fourth layer of plastic, which must also be clear. The thickness of the air gap should be 2 inches or more. Dirt or rocks are piled on the edges of the plastic sheets to hold them down. The puddle is drained by siphoning the water out, placing the siphon in the trough and holding it down by a rock or weight. If the bottom of the puddle is flat, well over 90 per cent of the water can be siphoned out.

Once the puddle is built it would be used by adding water each day, either by folding back the top 2 layers of plastic in one corner and adding water by bucket, or by using a fill siphon. The fill siphon should not be the same siphon that is used to drain the puddle, as the fill siphon is recontaminated each day, while the drain siphon must remain clean. Once in place the drain siphon should be left for the life of the puddle.

The only expensive materials used to make the puddle are a pasteurization indicator (about $2), a siphon tube (about $1), and four sheets of plastic (about $2 for the size tested).

Condensation in the top layer of plastic does not seem to be a problem, though if one gets a lot of condensation the top layer should be pulled back to let the condensation evaporate. Small holes in the top layers do not make much difference. The device works in wind, or if the bottom insulation is damp. The water temperature is uniform throughout the puddle to within 2° F.

After some months the top plastic layers can weaken under the combined effects of sun and heat and need to be replaced, but this can be minimized by avoiding hot spots such as places that are exposed to the sun but not cooled by the water. Another option would be to use a grade of plastic that is more resistant to sunlight.

There are many variations of the solar puddle. Adding a second insulating layer of air makes the device work even better, though this adds the cost of an extra layer of plastic. As mentioned, the device can cover a larger or smaller area if more or less water is desired. One could make a water heater by roughly tripling the amount of water so that the maximum temperature was only 120° F or so, and this water would stay warm well into the evening hours. The solar puddle could possibly cook foods like rice during an emergency. (Source: *Solar Cookers International Newsletter*, March 1995)

Solar fridges

Bharat Heavy Electricals Limited (BHEL), India, has developed a solar photovoltaic powered refrigerator which will facilitate storing vaccine at health centres located in remote areas. The cost of refrigeration will be much less than those powered by diesel/kerosene.

Application of photovoltaic power for vaccine refrigeration is significant in view of the dependence of the WHO immunization programme on one crucial factor, the cold chain. Under the cold chain system, vaccine has to be compulsorily under refrigeration from the point of manufacture up to the end user health centres.

Developed by BHEL's corporate research and development, the first such refrigerator installed at Kendriya Swasthya Bhawan (CGHS Hospital) in Negumpet, Hyderabad (India) is working satisfactorily.

The solar refrigerator has an array of PV which charges a bank of batteries through a battery charge controller, ensuring that the battery (typically 24 v or 12 v) drives a DC motor, which is directly coupled to a compressor. The motor/compressor assembly comes as a single hermetically sealed unit as in conventional refrigerators. (Source: *NAM S&T Newsletter*)

Selective-surface coating developed

Within six months, manufacturers of solar thermal absorber plates will be able to use a new selective-surface coating that has better performance and is more stable at high temperatures than the widely used black chrome. The new four-layer coating is being developed for high-temperature, flat-plate applications under a cooperative research and development agreement with Sandia National Laboratory, Albuquerque, NM, USA, and Energy Laboratories Jacksonville, Florida, USA.

The coating process starts with a substrate, usually copper. The first step is to activate the copper surface. After that, the surface is electroplated with electrically enhanced nickel. Then a binary-compound crystal is grown to create upward-pointing dendrites or bumps that under an electron microscope resemble a pine forest. This appearance of the crystals of undisclosed materials gives the process its name of "Black Forest". The final layer is an amorphous, transparent glassy material of nanometer thickness that fills in the spaces between the binary-compound "pine trees". This smooth top surface is applied through an evaporation process like cladding quartz and becomes an oxide barrier freezing the dendrites.

Absorptivity of the Black Forest is 0.98 in the laboratory and is expected to be 0.96-0.97 in production. Epsilon (emissivity) of the surface of a commercial product using Black Forest is anticipated to be the low range of 0.10 to 0.12, with better ratings demonstrated in laboratory runs. The coated copper product should be ready for commercial introduction in six months. Energy Laboratories is working on a prototype coating line for copper strips to be fabricated into solar absorber plates by solar-panel manufacturers/customers.

The patent-pending process uses no chrome or other toxins or carcinogens. The materials used in the process are safe enough to allow for landfill disposal. Laboratory runs are being made on 120 millimetre-wide (about 4.75 inch) copper coil, but the manufacturing process is expected to allow eventually for 24 inch coils to be coated to provide the widest possible use by absorber-plate manufacturers.

Sandia tested the coating at 300° C for 400 hours and found no property changes. Energy Laboratories has also explained the coating to concentrator-collector manufacturers. (Source: *The Solar Letter*, 22 March 1996)

Wristwatch with photovoltaic power generation

Citizen Watch Co. Ltd. has started to market eight new models of the Attesa line. The new Attesa is equipped with the Echo-Drive, the next-generation quartz power source, and does not require battery replacement. Six months of continuous operation is guaranteed when fully charged even if the watch is kept in a dark place.

A wristwatch with a built-in solar-power system and requiring no battery replacement was commercialized for the first time in 1986. It mounted a solar module that converts even a feeble beam of light penetrating through the dial plate into electricity.

The new Attesa series watches use various forms of light energy such as solar energy and room light energy which provide an effectively limitless supply. As the solar-powered Echo-Drive equipped in the new models adopts the titanium-lithium ion secondary cell, the Echo-Drive greatly enhances charge/discharge efficiency. There is no need to charge the battery.

The standard models can operate continuously up to six months when fully charged, while the chronograph + alarm type can run for 2.6 months and the multihand calendar type, for 2 months. The calendar type allows display of the day, date and the 24-hour time.

The "quick start" function allows immediate operation when the watch is exposed to light even if the power is totally down. The "rest alarm" reminds the Attesa owner to reset the alarm time after it has stopped temporarily, while another special feature "low power alarm" warns the user when the remaining power is low.

Titanium used in Attesa watch cases and bracelets is treated by means of multi-layer coating to render it twice sturdier than ordinary titanium. Thus, the surface is resistant to damage from fingerprints. The case and wristband are made of a low allergy specification titanium material that is kind to the skin, all assembled into a monoblock assembly.

Further information from: Citizen Watch Co. Ltd., Corporate Communications Division, 2-1-1, Nishishinjuku, Shinjuku-ku, Tokyo 163-04. Tel.: +81-3-3342-1232; Fax: +81-3-3342-1220. (Source: *Jetro*, March 1996)

Photocomm wins park service solar contract for Olympics outdoor lighting

National Park Service (NPS) has awarded Photocomm Inc., Scottsdale, Arizona, a contract to provide solar electric outdoor lighting at the Martin Luther King Memorial in Atlanta, Georgia, USA. The NPS project will represent what is believed to be the largest concentration of solar electric outdoor lighting in North America.

The project will consist of 65 custom-designed lighting structures, each with two high-efficiency lamp fixtures, using proprietary Photocomm technology used reliably in thousands of installations world-wide. The firm is the United States' largest publicly-owned manufacturer and marketer of wireless solar electric power systems.

According to the company, the project will showcase the environmental benefits and cost-effectiveness of solar lighting to the international audience visiting Atlanta. This contract indicates the progress made in developing the outdoor lighting market. (Source: *The Solar Letter*, 22 March 1996)

Heliocol finishes Olympics pools system

Heliocol Corp., Clearwater, Florida, completed installation on a solar pool-heating system spanning more than 10,000 square feet on the Aquatic Center at Georgia Institute of Technology, where the 1996 Summer Olympics swimming and diving matches will be held. Because of the natatorium's unique type of standing seam, rib-roofing system, no roof penetrations were used to mount the panels. A special roof clip was used on most of the panels for flush mounting; for 72 HC-50 panels, special aluminium racks were built. The 50-metre competition pool contains one million gallons of water, which will be pumped through Heliocol collectors at 600 gallons per minute by a 40-horsepower, three-phase pump. Pool water must be kept within a margin of 1° during Olympic competition. It is estimated that the system will save $12,000 per year in utility bills. (Source: *The Solar Letter*, 12 April 1996)

Chemical energy generation from solar energy

Professor Y. Tamaura and his team at the Research Centre for Carbon Recycling and Utilization, Tokyo Institute of Technology, have succeeded in generating carbon monoxide (CO) and hydrogen from a mixture of magnetite and coal powder by concentrated solar irradiation, in joint research with the Paul Scherrer Institute of

Switzerland. With the concentrated solar energy by a parabolic concentrator, the two materials undergo an endothermal reaction in a solar furnace at a high temperature of about 1,200° C to generate wustite (iron oxide), CO and hydrogen. Experiments at the Paul Scherrer Institute confirmed that the conversion of solar energy into chemical energy is possible with an efficiency near 50 per cent.

While burning of coals produces carbon dioxide and is said to cause global warming, the newly developed technique allows carbon dioxide reduction corresponding to the use of the solar energy. As the final product is methanol which is easy to transport, if the energy can be generated in desert areas and transported through ships in the future, this technique could help solve problems with the global environment and energy resources.

Magnetite is a black material absorbing sunlight with a wide range of wavelengths. Magnetite powder and coal powder were mixed at the ratio of 1:1, and the mixed sample was encapsulated in an octagonal rotating device in a solar furnace so that the concentrated solar energy was irradiated on one surface of each sample. The samples were rotated and the reaction time was varied by opening or closing the shutter to investigate. The reaction was not observed when the furnace temperature was less than 1,100° C, but a reaction started when the irradiation time is between 0.8 and 1 second, generating wustite and CO. The reaction started in 0.8 second after a shutter was opened and completed in only 0.2 second after absorbing 26.8 joules of heat. The rate of conversion from solar energy was as high as 47.6 per cent.

However, the theoretical conversion rate is higher when the solar light is condensed to 1,000 times, so there is room for improvement in this technique. The next target is the construction of a demonstration plant in a desert area.

More information is available from: Tokyo Institute of Technology, Research Centre for Carbon Recycling and Utilization, 2-12-1, O-okayama, Meguro-ku, Tokyo 305, Japan. Fax: +81-3-5734-3436. (Source: *JETRO*, March 1996)

Low cost solar dryer

A new type of solar dryer which can store heat in a special rockbed unit to facilitate drying even during the night has been developed, fabricated and installed at the Energy Research Centre, Thiruvananthapuram, Kerala, India. It consists of a solar collector, a rockbed heat storage unit, a drying chamber and a chimney.

Part of the heat collected by the solar collector is used to heat rock pebbles filled in the energy storage unit. The heated pebbles are used after sunset for drying operations, unlike a normal solar dryer whose operating hours are restricted to the period during which it receives solar radiation.

The elongated, rectangular air collector is covered with black polythene sheets on the sides and bottom. An opening in the front allows air to enter and travel along the length inside the air collector, becoming heated in the process. The air enters the rockbed at the other end of the collector. The rockbed is essentially a wooden box filled with rock pebbles, which help to insulate the heat inside. Above the box is a dryer where the products to be dried are kept in a tray made of wire meshes. The hot air from the rockbed travels through the products kept in the dryer and leaves the solar dryer through a chimney above.

The dryer is easy to fabricate with locally available materials, needs little expertise to make and is inexpensive. It is suitable for drying agricultural products such as paddy, cereals and coconut. (Source: *Tech Monitor*, March-April 1996)

Fuji solar panel cheaper to make, easier to install, but less efficient

Though less efficient than traditional solar-battery panels, a new 50 micron-thick solar panel from Fuji Electric is easier to install and less costly, according to the company.

The amorphous silicon panel consists of electrodes attached to a film base made of resin topped with two layers of amorphous silicon. Transparent electrodes are then fixed to the finished surface of the panel. The panel is 400 centimetres (cm) long, 80 cm wide and 50 microns, or 50-millionths of a metre thick. The silicon layer is 0.5 micron thick, or 0.0017 per cent the thickness of more traditional silicon panels.

The company initially found the cell's efficiency in transforming light into electricity at a low 6.8 per cent, with a 20 watt output. Subsequent tests of smaller panels increased the photovoltaic efficiency to 11 per cent.

The company will be conducting verification tests in conjunction with Misawa Homes Co. A panel with an 8.5 per cent efficiency and 27 watt output is possible later this year, the company stated.

Crystal silicon-based solar panels have run into some problems in being marketed to residential homes. The large panels require a foundation, and are heavy, discouraging homeowners from installing them. Canon Inc. has developed a similar type of panel, with an 8 per cent efficiency rate. Canon may begin to market the product incorporated into roofing material in the near future. (Source: *International Solar Energy Intelligence Report*, 15 April 1996)

Australian research team devises solar materials-processing concentrator

An Australian research team has developed a solar-power concentrator for processing materials such as polyvinyl chloride, polyethylene, polypropylene and polystyrene. Developed at the Queensland University of Technology (QUT), the solar concentrator complements the existing power beam and power jet technologies, such as laser-beam, abrasive-water jet and microwave induced plasma jet systems.

The company say it is a new approach to product manufacturing, where solar energy is harnessed by a 600 mm diameter parabolic mirror used to focus the rays of the sun. The sun rays, in turn, are reflected from a secondary mirror and directed through a lens system to obtain a power beam. The 250 watt facility concentrates solar energy and delivers a power beam density on a 2 mm diameter spot.

There was enough power supplied to process relatively low-melting temperature materials such as polymers, polymer matrix composites and solders. The power from the concentrator could be used for cutting, joining, curing and heat treatment manufacturing operations.

The concentrator will be equipped with a fully automated sun-tracking capability and interfaced with a six-axis robot to enhance the manipulation capability of the power beam. This will enhance the flexibility of the system and allow processing of components with intricate geometric shapes. The QUT team is seeking collaborative association for continued research or company interest in developing and marketing the equipment. (Source: *The Solar Letter*, 12 April 1996)

German architect designs award-winning, solar-heated terrace houses

Solar-house architect Rolf Disch of Freiburg has designed and built prize-winning terrace houses in environmentally friendly wood, using solar power, and at a low cost per square metre. The concept reportedly won an award from the financial institution Schwaebisch-Hall Building Savings Bank.

The eco-concept is apparent even at ground-breaking. The houses, each offering 130 square metres of space, are conical in shape, which increases the surface area facing south that is much wider than the cold north side. From this, the sun's natural warming is increased.

On the sunny side, solar collectors are integrated into roof extensions or overhangs over the terraces and balconies. Solar energy heats a 200 litre water boiler. Additional automatic water heating (from gas) is only needed when the pre-selected desired temperature cannot be reached. The house entrance is on the small north side as well as steps to a storage cellar that is reachable only from the outside.

The houses are apparently expandable. Glass walls can be linked to the solar roof-overhangs, thus adding a "winter garden". The houses can also be constructed with complete solar installations, and are especially well-insulated and airtight. The houses are reportedly equipped with air-exchange systems, ensuring circulation of fresh air while saving on heat loss. (Source: *The Solar Letter*, 12 April 1996)

Solar-powered communication stations

Maintenance staff of the communication network posted at remote repeater stations face many problems in manning such stations. To overcome these problems, the Western Railways of the Indian Railway system have established solar-powered communication systems at remote locations switching over from conventional electric power to solar power, at remote repeater stations. This has given the Western Railway a twofold advantage: the network does not require staff to handle it, and in financial terms, it has resulted in a saving of Rs.204,000 in the annual expenditure at three such stations. The system in operation till recently at such remote stations relied on conventional electric power, lead acid batteries and diesel generation sets. The solar power plants were supplied by Tata BP Solar, Bangalore (India). (Source: *Tech Monitor*, May-June 1996)

Solar industry champion pushes practical rooftop applications

Elegant technology must be reduced to practical systems that can be used by the average person, according to a solar industry engineer.

The engineer has been a pioneer in the development and the manufacture of thin-film, polycrystalline silicon solar cells, which are low-cost solar cells with great potential.

His company has developed thin-film polycrystalline silicon solar cells. They decided to identify the obstacles to progress, after being asked repeatedly how to buy and use rooftop solar power systems, which can produce electricity better and cheaper than ever.

There have been gains in efficiency in converting sunlight to electricity. But rooftop systems are too difficult to acquire, to integrate with the electricity grid, and it is too difficult to measure the energy produced.

Contact: Debby Gehman, Inge Parlo, Dagastine Public Relations, (518) 786-6488. (Source: *International Solar Energy Intelligence Report*, 27 May 1996)

Patent going to low-cost solar generator using ocean storage

A low-cost solar energy generator that captures and stores solar energy on the surface layer of the ocean has received a US patent. Ocean Thermal Enterprises Inc. (OTE) of Oakton, VA, received the patent for the generator that runs 24 hours a day, 365 days a year.

The generator is versatile, because it could produce as few as four or up to 16 megawatts of electricity in a single module. That range of capability makes it available to one-third of the world's population, OTE said in a recent public statement.

OTE's is the first design said to be economically viable. The Department of Energy has been successfully operating a solar heater to generate electricity in Hawaii since 1981. The new design is favourably competitive with conventional fossil-fuel heaters, but has a longer life, because it consumes no fossil fuel, according to the company.

The OTE generator is modular. Its small size makes it attractive for large resort hotels and companies using substantial commercial power. Excellent sites for OTE plants are off Florida, off the coast from Brazil through Mexico, Africa, the Caribbean, India, Indonesia, the Philippines, Oman and Taiwan.

Deregulation and state-of-the-art transmission technologies are expected to open large markets in temperate latitudes, according to OTE's statement. Also, the OTE plant can be configured to produce desalinated water at an effective rate of \$1.12 to \$3.13 per thousand gallons, making it accessible in tropical zones, where fresh water is often scarce and expensive. The process is large-scale flash distillation, which condenses and collects evaporated water.

Contact: Linda Welch, OTE, Oakton, VA; (703) 359-6920. (Source: *International Solar Energy Intelligence Report*, 27 May 1996)

Solar powered equipment for Canary Islands

Tideland Signal Ltd. recently won a second contract to supply solar-powered equipment for a project in the Canary Islands.

The company supplied the island's first solar-powered buoys in 1992 when they were used to mark submerged telephone cables. Because of their performance and reliability, the major Spanish utility company, Fomento de Construcciones y Contrates (FCC), chose Tideland lanterns and buoys, this time to mark an underwater pipeline off-shore from Las Palmas on Gran Canaria.

The point where the pipeline enters the sea is indicated by a Tideland ML-155 lantern, mounted on a 6 metre high steel pedestal with a special yellow X topmark. Two SB 2.5M skirt-type marker buoys, each with an ML-140 lantern, mark the path of the pipeline. All the lanterns have a range of five nautical miles under normal atmospheric conditions.

The ML-155 lantern is fitted with a TF-3B Micro-Power multi-code flasher/lampchanger. Solar power for the pedestal lantern is provided by SSV-6L solar module assemblies, while the buoy lights are powered by SSVB-12LU units. The solar arrays gather and store energy during the day, even in very low light conditions, to power the lantern at night. (Source: *The Dock & Harbour Authority*)

Sunlight collection and transmission system

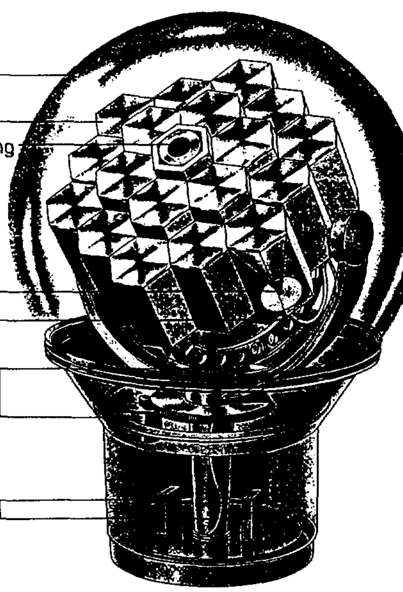
LAFORET Engineering Co. Ltd., a sunlight collection and transmission system manufacturing company established jointly by Mori Building Co. Ltd. and Asahi Glass Co. Ltd., has marketed a sunlight collection and transfer system "Twelve-Eyed Sunflower" for use by general households.

A special type of lens and an optical fibre cable are used to induce sunlight into rooms with poor illumination or into cellars. Compared with the conventional 18-eyed type system, a larger lens is used whose light collection area is increased by roughly 20 per cent, while the diameter of the optical fibre has been increased from 0.8 mm to 1.0 mm, by which the volume of collectable light has been increased by about 40 per cent.

With this system, a built-in microcomputer computes the sun's position from the year, month, day and time and directs the lens toward the sun, while a light sensor performs angular fine adjustment each minute to track the sun accurately. Further, the sunlight is collected with optical lenses and transmitted to the rooms.

Two optical fibre cables are used, each of which supplies light equivalent to a 100 w incandescent lamp. When the sunlight passes through the Fresnel lens, the light is divided into ultraviolet, visible, near infrared, and far infrared waves due to the difference in the index of refraction, so by setting the optical fibre input terminal plane to the domain concentrating the visible light, it is possible to input only visible light, while virtually all other wavelength components shorter than that of visible light and longer than that of visible light are cut off to prevent rooms of furniture from being burnt and overheating. The sunlight also has other applications, such as tanning the body and culturing decorative plants.

The optical fibre cable is available in lengths of 10 metres, 15 metres and 20 metres. The price has been lowered by using a lens commonly used for various purposes and by decreasing the total volume of the optical fibre cable.



Further information can be obtained from: LAFORET Engineering Co. Ltd., Public Relations Dept., 2-7-12, Bakuro-cho, Nihonbashi, Chuo-ku, Tokyo 103. Tel.: +81-3-5640-6511; Fax: +81-3-5640-6517. (Source: *JETRO*, June 1996)

Around the world on solar power

A British woman is planning the first round-the-world voyage by a solar-powered boat.

Karen Howarth will spend 205 days next year on her 45 ft catamaran circumnavigating the world via the Panama and Suez canals. She will not use sails. The boat will be powered only by energy collected from the sun.

Howarth's boat, the Global Green Cat, will carry 58 sq metres of solar panels—enough to power eight electric motors at a top speed of 10 knots (11.5 mph).

Daily reports of her progress during the 26,000 mile voyage will be posted on the Internet, and Howarth, 32, a television director, plans a satellite link to transmit television pictures from the ocean. She will carry out experiments to improve the understanding of global warming, ocean pollution and plankton populations. The silent boat is also ideal for recording the communications of whales and dolphins.

Howarth is making the trip to show solar power is a viable alternative to traditional fuels.

Howarth and her team have spent more than £150,000 on Green Cat and have attracted sponsorship and equipment from 37 companies and organizations. She is still seeking a sponsor that can afford £250,000 for the solar panels and voyage back-up facilities.

The record for the longest solar-powered boat voyage is 1,305 miles, down the Murray river in Australia. A Japanese sailor, Kenichi Horie, is trying to cross the Pacific from Ecuador to Japan in his 31 ft solar-powered boat made out of aluminium recycled from 27,000 beer cans.

To smash all solar boat records Howarth must leave Weymouth in the early spring to avoid hurricanes and tropical storms around the equator. It will take 43 days to cross the Atlantic to Panama, another 73 to reach Darwin in Australia, 60 more to Suez and a final leg of 29 days to get back home.

Designing Green Cat has been a challenge in itself. Howarth has had to balance displacement and hull shape against solar-panel area, power output, battery capacity and motor efficiency. The balance was found with a boat 13.9 metres long and 7 metres wide, providing a 58 sq metre space to position the solar panels.

There are 20 main watertight compartments plus four huge sealed crossbeams, allowing Howarth to claim it is unsinkable. To keep the weight down, holes have been cut out of surfaces wherever it has been safe to do so.

The photovoltaic solar panels will generate electricity, even under cloudy conditions. Any surplus power will be stored in batteries for use at night. In the event of a total power failure, Howarth has access to a mast and sails locked away and sealed by the World Speed Council, which will ratify her trip.

To find out more about her world record attempt, visit the Green Cat home page on the World Wide Web. It is at http://www.greencat.co.uk. (Source: *Sunday Times*, 4 August 1996)

Solar desiccant cooling systems

Desiccant cooling—technique and state-of-the-art

Two main motives lead to the search for alternatives in cooling techniques: the replacement of cooling systems involving CFCs and the requirements for a rational use of energy in order to save resources and to decrease CO^2 emissions. The first objective may be obtained by the introduction of new working fluids in compression machines while the second requires both new energy-saving building concepts and alternative techniques for the remaining active cooling demand. The installation of desiccant cooling systems has the potential to fulfil both of these requirements since the "working fluid" is water (vapour) and the energy input is low temperature heat and offers the possibility of the use of waste heat or solar energy.

In general, a desiccant cooling system consists of the following main components: air dehumidifier, air-to-air heat exchanger(s), air humidifier(s), air heater(s) and ventilator(s). Different desiccant systems are discussed in literature: cycles based on liquids, operating under either isotherm or adiabatic conditions and cycles based on solids generally operating under adiabatic conditions. Cycles based on solids may be built either as periodically working fixed beds or as rotary drying wheels. Most important materials that were investigated as desiccants are lithiumchloride, calciumchloride, triethylenglycole (liquid systems) and lithiumchloride, silicagel, molecular sieves and polymers (solid systems). From all these alternatives, the system based on drying wheels containing silicagel seems to have reached most economical importance.

From the different possibilities of combining the system components the so-called "ventilation cycle" or "Pennington cycle" is applied in most cases. The principle of this cycle and the integration of solar thermal energy is demonstrated in Figure 1: ambient air (1) is dehumidified adiabatically and leaves the drying wheel as dry and hot air (2). It is cooled down by the regenerator (sensible cooling) (3) and further cooled down by humidification (5→6) before entering the room. The heat exchangers (3→4 and 4→5) are only used in the heating case. At the same time air is sucked out of the room (7), cooled down by humidification (8), heated up in counterflow to the ventilation fresh air (9), heated by the solar system heat exchanger (10) and—if the temperature is not sufficient for regeneration—by an auxiliary heat exchanger (11) and finally conducted through the drying wheel for regeneration of the desiccant (12).

Typical regeneration temperatures are in the range of 60° C to 90° C at which lower temperatures require higher efficiency of the components, especially of dehumidifier and regenerator. The COP, i.e. the cooling power per unit of external heat input, of state-of-the-art systems lies in the range of 1; this value is dependent on the performance of the system components but also on the climatic conditions of the site and internal loads (latent loads, sensible loads). Typical ranges of air flow rates for one system are between 5,000 m^3/h and 40,000 m^3/h.

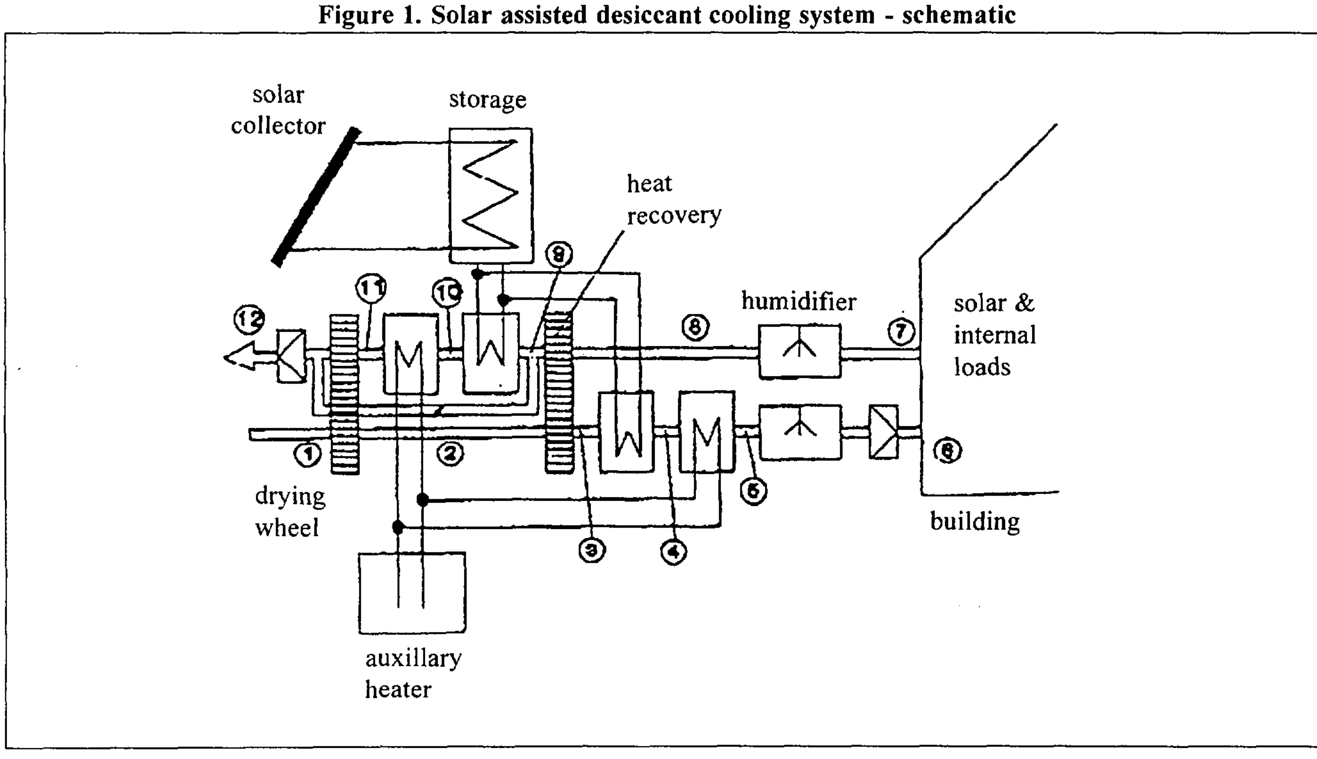
For the design of desiccant cooling systems it is important to have in mind that cooling loads are purged by means of air flows; thus in general air circulation rates of 5/h and above are required. In order to avoid very high circulation rates an accurate building design is necessary in which high cooling loads are suppressed (e.g. shadowing devices, low energy lighting, daylighting...).

Solar desiccant cooling systems

While the desiccant cooling technique has reached a level of commercialization, solar desiccant cooling has not left a state of investigation or demonstration projects. In most projects liquid desiccants have been employed that were regenerated directly in a still type solar collector, i.e., the diluted fluid flowed as a film above the absorber surface. A detailed study of a solar-assisted desiccant cooling system employing rotary dryers containing solid adsorbents has been carried out in Florida. The authors conclude that the technique can help to reduce energy consumption for space cooling, especially in hot and humid climates. So far, no solar-supplied, or solar-assisted desiccant cooling system of the rotary drier type has been installed in Europe up to now.

First calculations of solar-assisted desiccant cooling systems indicated that under the meteorological conditions

Figure 1. Solar assisted desiccant cooling system - schematic



of southern Europe the following values may be achieved under the given design values:

- Designed collector area: 5 m^2 per 1,000 m^3/h nominal air volume flow;
- Designed storage size (hot water): 50 kg per m^2 of collector area;
- Annual solar fraction: 75 per cent for cooling and 60 per cent for heating;
- COP of desiccant cooling system: 1;
- Average collector system efficiency: 35 per cent;
- Primary energy savings compared to conventional active systems for comfort climatization of buildings: >50 per cent.

These values are based on the climatic conditions of Cagliari/Sardinia and the load pattern of an office building. They give only rough ideas about system performance and may be different for other load profiles, different building structures and different meterological conditions.

The Fraunhofer Institute for Solar Energy Systems has a lot of experience in both the design of solar thermal systems consisting of solar collectors, storages etc., and the management and evaluation of demonstration projects in the field of energy technologies in buildings. There is a broad knowledge about open cycles for building climatization. The Institute is very interested in new application fields for solar collectors, besides the standard application of domestic hot water production (DHW-systems). (Source: *Fraunhofer Institute for Solar Energy Systems*)

Six postulates on the future of solar energy

by Professor Joachim Luther

1. Photovoltaic energy conversion is already a mature technology today. Photovoltaics is distinguished by high reliability, very long lifetimes and completely non-polluting operation.
2. Photovoltaic power applications are economically competitive particularly for autonomous consumption in the range up to several kilowatts, when the alternatives are batteries, grid extensions or small diesel generators. This market grows constantly with falling PV modules prices.
3. Photovoltaic energy conversion still possesses considerable potential for technical innovation, higher efficiency values, large cell areas, simplified production processes, etc. to be accompanied by a marked cost reduction.
4. Under the condition that external costs will be realistically included in tariffs for conventional energy sources, grid-connected photovoltaics will become significant; initially to support the grid periphery, but then also to provide energy on a large scale.
5. Photovoltaics has the greatest technical potential for generating electricity from renewable sources, both on a global scale and in Central Europe. In Germany, 20 per cent of the current electricity demand could be supplied on a long term basis by solar cells just on suitable house roofs and walls.
6. Photovoltaics technology today is based almost exclusively on crystalline silicon (cells with a thickness of about 200 micrometres) for the high power range. In the future, thin film technologies (copper indium diselenide, thin silicon,etc.) will also have good chances. Photovoltaic conversion processes based on fundamentally different processes for charge generation and separation are also conceivable, such as sensitized cells made of dyes and nanocrystalline semiconductors.

Professor Joachim Luther is the Director of the Fraunhofer Institute for Solar Energy Systems, Fhg-ISE, in Freiburg. (Source: *Fraunhofer Institute for Solar Energy Systems*, FhG-ISE, Freiburg, Germany)

C. TRENDS IN RESEARCH AND DEVELOPMENT

Solar power station in space

Indian scientists are working on the setting up of the first-ever Solar Power Station (SPS) in space to rid the nation of the never-ending power shortage. The dream project can mitigate the perennial shortage of energy because sunlight will be available to the stations for almost 24 hours with the shadow period being less than 12 minutes near midnight when power demand is the least. A ground based system will get direct sunlight at the most for 12 hours. The intensity of sunlight in space will be much more where it does not have to pass through the Earth's biosphere. India and the USA are to be the primary partners in this venture, with other world industries helping with collaborative technology development.

The initial objective would be to design and construct high efficiency, heavy lift aerospace planes and construct large space/ground based photovoltaic power stations.

Experts say that for establishing the SPS, they would need heavy lift space launchers, with a performance better than the space launch vehicles available now. The mission is an affordable megaproject for a borderless world.

The satellite solar power station was first conceived in the USA but was not commercialized then, essentially because of non-availability of heavy lift space cargo launch vehicles capable of low-cost launch operations.

In 1988, at the 38th Conference of the International Astronomical Federation, India presented a new aerospace vehicle design concept for a heavy lift space launcher called "hyperplane".

This design in the last few years had been closely reviewed by India and Russia and also several leading aerospace companies in the USA. Today, the hyperplane design has become a practical reality.

"Hyperplane" design introduced an "aerobic" principle by which the spaceplane takes off horizontally from any airport like a conventional aircraft launch vehicle with payload fractions of 15-20 per cent—a feat not imaginable in the 1970s.

India's aerobic design space launch vehicle "hyperplane" has been internationally declared as feasible and described as a "true aerospace plane". A solar power station in space would have a lot of advantages over a ground solar power station. (Source: *Tech Monitor*, May-June 1995)

Renewable energy technologies

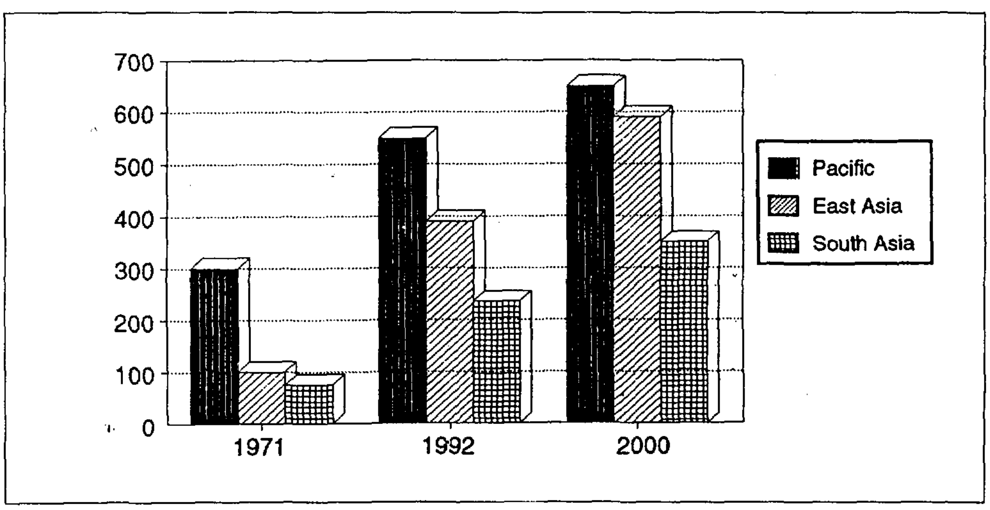
Towards sustainable development
Dr. V. Bakthavatsalam, Managing Director, Indian Renewable Energy Development Agency Ltd., New Delhi, India

Looking beyond the year 2000, it seems certain that we are moving to an era when energy costs are going to rise and the pressure on fossil fuels and wood is going to become more and more acute. Energy supply patterns are going to determine the course of future economic and social development. Energy supply will be the basis for a high and sustainable level of security and comfort. The energy mix will also determine the environment and ecological balance.

History to a great extent has been shaped by mankind's choice of energy technologies. The use of draught animals, sailing ships and water wheels presented new opportunities for our ancestors. The introduction of the coal-fired steam engine was a precursor of the industrial revolution. Internal combustion engines and turbines shaped the transportation systems of the modern world. The energy sources and technologies that we use today are going to have far-reaching effects tomorrow. There is also mounting evidence that many of the energy technologies that we use today are not ecologically sustainable, and have the potential for serious and irreversible climatic change and also the reality that most of these sources of energy cannot be renewed and are being depleted fast.

This brings us to the renewable energy sources. Wind energy, small hydro, solar energy and biomass are plenti-

Figure 1. Energy demand: primary energy
(millions of metric tones of oil equivalent)



Source : World Energy Outlook 1995, IEA tiful, widely distributed and environmentally attractive. These sources add no net contributions to the atmospheric carbon dioxide and add no heat to the global environment. Renewable energy technologies fit well into a system that gives due recognition to decentralization, pluralism and local participation.

The special characteristics of renewable energy that makes it attractive are:

- Decentralized production and use involving a large number of producers and consumers;
- Relatively higher initial cost compared to conventional systems but zero or low cost fuels;
- Low gestation period, providing quicker benefits.

Solar energy

The Earth continuously receives about 1.73×10^{14} kW of power input from the sun. This translates to 1.5×10^{18} kWh/year which is about 10,000 times the world's annual energy consumption. Since sunlight is ubiquitous and can be used in decentralized facilities, the solar options for electricity generation would dispense with the expensive transportation and distribution networks that encumber conventional energy systems. Solar energy technologies have a vast potential in a tropical country like India, since most of its landmass receives sunshine almost throughout the year. The total solar insolation over the land area of India is estimated to be 5×10^{5} kWh/year.

One important element in solar strategies is the thermodynamic matching of appropriate energy sources with compatible uses. The quality of energy sought from the sun and the costs of collecting, converting and storing that energy correlate directly. Solar radiation is currently being used to generate power via two technologies: photovoltaics and solar thermal.

Solar photovoltaics

Solar photovoltaics (SPV) has an immense potential and appears to be one of the most attractive ways of meeting the increasing energy demands of the future.

Photovoltaic systems are now more reliable and economical than many other energy technologies for most standalone and consumer product applications. An SPV system can either be grid-interactive or it can act in a standalone and self-reliant mode. SPV systems are very relevant to the developing countries and the Asia Pacific region, because there is a shortage of electric power supply, particularly in rural areas in most of the countries in this region. It is particularly relevant to rural development activities because the electric power which becomes available through PV conversion of solar energy can be used in a decentralized manner.

Solar thermal energy

The methods of solar thermal power generation are essentially the same as conventional technologies, except that the fuel is direct heat energy rather than stored energy in the form of fossil fuels, from which the heat energy needs to be released by combustion. The entire temperature range required by domestic and commercial applications can be covered with the available technologies of conversion of solar energy to thermal energy. Various solar thermal devices and systems such as water and air heating systems, timber seasoning kilns, dryers, desalination systems and cookers have been developed for solar thermal energy applications. These technologies are already field proven; they have been commercialized and are finding wide and increasing applications. While simple low-efficiency solar thermal systems are suited mainly to domestic users, a breed of more advanced, higher-efficiency systems have been developed to cater to industrial and commercial applications. Such systems are capable of raising high temperatures to pre-heat boiler feed water, for direct water and air heating in industrial processes and for steam production and power generation. The solar-thermal power plants use the sun's rays to heat a fluid, from which heat transfer systems may be used to generate steam that in turn is used to drive a turbo generator.

Solar desalination

There are many areas where potable or fresh water (less than 500 ppm of salt) is not available. Solar energy can be utilized for potable water in these remote areas for agricultural and industrial production. Solar stills can also be used for providing distilled water for laboratories and battery charging.

Solar ponds

Solar ponds collect and store thermal energy for various applications. Most commonly, the concept referred to is a gradient pond in which a portion of the pond's depth is stabilized against motion by dissolved salt with more salt towards the bottom than the top.

Solar refrigeration/air conditioning/cold-storage

Solar energy can be used for producing cold, either for cooling or refrigeration applications. The ways of producing cooling effect using solar energy are:

- Using the vapour absorption cycle with liquid and/or solid absorbents;
- Using a vapour compression cycle employing a solar powered Rankine cycle;
- Using the vapour compression cycle with the compressor driven by electricity from SPV panels;
- Nocturnal passive cooling.

(Extracted from *Tech Monitor*, May-June 1995)

The use of solar energy for ecologically sustainable development

Professor W. W.S. Charters, Dean of Engineering, University of Melbourne, Parkville, Victoria, Australia

Introduction

In the later part of this century the driving source for solar energy utilization in many countries is concern for the environment in both the local and global context. This is in sharp contradiction to previous scenarios where the impetus for solar development was clearly costs of conventional energy supply, national energy security or balance of trade considerations.

Research and development on solar energy as a clean renewable energy resource has led to the development of reliable and cost-effective alternative energy technologies even in a time of declining government solar energy budgets. There is no doubt that the potential for solar energy conversion technologies to provide a significant input to the global demand for electrical power has been demonstrated over the last decade.

If the world is to move towards a truly sustainable energy economy it will be essential to integrate these relatively new solar technologies with the currently available non-renewable energy plant, in the most effective ways, taking into account the socio-economic and technological factors involved in such a transition process.

Power generation from the solar resource involve either direct conversion photovoltaic generation systems (PVGS) or solar thermal electric generation systems (STEGS). Research, development and commercialization of these discrete technologies has advanced, each of them dramatically over the past decade of international solar work.

Recent emphasis on environmental degradation and atmospheric pollution including acid rain and global warming from conventional stationary power plants has refocused attention on the relatively benign nature of renewable energy technologies.

Solar resource assessment

It is vital to know the extent, availability and nature of solar radiation at a particular location in order to make a realistic appraisal for any new proposal for solar PVGS or STEGS. A comprehensive manual dealing with all aspects of solar radiation as an energy source was compiled for the UN Conference on New and Renewable Sources of Energy held in Nairobi in 1981. This document, produced by the World Meteorological Organization (WMO) based in Geneva, is the prime reference for solar resource assessment. To utilize solar energy effectively as an energy source it is important to have a good quantitative and qualitative assessment of the availability and characteristics of solar radiation.

The incoming solar radiation to the Earth is not only available continuously in great quantity but it is also widely distributed over the surface of the globe. This is an immediate advantage if one considers the use of solar energy in a decentralized way but leads immediately to the conclusion that it is necessary to provide large areas of collectors to harness the solar resource on a large scale. Although solar energy is often spoken of as a "free resource" this is evidently only true in terms of the free availability of solar radiation as opposed to the prices of competing fossil fuels. In reality, it is far better to talk of solar technologies as being inherently capital-intensive but of low running cost.

The amount of solar radiation incident on a collecting surface is dependent on geographic location: day of the year, weather conditions, particularly atmospheric cloud cover, humidity and turbidity; and the orientation and tilt angle of the collector. There is of course the diurnal effect of night and day to be considered when designing solar collection systems and this introduces automatically the question of thermal and/or electric storage requirements for overcast conditions and for night-time use of energy.

The atmospheric effects of the Earth scatter this radiation so that at the Earth's surface there are two radiation components: "direct" or beam radiation coming from the position of the sun in the sky and diffused radiation which comes from wall angles within the celestial hemisphere. The distinction between these radiation classifications is therefore predominantly that one has directional characteristics associated with it and the other has not.

The relative proportion of these two radiation types is important when selecting the type of collector to be used in a solar system so it is important to have as much detailed meteorological knowledge as possible for sites selected for solar energy utilization.

In desert or arid regions, areas of the world where one can expect in excess of 300 clear sky days per year, the direct component may be well in excess of 85 per cent of the total radiation. However, in temperate and tropic regions the direct component may be quite low, possibly in the order of 10 to 20 per cent of the total radiation on some days.

Sustainable development

A critical factor in energy policy and planning for the twenty-first century will be the use of solar energy for ecologically sustainable development. Implicit in this is the unarguable fact that perpetual economic growth is not sustainable and that we should all be looking towards extensive use of materials recycling and a major shift to greater reliance on renewable energy resources even if these appear to be uneconomical in current terms using conventional energy economics. The introduction of true least-cost planning methods and a proper accounting for externalities is gradually changing the perspective of the true economic worth of environmentally benign renewable energy resources. Such an approach is vital if we truly intend to move the world from its present over-dependence on fossil fuels, which currently supply over 85 per cent of all globally traded primary energy. It is only in this way that we can safeguard the future of the planet for generations yet unborn.

In any development scenario for the world as a whole we must of course give credence to the fact that the level of development varies enormously from country to country and that the problems of the developed world pale into insignificance when compared with those of the developing nations. These critical problems include the necessity of providing an adequate energy supply to major new populations as recent forecasts indicate that 90 per cent of the population growth is likely to occur in developing nations.

It is therefore reasonable to expect, based on recent extensive international studies, that the energy growth rate in the developing nations is likely to run at five to six per cent whilst stabilizing in the world as a whole at one and half to two and a half per cent. Excessive dependence on imported oil in the developing nations can also pose a crippling debt burden and adversely dominate the balance of trade ratios for these countries.

Renewable energy waves

Solar energy research, development and commercialization in this century has been driven by a variety of different forces. Firstly we had the vision and enthusiasm of solar pioneers like Abbot, Robinson, Daniels and Yelott, to name only a few who saw in this unlimited natural resource a secure clean energy resource for the post fossil fuel era. Some of these eminent scholars and others like them helped to bring together the international solar scientists and engineers in 1955 at Phoenix, Arizona, which led to the formation of the Solar Energy Society, now the International Solar Energy Society.

The second wave of interest broke in the mid seventies with the advent of the Middle East Oil Cartel known as OPEC and the overnight quadrupling of the price of crude oil in 1973 and 1979, reaching a price of almost US$40 per barrel from a base price of US$3 per barrel. Although the international economy adapted rapidly to these price increases the seeds of doubt had been sown in terms of price instability and supply uncertainty, leading several nations to implement major renewable energy programmes focused on energy supply security and national independence.

The third and possibly final wave in this century, is the increasing emphasis on minimizing environmental degradation in all its diverse forms and protecting vital land, water and air resources whilst sustaining economic productivity and attempting to provide useful employment for the workforce.

In each of these cycles it is possible to chart the ebb and flow of the fortunes of the solar energy community as Governments and industries responded to the new challenges posed.

The intensive development and commercialization of solar power in this same period saw a continuing reduction in solar power installed costs and levelized power costs and a dramatic improvement in plant reliability and standalone capability and availability. This is particularly impressive when compared with other more conventional power plants where cost escalation rather than cost reduction has taken place in this time.

Solar thermal systems

Significant advances in solar materials and selective surface preparation have led to Intelligent Windows and advanced solar building incorporating day lighting.

Advances in transparent insulation materials, collector design and solar heat pumps have also contributed greatly to industrial and agricultural process heat applications.

Solar power systems

Solar thermal electric power systems

High temperature collectors have been designed and built to operate reliably at temperatures suitable for use with relatively conventional power conversion technologies such as steam engines and turbines, gas turbines and Striling cycle engines with power outputs ranging from 25 kWe to 80 MWe.

Solar photovoltaic power systems

Recent interest in the widespread use of PV arrays appears to be increasing rapidly for decentralized or distributed applications including individual building applications both grid inter-connected and standalone. On the other hand, some industrial countries such as Japan, Italy and the USA are still committed to larger scale centralized PV power generation.

Industry cooperation and involvement in solar R&D

Close industry cooperation in the R&D and demonstration phases of solar research has been seen to accelerate technology transfer and commercialization of new solar products. In many countries world-wide this has led to Government and industry cost sharing on solar R&D programmes similar to that introduced by ERDC (Energy Research and Development Corporation) in Australia since 1991.

Future roles for solar energy

In terms of application, solar energy harnessed on a major scale can contribute substantially to:

- Small, medium and large-scale decentralized power generation systems based on solar thermal photovoltaic supply. This step alone could lead to energy and power being supplied to billions of people currently living at or below subsistence levels in many countries of the world.
- A range of industrial process heat applications, in particular in the food processing industries, which could lead to a very substantial reduction in the consumption of conventional fuels.
- Vital food preservation through drying and refrigeration to minimize post harvest and post processing losses. In developing nations 50 per cent to 70 per cent of the food produced is lost due to inadequate drying and storage handling.
- Improved public health services through water purification and supply, water pumping for drinking and irrigation and the provision of a vaccine cold chain. The immediate and dramatic effects on improved health of the community have been demonstrated in many countries where action along these lines has been initiated with small-scale pilot projects.
- Accelerated production of solar fuels and chemical storage materials such as ethanol, methanol, methane and ultimately hydrogen. This is an essential element of any long-term solution to transport energy problems and could assist in reducing urban air pollution and conserving our vital petrochemical resources for other useful industrial purposes.

The improved solar plant used for each and every one of these applications will of necessity incorporate advanced state-of-the-art electronic and computer circuitry, and will benefit from recent and continuing advances in materials technology such as the production of "cermets and other advanced composite materials".

Many of the materials used in advanced electronics will become available to solar workers in different forms as specialist coatings and substrates. We have already seen the introduction in recent years of transparent insulation materials specifically tailored for solar applications in buildings and in thermal collectors. This trend will continue and accelerate as solar energy impacts on and becomes a part of everyday life. (Extracted from *Tech Monitor*, May-June 1995)

The next energy revolution

We live in a futuristic world of cyberspace, genetic engineering and other mind-boggling technologies. Yet when it comes to energy, most experts seem to think that our decades-old oil and coal-based energy systems will barely change. Developments around the world are already proving them wrong, however. We may soon witness the most dramatic changes in the world energy economy in a hundred years.

Two major US corporations have made an announcement that may one day be seen as a big step in launching the energy systems of the twenty-first century. Bechtel Enterprises Inc., once a leading builder of nuclear power plants, and PacifiCorp, a giant utility that operates several huge coal-fired generators in the north-western United States, announced that they were teaming up to invest in solar energy and other "human-scale energy systems".

The new joint venture, called EnergyWorks, will pursue projects around the world based on wind turbines, biomass generators, industrial energy efficiency, and other technologies that most large energy firms have spurned as being systems that cannot possibly meet the expanding energy needs of close to six billion people.

Historians of technology may one day argue that by the mid-1990s, the world energy economy was already in the early stages of a major transition. The fastest growing energy market in the early 1990s is not oil, coal, or even natural gas—it is wind power, which expanded from 2,000 megawatts in 1990 to 4,500 megawatts in 1995.

Around the world, advanced electronics, new kinds of synthetic materials, and the techniques of mass production are allowing engineers to substitute clever technologies for brute force. The result is a variety of new modular, mass-produced energy systems that have the potential to be more economical and flexible than the traditional energy systems they replace.

Here, as in the mercurial worlds of computers and telecommunications, it is impossible to predict the future, but the broad outlines of a new energy economy are beginning to emerge. Its chief feature is likely to be a radical decentralization. The new technologies will make it possible to decentralize power generation, even down to the household level, harness the world's most abundant energy resources—solar energy and wind power—and greatly reduce the burden that current energy systems place on the world's atmosphere.

But these changes may add up to more than the sum of their parts. Using technologies such as fuel cells and mass-produced solar generators, it should be possible in the long run to replace virtually all fossil fuels with a hydrogen-based energy system, something that author Jules Verne dreamed of more than a century ago. The hydrogen would be produced using sunlight harnessed on rooftops as well as in remote desert collectors, and would be conveyed to homes and industries via pipeline. Although this vision may sound futuristic, most of the inventions needed to make it real have already been made.

Rooftop power

One of the most neglected "fringes" of the world energy economy is made up of thousands of rural villages that are home to some two billion people who lack access to electricity or other modern fuels. Yet these villages are now at the centre of one of the most revolutionary new developments: during the past 10 years, silicon cells that turn sunlight directly into electricity have been installed on or adjacent to at least 250,000 homes, mostly in remote areas of countries such as Sri Lanka, China and Mexico.

In Kenya, in 1993, more homes were electrified using solar cells than by extending the grid. In Brazil, utility companies are starting to support solar electrification in the Amazon and other areas where it is impractical to extend power lines. In South Africa, the Government has launched a major effort to provide solar power to millions of people. And in Viet Nam, where only 14 million of the country's 72 million people currently have electricity, the Viet Nam Women's Union has launched a solar electrification programme.

Solar electric systems are also beginning to appear on the roofs of suburban homes in industrial countries. In Sacramento, California, for example, the municipal utility is putting shiny blue solar electric panels on 100 homes each year; their rooftop systems are connected to the utility's electric grid so that power not needed within the home can be sold to other consumers. Consumers pay for the systems via their monthly power bill, at a rate that is only slightly higher than their neighbours'.

In Switzerland and Germany, more than 1,000 buildings have been outfitted with solar power systems in recent years, with government funding. Thousands more are planned. The Japanese Government plans to install some 62,000 building-integrated solar generators by the end of the decade. Although such systems must be subsidized to be affordable today, they could become fully competitive with traditional power sources as large-scale production brings manufacturing costs down.

A product of the electronic revolution, solar cells bypass the mechanical generators now used by virtually all power plants, whether they run on fossil fuels, hydropower or nuclear energy. First used to power orbiting satellites in the US space programme in the 1960s, solar cells are a close relative of the microprocessors that make today's computers possible. The cells consist of semiconductors—usually made of silicon—that emit electrons when struck by sunlight, thereby producing an electric current.

Japanese, Swiss and US manufacturers have designed experimental "solar tiles" that shelter occupants while also powering their appliances. In Europe, Flachglas, a leading producer of architectural glass, has developed a semi-transparent "curtain wall" that provides filtered light as well as electricity. In a joint venture in the United States, Corning Glass and Siemens Solar are developing a similar product.

The cost of solar cells has declined from more than $70 per watt in the 1970s (in 1994 dollars) to $4 per watt today, and is expected to drop to between $1 and $2 per watt within a decade, according to the National Renewable Energy Laboratory in Colorado, USA. As a result, the potential applications have multiplied. The world market went from 34 megawatts in 1988 to an estimated 90 megawatts in 1995.

Aerial photographs show that even in the cloudy climate of the British Isles, putting solar cells on all the country's existing flat roofs could generate 68,000 megawatts of power on a bright day—about half the United Kingdom's current peak power demand. With a strong push by Governments and private investors, it is possible that rooftops alone could provide as much as a quarter of the world's electricity by the middle of the next century.

Storing power

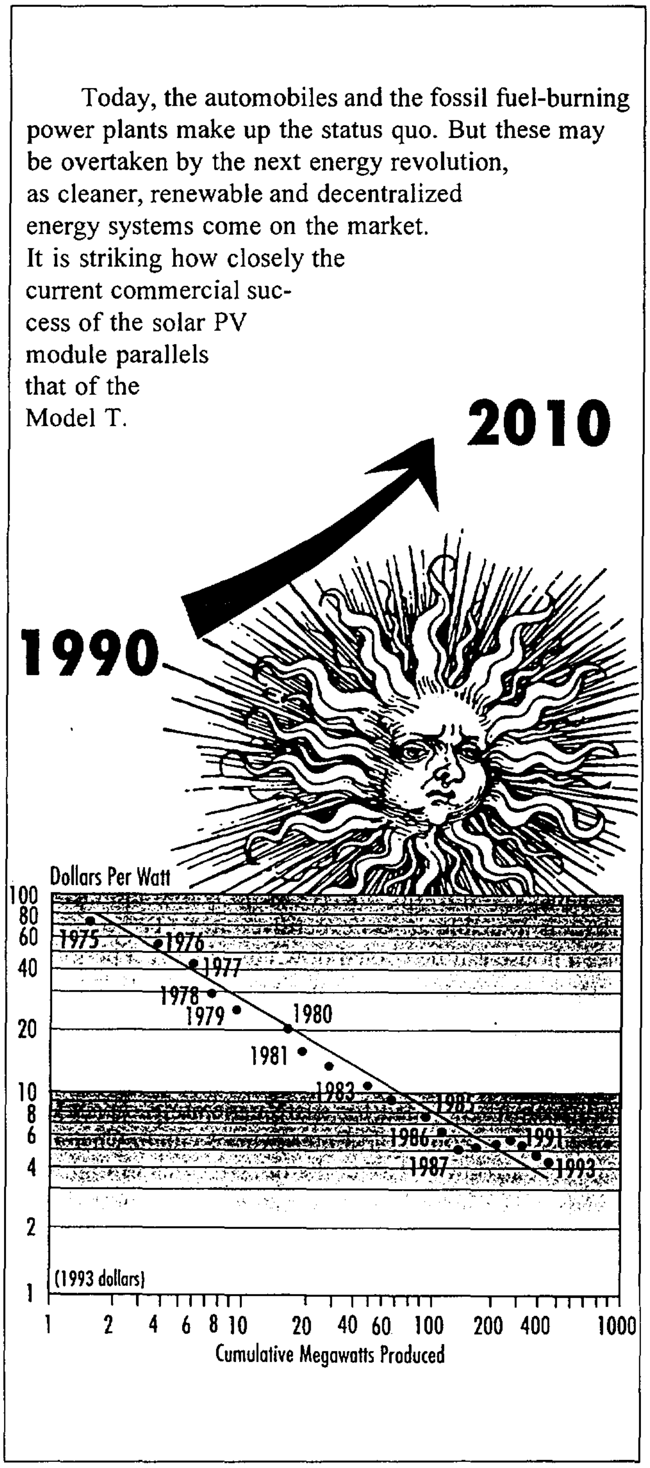
Just as buildings of the future are likely to generate their own electricity, they may also be able to store it. During the past five years, at least five companies have begun developing flywheels, which function like mechanical batteries. Operating on the same principle as a potter's wheel, a flywheel disc is set to spinning at high speed by an integrated electric motor/generator. It is contained inside an airless case, almost eliminating resistance so that the ensuing long duration of the spin serves as a means of storing kinetic energy—which can then be converted to electricity by the generator as needed.

Although it was invented over a century ago, the flywheel only became practical with the development of strong, lightweight composite materials in the 1970s and 1980s. Modern composites can spin a vacuum at up to 200,000 revolutions per minute, with the potential to store and release energy at an efficiency of more than 90 per cent. Because they have virtually frictionless electromagnetic bearings, flywheels can store electricity for weeks, and last years before wearing out.

At the Lawrence Livermore Laboratory in California, scientists and engineers are developing a mass-produced device half the size of a clothes washer that could sit in a building's basement, storing cheap electricity at night (or solar energy during the day) and releasing it to the grid when needed.

Several large and small companies are developing similar devices.

Flywheels would last much longer than chemical batteries, and would not require toxic substances. The materials needed to manufacture them are not expensive, and their design readily lends them to mass production, which will yield much lower costs. Because they could be used as storage devices in electric cars as well as in buildings, the ultimate market for flywheels could add up to millions of units. It will probably be 10 to 15 years before flywheels are widely available commercially, but after that, their use could grow as fast as that of cellular phones has in the early 1990s.



Photovoltaic modules:
Price versus cumulative production, 1975-1993

Forces of change

From some perspectives, the mid-1990s are a dark time for the world energy system. Oil consumption is approaching the record levels of the late 1970s, with demand in some countries growing at rates as high as 10 per cent per year. Even the use of coal is still expanding in many nations, pushing emissions of carbon dioxide, the leading greenhouse gas, to more than 6 billion tons per year. Emissions are growing particularly rapidly in China and India, but even the United States and Canada are failing to hold carbon dioxide emissions steady as they are supposed to under the Rio climate convention.

Although most energy analysts view such trends as convincing evidence that the world energy system will not change soon, the reverse may be true.

As already suggested, evolutionary bursts are usually precipitated by strong pressures. Today, three major forces of change are bearing down on the world energy economy—new technologies, industry restructuring and tougher environmental policies—all of which are likely to be intensified by incipient climate change.

New technologies are the most obvious. As noted earlier, advanced electronics, new materials and biotechnology are now being put to use in energy systems. The modern automobile, for example, has become virtually a computer on wheels, with electronic controls that provide not only easier steering and braking but improved fuel economy and lower emissions. Thanks to such developments, spurred by two decades of strong government support for R&D on new energy technologies, it will soon be possible to harness solar and wind energy on a much larger scale.

Industry restructuring is also spurring change. In the past, most electric power systems have been operated as government-owned or controlled monopolies that manage everything from constructing power plants to reading the meters attached to customers' homes. These monopolies have been drawn to giant plants and inefficient, entrenched technologies, and have had little incentive to pursue innovation.

But today, all that is changing. In Brazil, India, Poland, UK, Japan and the United States, utility systems are being broken up and sold to private investors. In many nations, the generation of electricity is increasingly provided by independent power producers that have no monopoly franchise on the business. Local distribution utilities and industrial users buy power from those producers, using the electricity transmission systems as a common carrier, in the same way that railroads and telephone lines are used.

This restructuring has led to an unprecedented wave of innovation, as independent producers find that in order to be competitive, they have to build ever more efficient and less expensive plants. Such producers are pursuing smaller and less environmentally damaging energy sources than did their utility brethren.

India provides a particularly strong example of the impact of restructuring. As the State utility monopolies were broken in the early 1990s, independent power generation blossomed. Scores of projects are now under way, in a competitive rush to reduce the country's chronic power shortages. Although many of the new plants are coal and gas-fired, dozens of wind and solar energy projects are also under way, attracting foreign investment and creating a manufacturing boom.

The third force driving rapid change is the growing reach of policies intended to protect the Earth's embattled environment. In many countries, emissions and waste-disposal laws have greatly added to the cost of building coal-fired power plants, and nuclear generators have essentially been ruled out as having unacceptably high costs and risks. These changes have boosted the market prospects for efficient natural gas and renewable energy generators.

To help protect the environment, some Governments have changed tax and utility laws to level the playing field between "dirty" and "clean" technologies. India, for example, allows a full income tax deduction for renewable energy investments, and the United States offers a 1.5 cents per kilowatt-hour subsidy to renewable power. In Germany, renewable power generators have been granted the right to sell power to utilities at a rate of 0.17 DM (12 cents) per kilowatt-hour—thereby priming the pump for renewables.

As more countries enact similar changes, the boom in renewable energy development now taking place in Germany and India is likely to spread. Japan, for example, has just opened its power grid to independent generators, with special incentives for renewables. Brazil is opening the gates to independents as well, and renewable energy developers are reported to be exploring the coasts and deserts of the country's northeast, which has prime wind and solar sites.

The hydrogen age

In elaborate studies churned out by Governments and corporations each year, powerful computers are used to project future energy trends. Although the results of such studies are received by many policy makers as gospel, they are generally based on a narrow band of oil price and economic growth assumptions. Indeed, what passes for energy analysis today is dominated by a preoccupation with econometrics and the geopolitics of the Persian Gulf, leaving unquestioned the assumption that we will stay hooked on oil until it is gone, and that coal's role must expand simply because coal is abundant.

Economists who conduct such studies often ignore ongoing technological trends, let alone the broader policy environment. If earlier forecasters had used similar techniques, they would have concluded that we—in the 1990s—would still be driving around in horse-drawn carriages and writing on typewriters. After all, we never ran out of either hay or paper.

What was true for transportation towards the end of the nineteenth century and for communications towards the end of the twentieth will be no less true for energy at the start of the twenty-first: when breakthroughs alter the relative competitiveness of a long-dominant resource, its continued abundance becomes suddenly irrelevant.

Just as our forefathers at the turn of the last century had a hard time envisioning what was to come, so we now have a hard time seeing what lies beyond the age of fossil fuels. A number of scientists and other experts have been able to offer at least a glimpse of what we are moving towards: a solar hydrogen economy.

Hydrogen is the simplest of the chemical fuels, and unlike methane, the cleanest fuel used today, is entirely carbon-free. Hydrogen is the lightest of the elements as well as the most abundant. Three-quarters of the mass of the universe consists of hydrogen, which is also a principal constituent of water. When the time comes to use the hydrogen as fuel, it is combined with oxygen to produce water, releasing energy but no pollution.

Scientists have foreseen the possibility of a transition to hydrogen for more than a century, and today it is seen as the logical "third wave" fuel—hydrogen gas following liquid oil, just as oil replaced coal decades earlier. The required technology—using electricity to split water molecules through electrolysis—is already being used commercially. (All the world's current energy needs could be met with less than 1 per cent of today's fresh water supply, and hydrogen can also be produced from seawater.)

The challenge now holding up the transition to hydrogen is finding inexpensive sources of energy to split water. The key to the puzzle lies in the possibility of storage and transportation. Wind and solar energy are often found in the wrong place at the wrong time, but those energy sources can be used to feed the electricity grid when power demand is high, and to produce storable hydrogen when it is not.

In fact, hydrogen may provide the ideal means of storing and distributing these intermittent power sources. Additional hydrogen can be produced in homes and commercial buildings using rooftop solar cells. The hydrogen can then either be stored in a basement tank for later use in a fuel cell or conventional boiler, or be piped into a local hydrogen distribution system.

In either case, a decade or two from now, hydrogen could begin to enter the markets now dominated by oil and natural gas—including home heating, cooking, industrial heat and transportation. In fact, scientists have determined that in the early stages hydrogen fuel can be derived from natural gas and that during the transition, consumers may use a mixture of hydrogen and methane gas. Experimental hydrogen-powered cars have already been developed by Mazda and Mercedes. With the advent of small fuel cells, such cars may become highly efficient and affordable. By the middle of the next century, oil and coal could be phased out.

Although renewable energy sources are more abundant in some areas than others, they are far less concentrated than oil. Moreover, the coming solar-hydrogen economy is likely to be based on a diverse array of renewable resources, with the mix varying by region. The hydrogen can be carried to where it is needed through pipelines similar to those used to carrying natural gas.

Over time, solar and wind-derived hydrogen could transform the way energy is produced and used virtually everywhere. All of the world's major population centres are within reach of sunny and wind-rich areas. The Great Plains of North America, for instance, could supply much of Canada and the United States with electricity and hydrogen fuel. For Europe, solar power plants could be built in North Africa, with hydrogen transported along existing gas pipeline routes. In China, hydrogen could be produced in the country's vast western deserts and shipped to population centres on the coastal plain.

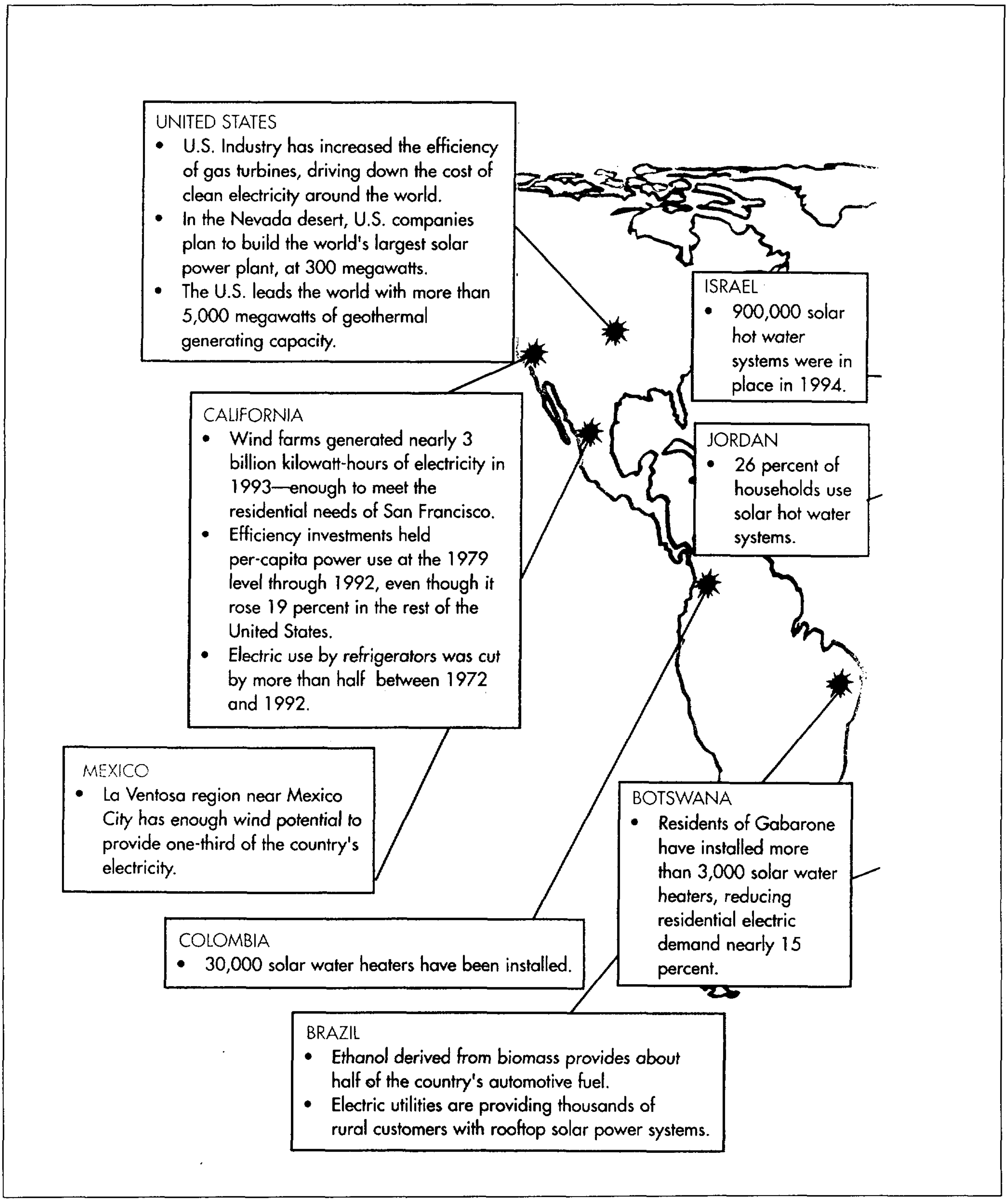
Many people assume that producing sufficient hydrogen from solar and wind energy requires huge swaths of land, but these technologies actually use less than one-fifth as much land to produce a given amount of energy as does hydropower, which now supplies nearly a third of the world's electricity. Moreover, while much of the land used for hydropower has to be condemned for flooding, the tracts used for wind farms can still be used for crops and grazing.

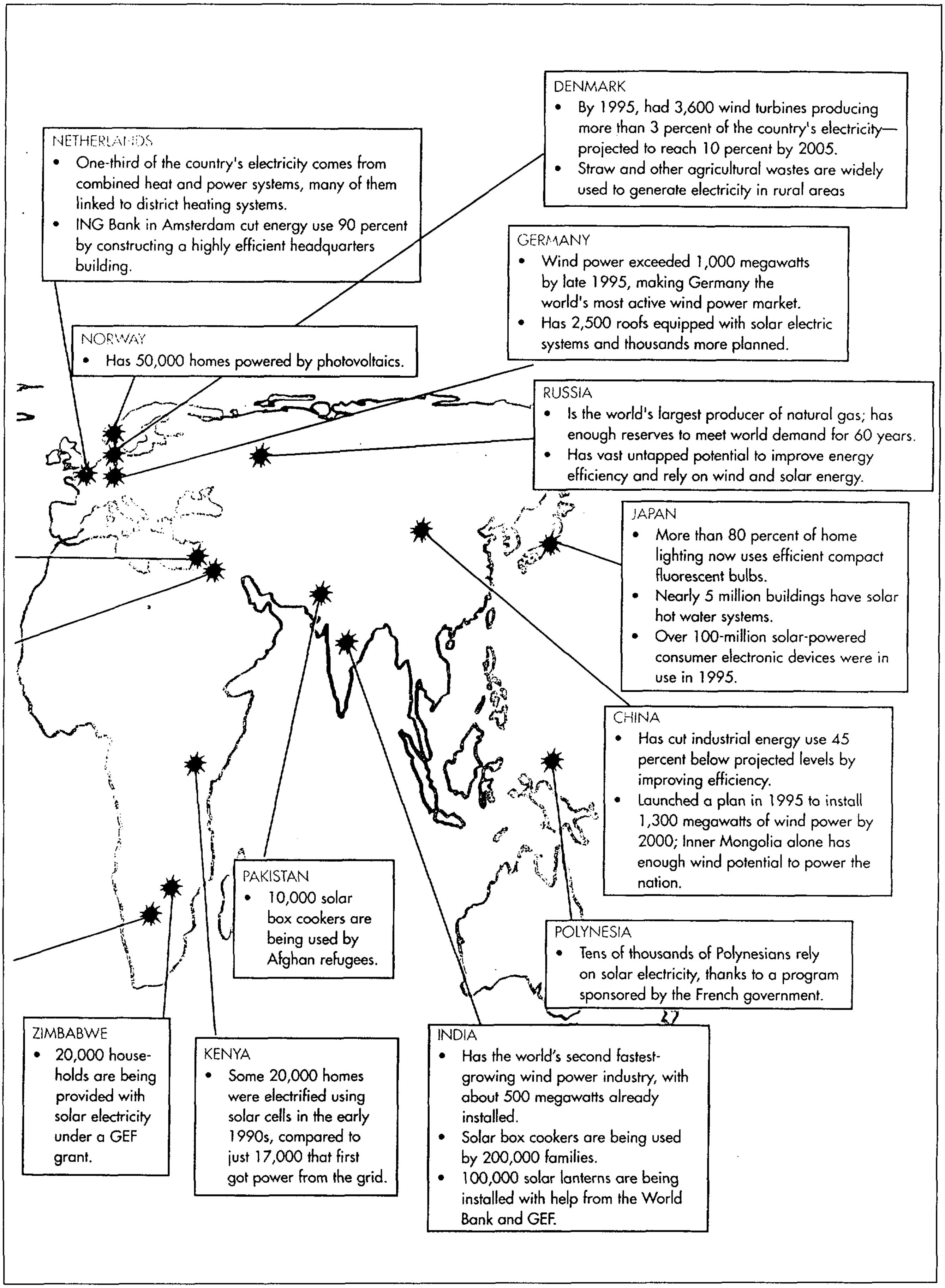
What then would a solar-hydrogen energy system look like? One of its chief advantages is that it would be largely invisible. Fuel cells and flywheels would be hidden in people's basements; solar rooftops would be nearly indistinguishable from conventional rooftops; and hydrogen pipelines would be buried underground, as are today's natural gas pipelines.

Power shift

The global shift from coal and oil-fuelled electric power generation to the energy sources of the future has already begun. Windpower, which is non-polluting and abundant, is becoming competitive with fossil fuels. Photovoltaics (PVs) and solar heating systems are proliferating in areas not served by grids. And the key traditional resource, natural gas, is undergoing rapid development.

Christopher Flavin is Vice-President for Research at Worldwatch Institute and co-author with Nicholas Lenssen of *Power Surge: Guide to the Coming Energy Revolution* (W.W. Norton: 1994), on which this article is based.





(Source: *World Watch*, January-February 1996)

New PV materials are studied in EPRI-backed research

A research programme involving four universities and sponsored by the Electric Power Research Institute (EPRI), USA, is exploring the commercial potential of a new generation of polycrystalline photovoltaic materials.

Currently, the most promising PV technologies for cost-effective utility applications include high-concentration PV with small, high-efficiency crystalline silicon cells and multijunction thin-film PV with less expensive, but lower-efficiency amorphous silicon modules.

Ten to 15 years in the future, however, attention will be focusing on a new generation of PV devices now appearing on the research horizon. This advanced technology promises to have the low cost associated with thin-film manufacturing while featuring efficiencies as high as today's best crystalline cells.

Two fundamental changes are anticipated. Firstly, the new technology will not be silicon-based. Instead, devices will be created from thin films of compound semiconductor alloys, such as those based on copper indium diselenide (CIS). Secondly, the microstructure will be polycrystalline, composed of crystal grains with diameters of 1 to 5 micrometres.

The current generation of silicon cells are made from huge single crystals up to 8 inches across, and current amorphous silicon films are homogeneous with their silicon atoms randomly arranged.

To explore the commercial potential of such polycrystalline PV materials, EPRI's Strategic R&D Business Unit is sponsoring an integrated programme of research at four universities. Scientists at the University of South Florida are studying materials problems that limit the performance of CIS alloys. At Pennsylvania State University, researchers are conducting computer simulations of CIS-based PV devices to better understand them. Improved ways to grow polycrystalline thin films are being investigated at the University of Delaware, and researchers at the University of Illinois are using their materials-characterization tools to help the other centres better understand CIS films and make improved thin-film samples and devices.

The scientists have reached the stage where it is possible to create materials with good optical and electronic properties and also to make decent single-junction PV devices. The University of South Florida has found ways to tailor these properties by selectively substituting gallium for indium and sulphur for selenium in the polycrystalline CIS thin films. The next major step will be to create multi-junction PV cells, which can increase conversion efficiency by absorbing different wavelengths of light in each layer.

Amorphous thin-film PV modules are expected to be available soon in an eight-square-foot size with a net conversion efficiency of over 8 per cent, evolving to efficiencies of 10 per cent to 12 per cent. Within a few years, they may achieve EPRI's 15 per cent target efficiency for flat-plate PV. However, polycrystalline thin-film modules seem a good bet to eventually achieve about the same manufacturing cost—but with efficiencies of over 25 per cent. (Source: *International Solar Energy Intelligence Report*, 4 March 1996)

Crystalline silicon to remain dominant PV material despite thin-film advances

Despite recent advances by Solarex and United Solar Systems Corp. to boost production of thin-film photovoltaic technology, the National Renewable Energy Laboratory, USA, expects crystalline-silicon PV to retain commercial predominance for several years to come.

This dominance is due to crystalline silicon's lengthy track record, its reputation for stability and the availability of PV-module warranties for up to 20 years. With recent incremental improvements in manufacturing technology, commercially available crystalline-silicon modules are expected to become increasingly competitive with more conventional sources of electrical generation.

Nevertheless, one or more thin-film PV technologies could snatch a substantial market share from crystalline PV in the near future. Thin-film has greater flexibility in product configuration, surface appearance and colour. These options will appeal to the notoriously discriminating market of building professionals who are eager to integrate PV into residential and building facades.

The following highlights some developments.

- **Ames-based Iowa Thin Films**, which is developing amorphous-silicon PV modules on continuous polymer substrates, believes it can reduce its overall manufacturing costs by 68 per cent. The thrust of the firm's effort is to increase throughput of its metallization, deposition, laser scribing and welding processes.
- **United Solar Systems Corp**'s (Troy, MI) triple-junction amorphous-silicon module could start to close in on the efficiency of other companies' crystalline silicon. The company recently announced that optimization of its triple-junction a-Si cells has resulted in higher initial and stabilized efficiencies.
- **Solarex**, Frederick, MD, within the next two years hopes to: increase average PV cell efficiency from 12.8 per cent to 15 per cent; heighten automation in module assembly and wafer handling; enhance module manufacturing throughput, yield and process control while cutting labour expenses; raise wafer production via reduced-kerf wire saws; develop bigger cast ingots for larger wafers; and triple capacity of commercial module manufacturing.
- **ASE Americas Corp.**, Billerica, MA—which is making PV modules based on edge-defined, film-fed growth (EFG) ribbon technology—is focusing on reducing EFG wafer, cell and module-manufacturing costs for a net reduction in module-production costs of 25 per cent. EFG cells could achieve an average efficiency of 15.5 per cent on 10 cm x 10 cm area wafers. ASE Americas will also seek to develop a front-surface texturing layer for light-trapping; an environmentally safe and reduced-cost diffusion glass-removal process; and an integrated method to accomplish cell interconnection, lamination and fabrication.
- **AstroPower Inc.**, Newark, DE, is attempting to optimize solar-cell processing and improve module-assembly in manufacturing. The firm wants to develop a 30 cm x 60 cm Silicon-Film™ solar cell (*TSL*, 9 December 1994, p. 308) and a manufacturing capability for a 4 ft. x 8 ft. Silicon-Film™ panel for utility-scale applications.
- **Various firms** are pursuing copper indium diselenide (CIS) technology by refining the manufacturing process to boost yield and limit production material defects. Although modules of CIS and related alloys are not currently in commercial production, the materials have shown great promise for high-efficiency, low-cost photovoltaics. (Source: *The Solar Letter*, 22 March 1996)

Contract on TiO_2 technology signed

New York officials and Direct Gain LLC, Cottekill, NY, have signed an agreement to identify potential markets and applications for a new type of solar cell based on titanium dioxide (TiO_2) and developed by Swiss Federal Institute of Technology scientists.

In this type of solar cell, a light-sensitive dye is chemically bonded with the TiO_2 semiconductor and, like chlorophyll, absorbs light, forcing an electron to the semiconductor material. This action results in a positive charge remaining on the dye molecule that is discharged through an electrolyte. The technology, suited to consumer electronics and hand-held devices, may appear in various colours.

Under the agreement with New York State Energy Research and Development Authority (NYSERDA), Direct Gain will identify manufacturers and products that could incorporate TiO_2 cells. NYSERDA and Direct Gain will initially investigate smaller, indoor applications that can be developed in the near term. As the technology evolves, larger-scale, long-term applications will also be identified.

Standish Industries Inc., a Wisconsin-based liquid crystal display manufacturer, will produce the cells as part of a joint venture with Direct Gain. National Renewable Energy Laboratory, Golden, CO, is investigating methods of improving the efficiency of the cells.

In other news, SunStone Design, a photovoltaic-design company, has been formed as a joint venture by Direct Gain LLC and KDA Industrial Design, Addison, ILL. The new company will bring together the experience of an industrial design firm and a PV market-development company. The result will be a company that knows how to design PV products with the customer in mind.

For the first time in the history of the PV industry, top industrial designers will be concentrating on PV-integrated product development as a focus rather than an afterthought. Until now, most module manufacturers have designed their products and expected customers to figure out what to do with them. Similar to the old Fordism [saying by Ford Motor Co. founder Henry Ford] "you can have it any colour you want as long as it is black", manufacturers built rectangular sheets of glass and let the original-equipment manufacturer worry about how to integrate PV into their product. With this new capability the company can now focus on the customers' needs first and then design a product to fit those needs.

In a related development, Greg Smestad, Seaside, CA, has signed a joint-venture agreement with Direct Gain LLC to manufacture and market do-it-yourself solar cell educational kits. The kits are based on the new dye-sensitized TiO_2 (the Graetzel cell) solar technology developed by the Swiss Federal Institute of Technology (EPFL).

The kits will teach students how solar cells work and include other topics of photosynthesis and nanocrystalline technology. These unique kits will allow students the opportunity to make their own chlorophyll dye from simple plant leaves. Additional information on the invention of the technology and other potential uses and experiments will be included. The kits will be sold through academic and environmental catalogues and retailers.

The agreement is expected to result in the formation of a new joint-venture company that would include the participation of a Swiss battery manufacturer, which is a licensee of the technology and is working on a line of its own products based on TiO_2 technology. (Source: *The Solar Letter*, 22 March 1996)

Hybrid fuel-cell car leading the way to distributed generation

The renewable-energy community and the hydrogen-fuel community are eyeing new links to strengthen their position as the United States' and the world's energy infrastructure is overhauled, speakers told the Seventh Annual US Hydrogen Meeting, held by National Hydrogen Association (NHA) in Alexandria, VA, 2-4 April.

The opportunity for hydrogen fuel-cell automobiles could also pave the way for renewable resources used to electrolyze water to produce the gaseous fuel, according to the Rock Mountain Institute (RMI), Snowmass, CO, who informed NHA about their work on the 300 mile-per-gallon-equivalent "hypercar" concept involving proton-exchange membrane fuel cells (PEMFC) that RMI and a group of industrial clients are exploring.

RMI in March concluded a multi-client proprietary strategic study with a team of about 12 industry participants, two-thirds of which are in the automobile manufacturing business, to help develop an inexpensive hybrid-electric hypercar that is 2-3 times lighter, several times lower in aerodynamic and rolling resistance, 1-2 orders of magnitude less polluting and comparable or superior in safety, performance, amenity and cost to standard internal-combustion automobiles.

Hydrogen car as solar entré

Hypercars appear able to obtain the distinctive advantage of electric propulsion without the disadvantage of batteries, the multi-client study said. Although the wheels would be driven by special electric motors, the electricity would be produced onboard from fuel and electronically recovered from braking energy for reuse. A small, 40 kilowatt, 0.5 kilowatt-hour buffer storage device, such as a high-power battery, superflywheel or ultra-capacitator, would mediate between electrical supply and demand.

This load-levelling would permit the onboard power plant to be small, light and inexpensive. Whether it is an internal or external combustion engine, a miniature gas turbine, a fuel cell or another sort of conversion device—each of which was analysed in the multi-client study—the power plant would need to produce only about 10-25 kWe or about 4-10 times less power than in today's cars or electric versions of them. Moreover, because hypercars would not be recharged from the grid, they would not need a special infrastructure.

Hypercars running on hydrogen or other gases would need so little fuel that the fuel tank could weigh several-fold less than, and range in size from 25 per cent smaller to 50 per cent larger than, a comparable gasoline tank. In addition, hypercars could afford to use relatively costly fuel, such as hydrogen electrolyzed from water by renewable energy or hydrogen reformed from natural gas. PEMFCs have an efficiency of 65 per cent when fuelled with hydrogen and achieve that maximum efficiency over a wide range of partial loads well-matched to common driving conditions. As a result, a PEMFC hybrid car could convert hydrogen into traction about 3-4 times as efficiently as today's cars convert gasoline into traction, thereby compensating for the costlier fuel and tank, and largely or wholly offsetting hydrogen gas's low energy content per litre.

A study by Directed Technologies, Arlington, VA, showed that if hydrogen were made by splitting water using 4¢-per-kilowatt-hour electricity, such as from off-peak retail power or cheap renewable energy technologies, the hybrid automobile's fuel would cost less per mile than a conventional car's petrol in America. (Extracted from *The Solar Letter*, 12 April 1996)

Business and technology briefs

The **Solarex** business unit of Amoco/Enron Solar has reported it entered into several strategic market alliances with international balance-of-system (BOS) manufacturers to provide cost-effective equipment that complements the Solarex line. The companies involved in the alliances are Ananda Power Technologies Inc., Nevada City, CA, which will provide solar charge-control, monitoring, safety and integrated Powercenter equipment; Morningstar Corp., Newtown, PA, which will provide PV charge-controllers; SEC Industrial Battery Co. Inc., Lower Gwynedd, PA, which will provide batteries; SHURflo Pumps, Santa Ana, CA, which will provide water-pumping equipment; Solar Outdoor Lighting Inc., Stuart, FL, which will provide sign and street-lighting equipment; and Trace Engineering, Arlington, WA, which will provide power inverters and solar charge-controllers. Solarex BOS say that the non-exclusive alliances, all but the one with Solar Outdoor Lighting being set up recently, were undertaken to provide Solarex distributors with the highest-quality BOS equipment world-wide at a prearranged discount. To further help the approximately 65 distributors working in 50 countries, Solarex is looking towards additional alliances covering enclosures and other equipment wherever needed. (Source: *The Solar Letter*, 12 April 1996)

Solar power to boost electricity grid

Queensland University of Technology (QUT) staff have built a solar system to feed power to Queensland's electricity grid. A photovoltaic system of eight solar modules, eight sealed gel batteries and a synchronous inverter has been set up at QUT's Brisbane campus to store solar energy before exporting it to the grid.

The project team has said that this was the first system using batteries to be connected to the state grid. Renewable energy is a proven compliment to Australia's energy production policy and currently supplies 12 per cent of Australia's total electricity. The system's installation has been beneficial in many ways. Being the first system of its kind on the grid, a lot can be learned, such as performance evaluation for different modes of operation, reliability of components, technical issues like start-up and shut-down, real and reactive power flows and safety.

For more information contact: Dr. Kame Khouzam, School of Electrical and Electronic Systems, Queensland University Systems Technology, GPO Box 2434, Brisbane, QLD4001, Australia. (Source: *Australian Science and Technology Newsletter*)

D. INTERNATIONAL AND NATIONAL PROGRAMMES

Australia

Solar's warm glow

While many Governments are worried by the levels of pollution caused by fossil and nuclear fuels, efforts to harness solar energy—often put forward as the best of the alternative energy sources—as a leading power source have proved disappointing.

Australian scientists are developing solar cells that are both extremely cheap and efficient and have the potential to produce electricity at rates which are lower than with existing fuels.

A team at the University of New South Wales in Sydney, the Centre for Photovoltaic Devices and Systems have been developing more efficient solar cells since 1975. In 1985 they made a significant break-through when they produced the buried grid technology which uses conductor strips buried within the cell to collect the generated electricity. Previously, the conductor strips lay on the surface of the cell.

That change resulted in an increase in efficiency of 10 percentage points and the technology has since been licensed to most of the biggest cell manufacturers in the world. BP Solar has used it in many important installations including the world's most efficient photovoltaic electricity-generating systems.

The Centre has remained at the forefront of solar research and by 1995 was producing cells with an efficiency of 24.5 per cent, where almost one quarter of the light energy falling on the surface is converted into electricity. However, it is the solar cells currently under development which show the most spectacular potential.

These new cells combine three important initiatives. First, a means of using extremely thin silicon layers has been developed. These cells are composed of five layers with a total depth of only 20 microns (half the thickness of a human hair) and use only one twentieth of the volume of the silicon material used in traditional single-layer cells, which have a thickness of 400 microns (0.4 mm).

Because of the peculiar physical properties of light penetrating these very thin layers, inferior and much cheaper material can be used in the manufacture—in fact, material up to 1,000 times less pure than that used in existing cells. Even with this poorer material, an efficiency of 15 per cent can still be achieved.

Second, the buried grid technology has been successfully adapted to the new cells. Third, the new modules can be assembled automatically, thereby greatly reducing manufacturing costs.

These three innovations will have an enormous impact in lowering the cost of producing electricity and it is expected that by the year 2000 installation costs for solar-generating plants will be reduced to less than $2 per watt peak (costs estimated in US dollars).

An installation of one watt peak is one which produces one watt of electricity during the sunniest period of the day, usually around noon. Experience has shown that, on average, solar cells produce five watt hours of electricity per day in suitable locations for each one watt peak of installation. A generating establishment costing $2,000, where the unit cost is $2 per watt peak, would produce 5 kilowatt hours of electricity per day over the life of the establishment, which could be expected to be about 30 years.

Allowing for overheads, production costs for such an establishment would be less than 20 cents per kilowatt hour (or about one-third the present cost of producing solar electricity). At that level, solar energy would be more viable as a significant power source for remote areas, such as the outlying islands of Indonesia, or countries where production costs are high because of lack of raw materials, as in Japan.

However, the team is confident that the technology being developed will be capable of much lower costs when in full production, which the team expects to take a further 10 years. Present estimates are that by 2010 establishment costs will have fallen well below 80 cents per watt peak. At that price solar electricity will be a viable, economic alternative to traditional forms of electricity production in most countries.

The replacement of traditional power stations by solar ones would overcome most of the pollution problems facing the world today.

Some problems will remain with storage of solar electricity. However, these can be overcome by a range of initiatives, such as introducing variable tariff rates to encourage maximum use during daylight hours, broadening the hours of direct availability by transmitting electricity across vast distances, and linking solar power stations to hydroelectrical schemes to give 24-hour availability.

This type of linkage already exists in the supply of electricity to cities in eastern Australia—peak load power is generated by hydroelectrical stations with water pumped back up into reservoirs during the night using off-peak electricity supplied by thermal power stations. (Source: *Financial Times*, 12 June 1996)

Cambodia

Solar ovens

A small plant has opened in Phnom Penh to manufacture simple, low-cost solar ovens. E&T Appropriate Technologies is aiming at the 8.4 million Cambodians who each day rely on wood for cooking. In a country with an average per capita income of $US 200, the company's challenge is reducing the price of the ovens so people can afford them. E&T's model sells at $70, although the company is looking to develop a model well below that price and for an international agency to subsidize the cost. (Source: *The Solar Letter*, 12 April 1996)

China

The programme on new and renewable energy development in China (1996-2010)

Introduction

As a follow-up to the 1992 Rio Summit—United Nations Conference on Environment and Development, the Chinese Government has put forward 10-point response strategies and measures to address the issues of environment and development in China, and clearly pointed out that "clean energy such as solar, wind, geothermal, tidal and biomass energy should be tapped and utilized in a manner going along local conditions". In China's Agenda 21, the Chinese Government has stressed again that the development of new and renewable energy plays an important role in sustainable economic development and environmental protection.

In view of long-term strategies of energy development, human society must seek for the sustainable development of energy resources. New and renewable energy, with no or little environmental pollution, will be the base energy in the future. To China, they are also important energy resources to make up the shortage.

China is the largest developing country in the world with over 900 million people in rural areas. In China, there are still over 110 million people leading their life without electricity, 5 to 8 per cent of the total population waiting for a clean drinking water supply, and about 70 million people living under the poverty line. Because of energy deficiency in the rural area, economic development has been seriously hindered. Furthermore, the shortage of fuel in rural areas has triggered excessive deforestation, which has destroyed the vegetation and deteriorated the eco-system. In this context, it will be of great significance to vigorously develop and utilize new and renewable energy, in particular, convert them into electric power for living and production in remote areas and offshore islands, so as to achieve the objective "to eliminate poverty and become better off".

To further promote the development of new and renewable energy in China, the State Science and Technology Commission (SSTC), the State Economic and Trade Commission (SETC), and the State Planning Commission (SPC) have jointly formulated the "Programme on New and Renewable Energy Development in China, 1996-2010", which has been approved by the State Council and distributed nationwide. The following are the excerpts of the programme.

1. Current status

China is rich in new and renewable energy resources. Its exploitable hydropower resources are about 378 million kW, 11 per cent of which have already been developed. Biomass energy resources, including straw and crop stalks, firewood, and all kinds of wastes, amount to about 260 million tons of coal equivalent, which makes up about 70 per cent of the energy used in daily life and about 50 per cent of the total energy consumed in the rural areas. Over China's 6 million square kilometres of territories, the total annual solar radiation resources exceed 600 kJ per square centimetre. The total wind energy resource is about 1.6 billion kW, about 10 per cent of which can be utilized. Geothermal energy is also a resource to be developed further.

During the past two decades, great progress has been made in the exploitation and utilization of new and renewable energy resources in China. These energy resources have become indispensable constituents of the energy consumption system. At present, different kinds of new and renewable energy resources provide about 300 million tons of coal equivalent, which has played an important role in promoting the national economy and in meeting the daily energy demands of vast rural areas and remote areas.

Utilizing solar energy has entered a new development stage

Utilization of solar energy in China has found its main expression in solar water heaters, cooking stoves, passive solar paneled houses and solar dryers. According to incomplete statistics published in 1993, solar water heaters installed reached 2.3 million square metres, passive solar houses 1.8 million square metres, solar greenhouses 342,000 hectares, solar cooking stoves 140,000 sets, and solar dryers 13,200 square metres.

The application of solar photovoltaic power generation started in China in the 1970s, but it had seen little progress until 1982. Solar cells are now mainly used in telecommunications systems and in remote areas without electricity supply. The annual sales volume has reached about 1.1 mW. There are still 28 counties, nearly 1,000 townships and several thousands of islands without electricity supply in China. Photovoltaic power generation has played and will play a more effective role in solving electric power supply issues in these areas. In the fields of solar cell research, the efficiency of an applicable single-crystal silicon cell has reached 12 to 13 per cent, and that of polysilicon cell, 9 to 10 per cent.

2. Objectives and tasks

Two-phase objectives:

The first phase (1996-2000): the utilization of new and renewable energy should reach 298 million tons of coal equivalent.

The second phase (2001-2010): the utilization of new and renewable energy should be raised to 390 million tons of coal equivalent.

Objectives

In the next 15 years, the major objectives of new and renewable energy development are to raise conversion efficiency, lower production costs, and enlarge their proportion in energy consumption structure. Major breakthroughs in new technologies are to be expected. Large-scale and modern production, applying mature technologies is to be realized so as to establish an integrated production and service system. These efforts will make contributions to environmental protection and sustained development of the national economy. The amount of new and renewable energy used shall reach 390 million tons of coal equivalent. The objectives are to be realized in two phases.

The first phase: from now to the year 2000. Most of new energy technologies will approach or reach advanced world levels by strengthening research and demonstration. Some mature technologies should be industrialized as quickly as possible, brought to extensive applications and put into the market; the traditional low-efficient utilization of biomass energy should be gradually improved. The new and renewable energy resources, such as wind and solar energy, should be used to solve the power supply problems in remote areas and islands. The utilization of new and renewable energy should reach 298 million tons of coal equivalent.

The second phase: from the year 2001 to 2010. New energy technologies should be popularized nationwide, and advanced industrial and research systems be established. Main technologies should be applied to large-scale production, and the utilization of new and renewable energy should be raised to 390 million tons of coal equivalent.

Tasks

To realize the above-mentioned objectives, the main tasks include that in the future 10 years at the turn of the century and the beginning of the next century, a group of key R&D projects concerning the technologies of great value to the development of the national economy and ecological environment should be launched. The focus will be on strengthening the pilot demonstration of these technologies, transforming them into productive forces, promoting industrialization and realizing commercialized production as soon as possible.

Solar energy

A major aspect of these tasks is expanding the utilization of solar energy and focus on the popularization of energy-saving solar heating buildings, solar water heaters, and photovoltaic power generation systems. It is necessary to mass-produce solar heating buildings and solar water heaters, especially to develop high-efficiency, low-cost solar cell components and associated key technical equipment so as to reduce the system cost. The construction of photovoltaic power stations in nine counties without power supply in Tibet should be completed before the year 2000. Application of small photovoltaic systems should be popularized. Distributed and centralized megawatt-level photovoltaic demonstration power stations connected to power grids should also be established. The total amount of utilized solar energy is expected to reach 1.23 million and 4.67 million tons of coal equivalent in the year 2000 and 2010 respectively.

3. Response strategies and measures:

(1) To deepen understanding and improve management.

The development of new and renewable energy plays an important role in improving ecological environment and in balancing supply and demand of energy. It is very important to solve the problem of energy supply to rural areas, especially remote areas in the country. Governments and authorities concerned at different levels should deepen their understanding of the strategic significance and roles of new and renewable energy resources, regard the promotion of their utilization as a fundamental energy policy, and strengthen the management. The development of new and renewable energy should be linked with the overall plan of national economic development and listed in state financial budget.

(2) To formulate preferential policy.

Development of new and renewable energy is an undertaking benefiting the public and of far-reaching significance. At present most technologies in the field are at the initial stage of development, with the production small in scale, low in profitmaking and weak in competitiveness. They should be protected by States' macro control policies. Formulation of the policies favourable to the development of new and renewable energy is the strongest support.

- (a) To increase financial support and investment;
- (b) To expand credit scale and provide low interest loans;
- (c) To formulate policies on tax reduction and exemption, price subsidy and incentives.

(3) To intensify scientific research and demonstration on new and renewable energy.

(4) To promote industrialization.

(5) To encourage international cooperation and introduce advanced foreign technologies and capital.

(Source: *China Science and Technology Newsletter*, 20 June 1996)

Germany

Fraunhofer Institute for Solár Energy Systems

Profile

The Fraunhofer Institute for Solar Energy Systems (ISE) Germany conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis in industrialized and developing countries. For this purpose, it develops systems, components, materials and processes in the areas of thermal use of solar energy, solar architecture, photovoltaics, electrical power supplies, chemical energy conversion and storage and rational use of energy. The Institute's work ranges from investigation of scientific and technical fundamentals for solar energy use, through the development of prototypes, to the construction of demonstration systems. The Institute plans, advises and provides know-how and technical facilities. The Institute employs a staff of more than 300.

The research fields covered are:

- Photovoltaic systems and measurement technology;
- Materials;
- Solar cell technology;
- Thermal and optical systems;
- Chemical energy conversion and storage.

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Solar energy for power supply in non-electrified regions

Promising and successful technologies based on renewable energy do exist, which could supply billions of people with electric power. Due to technical and economic constraints, most underdeveloped regions of both developing and industrialized countries will not gain access to centralized electricity grids. Instead, the off-grid power supply by electricity from sunlight, so-called photovoltaic (PV) energy will play an ever-increasing role for rural energy supply.

Basic needs and desires in the domestic sector are lighting and radio/TV communication. Public services like schools, health and community centres need electric equipment such as telephones etc. Water supply and disinfection are other essential requirements that need energy. PV energy can be the key to an environmentally friendly, sustainable and economical off-grid power supply.

The Fraunhofer Institute for Solar Energy Systems has been at the forefront of research and development of solar energy for more than 10 years. It is the largest solar research institute in Europe, financed by public and private sources.

The Department for Photovoltaic Systems and Measurement Technology is the mediator between fundamental research and application in the field. They are involved in various national and international projects and joint ventures for grid-connected and off-grid applications of PV energy.

The introduction of new technologies affects not only technical aspects but also raises economic, social and organizational questions.

Therefore, the Fraunhofer Institute for Solar Energy Systems founded an interdisciplinary group combining technical, social and economic expertise. They are working together on the development, introduction and adaptation of renewable energy systems for remote regions.

In cooperation with local partners, the Fraunhofer Institute for Solar Energy Systems helps to create expertise in countries where solar energy is applied. In joint projects, experience is gained and project results are evaluated scientifically.

Local partners may be research institutes, universities, electric utilities, government and non-government organizations.

The Institute develops PV products and systems. Their priority is the definition and implementation of quality recommendations that meet the stringent conditions for off-grid applications. The technical products must be user-friendly, highly reliable and durable. Low investment costs, low maintenance, high safety standards according to international organizations, environmental friendliness and recycling ability are important requirements as well.

Comprehensive experience in testing and developing components for photovoltaic systems led to the development of quality requirements and standardized test procedures.

The Institute has developed and tested appliances and components for small-scale PV systems including electronic ballasts, refrigerators, water pumps, charge regulators, battery state-of-charge indicators and inverters for remote applications. A European market review of low-voltage DC appliances was conducted at the Institute.

One of the worldwide leading photovoltaic calibration laboratories is based at the Institute. A special laboratory for development and testing of low-voltage DC components was recently set up.

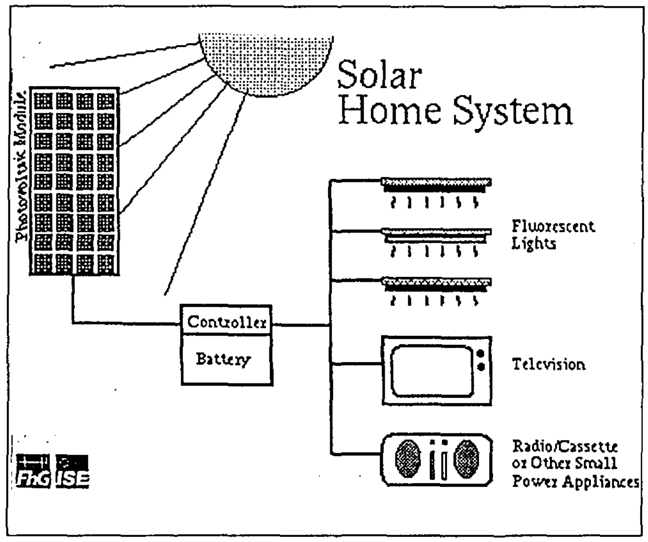
The adaptation of a product, developed in the laboratory, to its application under real-life conditions is a long process. The involvement of the users, producers and suppliers in the countries where the products are applied is essential. They aim to use locally produced components wherever possible.

In Nepal, a resource study at the village level was conducted and a spontaneous market development of Solar Home Systems growing from the consumers' own initiative was investigated.

A sustainable development of renewable energy requires the strengthening and broadening of existing human expertise in the countries involved. Therefore, the Fraunhofer Institute for Solar Energy Systems arranges training courses on PV energy resources, system technology and application experience.

These courses are adapted to special target groups such as decision makers, planners, technicians or scientists.

The Institute may help to organize "training on the job" for guest scientists, who want to become involved in joint research or technical development projects. The Institute can help to establish local expert centres and support the planning, purchasing, installation and operation of photovoltaic laboratories.



A typical Solar Home System for private owners provides light and power for TV and radio. It is estimated that several million people worldwide enjoy the modern energy services provided by Solar Home Systems.
(Source: Information Sheet, Fraunhofer Institute for Solar Energy Systems)

Solar house, Freiburg: from the vision to application

The Self-Sufficient Solar House belonging to the Fraunhofer Institute for Solar Energy Systems ISE has a new purpose and a new name: "Solar House, Freiburg".

Over the last four years, the house has become the symbol of energy efficiency. Ninety-nine per cent less heating energy means: a house in Central Europe can be built such that heating is marginal. With a 60 per cent reduction in electricity consumption, the inhabitants have demonstrated how easy it can be to "use your head instead of a switch".

The complete hydrogen system, the first such system to be installed in a residential building, is characterized by further superlatives: an autonomous energy supply throughout the year due to seasonal storage, a 1 kW fuel cell as a co-generating power plant in "pocket size", heating without a chimney by non-polluting catalytic combustion of hydrogen.

The results of the project, which was supported by the German Federal Research Ministry, the State of Baden-Württemberg and the City of Freiburg, have long since aroused the interest of industrial concerns. The working group, "Solar Building", at the Institute develops concepts on commission to industry for solar lowest-energy buildings.

And what about the Solar House, Freiburg? It stands for a new vision: Apply complex knowledge to the simplest possible system technology. The research group in Freiburg is now converting the house to this new purpose. From autumn, it will be accessible again with offices and a seminar room. New concepts include economic miniature heaters for minimal heating demand. Thermotropic glazing will be added to the façade with transparent insulation next year. Acting as a large-area optical switch, the thermotropic glazing will replace complex mechanical shading devices and thus can reduce the costs for solar heating by a third. Lastly, the solar house will be connected to the grid and feed its excess from the photovoltaic system into the public electricity supply. (Source: *Press release*, Fraunhofer Institute for Solar Energy Systems ISE, 24 July 1996)

Photovoltaics about to enter the market: successor programmes in Europe, USA and Japan

Solar radiation on the Earth

Solar radiation fluctuates strongly all over the Earth due to the alternation of day and night, the seasons and cloud or fog. In Germany, the differences are extreme: the solar radiation can range form a maximum of 8 $kWhm^{-2}$ per day to 0.1 $kWhm^{-2}$ on an overcast winter day. The annual total solar radiation on a surface tilted 45° and oriented to the south is between 900 and 1,200 $kWhm^{-2}$ in Germany.

In the sunny regions of the Earth, twice as much solar energy is available (Sahara 2,200 $kWhm^{-2}$, Israel 2,000 $kWhm^{-2}$).

Many thousands of safe and reliably operating PV systems prove that photovoltaics is technically feasible. Only the high prices prevent it from becoming more widespread. Today, the price for one kilowatt-hour of solar electricity is around two marks. As has been recognized everywhere, a drastic price reduction can only be achieved by mass production of raw materials, solar modules and system components. However, it is not clear when the time for this decisive step into the solar future will begin and which initiatives will help it to come faster. In view of the danger of a global climatic change, which can be largely attributed to the combustion of fossil fuels, many countries have expanded their programmes to develop renewable energy sources. There is no doubt that they will be the fuels of the future, but now they are needed more quickly and urgently than expected. Thus, many countries are trying to encourage their own solar research and development by funding programmes. The German "1000 Roofs Programme" has set an example which is being followed by a good number of successor programmes in other countries. They had obtained comprehensive information about the German programme and invited German representatives to give lectures in their own countries.

The Japanese Government is following its proven approach for success and is attempting to build up a powerful photovoltaic industry on a long-term and large-scale basis. There is discussion in Japan of installing a total of 4.6 gigawatts of photovoltaic power by 2010. That would be enough for around 70,000 roofs. In the main, grid-connected PV systems are to be installed on house roofs. During this long-term programme, an annual production capacity of around 100 megawatts could be established by the year 2000, and then even 500 megawatts by 2010. However, Japan is moving cautiously: as a start, only a 700 Roofs Photovoltaic Programme has been approved.

The SOLAR 2000 Programme announced by the US Government has set ambitious goals. By the year 2000, the photovoltaic market should have been expanded to 1,000 megawatts. Of course, the major part of the future market is reserved for the national industry.

Various funding programmes have been running for several years in Austria and Switzerland, which have provided a solid base for the industry there.

Research and development of photovoltaics is funded in all significant industrial nations. Apart from the reasons of protecting the environment and increasing the national energy autonomy with renewable solar energy, the potential of photovoltaics as a high-quality export product is also playing an important role. Germany, Italy, Japan and USA are the countries with the highest research budgets, each with around 100 million marks per year. At present, support has declined somewhat, but over the past 20 years, the German Ministry of Research and Technology has supported photovoltaics with a total of a thousand million marks. This far-sighted policy brought the German industry to a leading position in technological development.

The 1000 Roofs Programme has shown that the application of photovoltaics is meaningful in Central Europe. Now, further measures must follow to create a stable local market. The German photovoltaic industry could guarantee itself an important place in the promising export market to sunnier countries. A strong internal market is a recommendation for the quality of the PV products. Combined efforts of the State and industry are needed to introduce photovoltaics to the local and the export markets. Only a continuous and far-sighted approach can guarantee a successful starting position for both industry and research. (Source: Information Sheet, Fraunhofer Institute for Solar Energy Systems)

India

India signs solar energy agreement with Australia

An agreement between India and Australia on cooperation in solar energy has been formalized. The Memorandum of Understanding (MoU) was signed at the University of New South Wales (UNSW), Sydney. UNSW is at the forefront of Australian research into and development of solar systems, photovoltaic cells and storage battery technology.

Among the principal aims of the agreement are:

- Training of Indian engineers, architects and administrators to help India create expertise in the use of non-conventionally sourced energy and energy-efficient building design in the health sector;
- Provision of consultancy services for building design and implementation in projects as diverse as small village health centres and large teaching hospitals;
- Development of a demonstration project in India; and
- Establishment of a base for future cooperation between India's Hospital Services Consultancy Corporation (HSCC) and UNSW.

While in Australia, the Indian delegation viewed solar energy centres at UNSW and visited solar energy sites in Sydney and the Northern Territory. (Source: *Tech Monitor*, May-June 1995)

Five companies submit proposals for western India solar project

Five international companies have submitted proposals to build a solar power plant of up to 300 megawatt capacity in the western India state of Rajasthan.

The companies that responded to the Government's solicitation were Amoco-Enron, Kenetech Solar Energy Venture, Sun Source India, Goyal Gases and Energy International. The project would be constructed under a build-own-operate agreement.

Energen International, a joint Sri Lankan and German company with ties to India's Larsen & Toubre offered the lowest rates for the power that would be supplied by the facility. The company proposed building a 200 MW plant that would supply electricity at a rate of 2.24 rupees per unit for a 25-year period. Amco-Enron proposed a price of 2.25 rupees with an annual escalation clause of 9 per cent.

Bidders for the solar project were required to quote a rate for electricity to be sold to the Rajasthan Electricity Board. The state government notified potential participants that it would not provide any subsidies for the project. (Source: *International Solar Energy Intelligence Report*, 30 October 1995)

Amoco/Enron, Rajasthan sign PV power-purchase contract for 50 MWp

Amoco/Enron Solar Power Development has signed a 25-year power-purchase agreement with the Rajasthan State Electricity Board for the sale of up to 50 megawatts of electricity from what is expected to be the world's largest photovoltaic power plant to be built in the Thar Desert near Jaisalmer in Rajasthan state, India.

The accord comes three months after the two parties signed a letter of intent calling for the power to be bought on an escalating scale beginning at about 8 cents per kilowatt-hour. (Source: *The Solar Letter*, 22 March 1996)

India to offer low-cost loans to consumers for photovoltaic products

India's Government will give loans at 2.5 per cent interest to consumers to buy domestic photovoltaic (PV) products, according to the Indian Renewable Energy Development Agency (IREDA).

The World Bank already has given a $57 million loan to popularize domestic use of solar energy during the Government's ninth five-year plan, beginning in 1997, which will be used to extend such loans. Loans will be given to the extent of 90 per cent of the total equipment cost and will be repayable in 10 years. The primary reason for formulating the project is to create a market for PV-based products.

The Indian Government wanted solar energy to be used for water pumping and lighting in remote areas as well as for nursing homes, hotels and restaurants. Even farmers will be entitled to the loans to purchase solar-powered agricultural pumps. The idea of giving a thrust to solar PV was to enable domestic power consumers to become independent of the power grid.

Farmers and domestic power users should be energy self-sufficient, having their own source of energy while supplementing power to the grid, IREDA said. Power produced by conventional means should be made available exclusively for heavy industry. The federal Government also would extent loans to manufacturers of solar PV products but the interest rate would be 16.6 per cent.

The Government would also like to purchase surplus power from those who use solar energy. Policies and experimental projects in this connection were being worked out. The Ministry of Non-conventional Energy Sources launched a programme to install 2,000 solar pumps. So far, 1,200 pumps have been installed, and the rest will be done soon.

By the end of the eighth five-year plan in 1997, 7 megawatts of solar power would be produced in India and the figure would be doubled by the end of the next plan. Power also is being made available to farmers for free in states that produce power by conventional means. This was an unviable proposition, but once PV pump use is popularized, it could alleviate the problem, IREDA added.

IREDA is concentrating on harvesting wind and solar power, and with the vast solar potential there will be an all-out effort to promote it. (Source: *The Solar Letter*, 1 April 1996)

India's huge market, technical prowess, low-cost labour beckon to investors

Foreign investors should find India ideal for setting up renewable-energy projects and for the manufacture of equipment for this sector, even for exports, according to India's Minister for Non-conventional Energy Sources (MNES). India provides the largest domestic market and, with its highly qualified technical manpower and cheap labour, can help cut manufacturing costs substantially, he said.

An attractive package of incentives is already in place in most states. This offering includes the facility for wheeling, banking and third-party sale and purchase by state electricity boards at a remunerative price of Rs 2.25 ($US 1 = Rs 36) per kilowatt hour with a 5 per cent annual escalation for power from renewable sources.

The MNES has issued guidelines for consideration and adoption by state governments and SEBs for a uniform policy on power from non-conventional energy sources. The states have been asked to offer the most attractive package of incentives to encourage private-sector investment in this sector.

More than 100 joint-venture projects have been concluded during the past two years with foreign collaboration. Most participants are from the United States, Russia, Sweden, Norway, Denmark and the Netherlands, covering diverse renewable energy areas such as wind, solar, photovoltaics, small hydro projects, biomass, co-generation, waste use and alternative fuel.

India also has progressed in wind energy with about 600 megawatts of capacity installed. The wind-power sector in India is rated as the fastest growing in the world as, by the end of the eighth five-year plan in March 1997, the country is expected to become the second-largest wind-power producer, behind the US.

Progress deemed significant has been made in other areas, with more than 250,000 solar PV systems installed for an aggregate capacity of 17 megawatts. Annual PV module production has reached 7 MWe. (Source: *The Solar Letter*, 1 April 1996)

Solar equipment

Aditya, the country's first shop for solar equipment, was recently inaugurated in New Delhi. The Delhi Energy Development Agency will operate the shop near Connaught Place and will sell solar geysers, solar cookers, and other solar-powered items produced by Bharat Heavy Electricals Ltd. and other public-sector units. (Source: *The Solar Letter*, 12 April 1996)

Iran

Solar energy

National Power Generation and Distribution Co. has announced it will harness solar energy for commercial purposes, aiming to produce 5 per cent of Iran's electricity supplies from this source. This announcement follows a speech by the Iranian Minister of Culture and Higher Education that the country's solar resource amounted to more than 3,000 times the energy consumption of the Islamic State. Three government agencies in Teheran recently sponsored the First International Conference on Solar Energy for Islamic Countries. (Source: *The Solar Letter*, 12 April 1996)

Ireland

Solar energy in Ireland

Irish initiatives such as the highly successful Alternative Energy Requirement have acted as "pump-primers" for renewable energy. In 1995, the National Microelectronics Research Centre (NMRC), based at University College Cork, initiated a project to be undertaken in 1995 with the support of the EU ALTENER Programme, to address the need for a body of knowledge in all of these areas. Subcontractors in carrying out the work were Hyperion Energy Systems Limited, of Watergrasshill, Co. Cork. Its aims were to establish a national resource to help in assessing the potential of wind, hydro, and photovoltaic projects in Ireland and to assemble the expertise necessary to permit fully informed feasibility studies to be carried out in the areas of wind power; solar (specifically, photovoltaic) power; and hydro power.

The project entailed the establishment of panels of relevant expertise in the above areas, and the production of documented guidelines outlining the procedures to be followed in carrying out feasibility studies in these areas. The study also involved carrying out three feasibility studies, prior to preparing the guideline documents for each energy source.

Solar energy

The Altener project concentrated its attention specifically on photovoltaic (PV) solar energy—that is, the use of solar cells. PV systems consist of clusters of solar cells, enclosed in a glass frame. They have no moving parts, they operate quietly without emissions, and they are capable of long lifetimes with little or no maintenance.

However, even though sunshine may appear to be in short supply in Ireland, it is not all that bad. Daily average solar radiation falling on a horizontal surface of one square metre in Ireland varies from about 2.6 kWh in the north to about 3.0 kWh in the south. This is not insignificant, and PV systems do offer the possibility of electricity in low-charging power applications remote from the national grid. Examples would include electric fences, remote water pumping, weekend caravans and homes, and any other applications requiring battery charging in remote areas.

Apart from these small-scale applications, there is already one larger-scale PV application, presently located at Fota in East Cork. This plant has a capacity of 50 kWp ("kilowatts produced"). The Altener study looked at the feasibility of resiting it in the proposed Renewable Energy Park in Mallow, in North Cork. In this location, 25 kWp would be grid-connected and mounted on an independent structure; 10 kWp installed in commercial buildings; 10 kWp in a "hybrid" system (combined with auxiliary power sources); and a 5 kWp system for standalone applications such as pumping and refrigeration.

However, although PV systems are reliable and have low operating and maintenance cost, they remain the most capital-intensive of all renewable energy technologies. In all probability, it is passive and active solar systems that will prove to be of greatest utility in Ireland. Passive systems utilize the heat radiated by the sun through suitably located glass structures in buildings; active systems use solar collectors to collect heat from the sun for distribution to other parts of the building. A different study carried out by Hyperion and Cork County Council examined the application of active solar thermal energy, among other sources. It concluded that at least 65 per cent of the domestic and commercial buildings in the area (such as guest houses and hotels) were suited to the installation of solar thermal systems.

There are two basic kinds of active solar thermal systems available on the market. One is the flat plate collector, which is constructed from a flat plate of copper, aluminium or steel, through which the waterways are woven (and the surface painted matt black). The other is the evacuated tube collector, in which a matt black absorber plate is mechanically bonded to a heat pipe, and this assembly is contained within an evacuated glass tube. The condenser, which is the heat transferring part of the collector, is an extension of the heat pipe, and extends beyond the glass tube into the manifold where the liquid to be heated is circulated. The entire heating process may be monitored and controlled by a microprocessor-based controller.

The evacuated tube is more efficient than the flat plate collector, over the range of operating temperatures. However, it is also more expensive.

Currently, only 2 per cent of Ireland's energy is supplied from renewables. Over the coming two decades, this figure could easily be doubled—or more than doubled. This will not solve the problem of meeting the country's energy needs, or reducing emissions to an acceptable level. However, it will help. Additionally, it can bring employment with it: renewable energies tend to be more labour-intensive than the highly capital-intensive large-scale fossil-fuel based technologies. (Source: *Technology Ireland*, March 1996)

Israel

Increased use of solar power seen for Israel's rural areas

Israel's kibbutzim have embarked on a policy to increase the percentage of solar power used in the management of the country's rural agricultural settlements.

Kibbutz Samar, in the Arava desert, is the first settlement to build its own power plant using photovoltaic cells to produce electricity. An AC converter links the system of solar cells into the kibbutz's electricity grid. Energy not used by the kibbutz is fed into Israel's national grid.

The project, which involves researchers at the National Solar Institute at Ben Gurion University in Beersheva, compiles hourly measurements of the angle, direction and intensity of the sun, wind speed and temperatures at 10 locations in the Negev desert, and then adjusts the direction of the solar cells to fit the climatic conditions of the area.

The kibbutz has allotted an area of five dunams for the solar cell "farm," as it is called by the National Solar Institute. The pilot project has received has received more than $1 million in funding from Israel's Ministry of Environment. (Source: *International Solar Energy Intelligence Report*, 4 March 1996)

Israeli bill would end IEC monopoly, open up market to independents

The Israeli Government has proposed a bill that would breach Israeli Electric Corp.'s (IEC) power-supply monopoly and open up the energy market to producers of alternative energy sources while extending the franchise of IEC by an additional 10 years.

The bill calls for opening up the generation sector for private manufacturers of alternative energy sources. Under the bill, private producers may generate up to 10 per cent of the country's electricity production; a further 10 per cent may be imported, theoretically making it possible for the largely agricultural countries surrounding Israel to generate power from biomass; and private producers may sell electricity directly to consumers instead of having it fed into the grid. IEC would transmit the power for the private producers for a fee to be set by a public authority established under the law.

Plans are being made that could require IEC to allocate a portion of its development budget for solar and wind energy. IEC would also have to buy a portion of its electrical output from producers generating energy from solar and wind facilities.

IEC has drawn up a master plan to build large clusters of wind turbines on the Golan Heights in partnership with Syria. The plan encompasses 270 wind turbines built over six years for $70 million. Through the offices of Israel's Ministry of Energy, negotiations are being held with a group of Palestinian investors to establish wind farms in the West Bank, which has potential for a further 400 MWe. Egypt and Syria have a wind-power potential deemed major. One year ago, Egypt inaugurated a wind farm of 250 turbines at Hourgada on the Red Sea.

IEC also has announced that is has approved a 7.8 MWe wind farm near Yodfat in the lower Galilee region of Israel. The $8 million installation will be built in two stages starting with five 300 MWe turbines this year and another 21 after receipt of appropriate licences.

IEC also will invest $25 million to create a wind-energy facility in Eilat in southern Israel on the shore of the Red Sea. The 70-turbine wind farm will create 20 MWe of energy for area residents' use. Eilat engineers believe the project will create cheaper energy than what can be obtained by using solar energy. (Source: *The Solar Letter*, 12 April 1996)

Israeli sunshine in the pipeline

Technologists in Israel have overcome one of the biggest single obstacles to the development of solar power for industrial use by devising a process which, in effect, transports sunshine through a pipeline.

A chemical "heatpipe" system, developed by technologists at Israel's Weizmann Institute of Science, promises safe and efficient transmission of energy over long distances.

The system could break a vicious circle which has discouraged investment in solar power generation. Until large solar power plants are started, there is often no incentive to build a long and expensive electric transmission line—and few investors are prepared to build a solar plant until they have the means to get the power to market.

The system has three stages. First, solar energy collected in sunny and otherwise unproductive desert areas is concentrated and used to drive a chemical process at high temperatures.

Then the gases formed during the process are cooled and stored or transported to distant industrial centres where the energy is needed. Finally, the chemical process is reversed, releasing heat that can be used to run turbines generating electricity.

In the first part of the process, solar energy is absorbed in a special chemical reactor (reformer) where methane and other hydrocarbons are converted into synthesis gas (a gas mixture). The energy-rich mixture can be stored or sent by pipeline to the point of use.

In the third stage, the energy present in the synthesis gas is recovered by means of a methanator, a component of the chemical heatpipe, which converts it back to methane, and in the process releases heat which can be used in many ways.

The methane produced by the methanator can be returned to the solar plant to be used again for the production of synthesis gas, thus completing a closed loop system that neither uses fossil fuels nor emits gases into the atmosphere.

The feasibility of this concept has been demonstrated by Weizmann's materials research department. Israel's Ministry of Energy is to join the Institute next year in the development of large-scale industrial application.

Weizmann's solar facility comprises 64 giant computer-controlled mirrors that track the sun and concentrate its energy on to a 54 m receiving tower. It is being used in conjunction with a wide range of energy-generation, storage and transport experiments. Their potential range of application is enormous.

The Weizmann solution to storing and transporting solar energy by pipeline is likely to encourage substantial further research and development worldwide. Several recent studies have concluded that solar thermal technologies should be able to provide power within a few years at costs broadly competitive with the price of electricity derived from fossil fuels.

The sheer abundance of solar energy suggests that it will be the foundation of a sustainable world energy system a century from now, observes the Washington-based Worldwatch Institute. (Source: *Financial Times*, 12 June 1996)

Japan

New Sunshine Programme

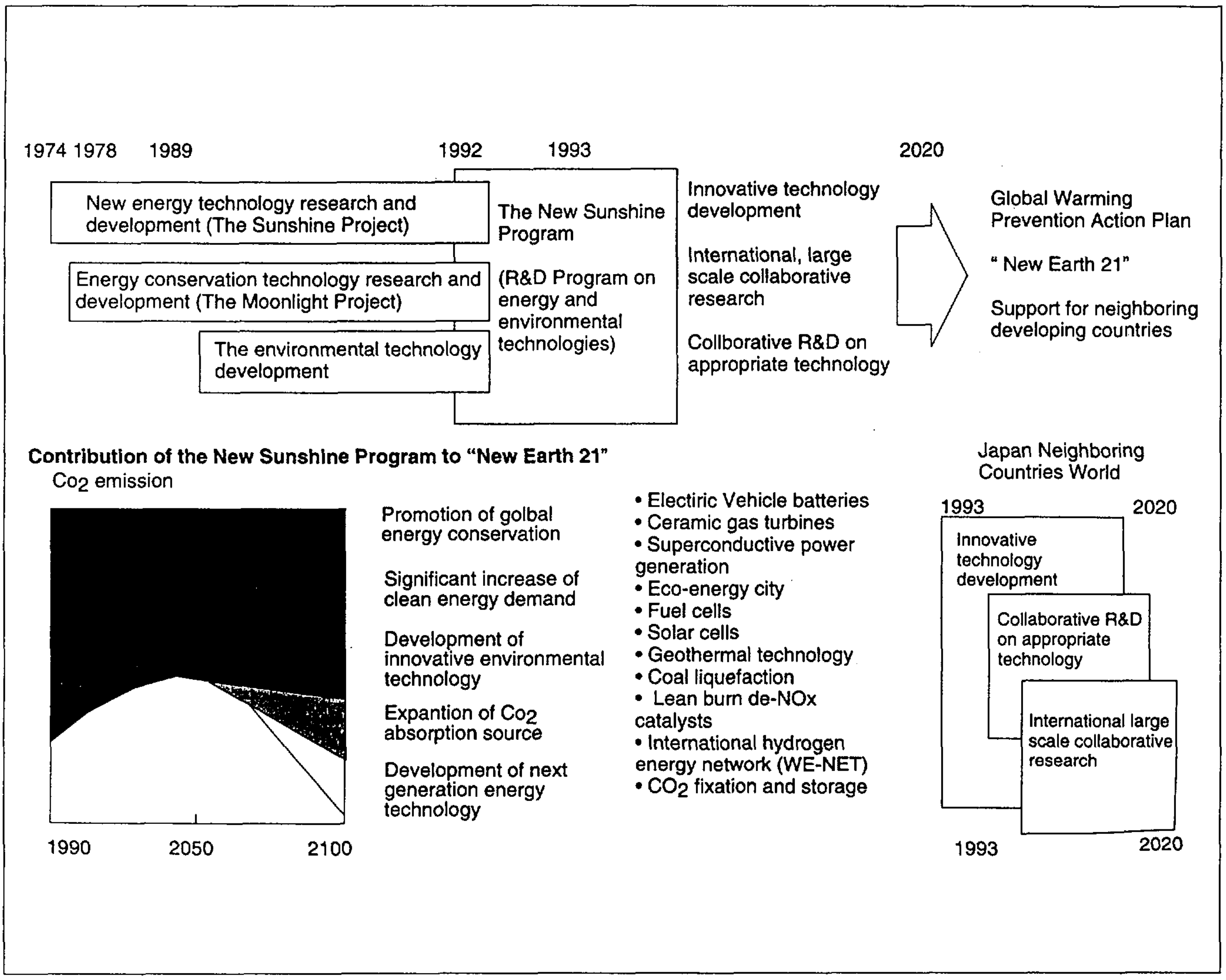
1. Purpose of the New Sunshine Programme

People are seriously concerned about environmental problems such as global warming, which are caused by expanding socio-economic activities.

In this respect, Japan needs to fully contribute to the world by using the accumulated experience in energy and the environment as a driving force for research and development in these fields. Great contributions are possible with positive cooperation in international research among developed countries and through research support and technology transfer to developing countries.

The Agency of Industrial Science and Technology of the Ministry of International Trade and Industry started the Sunshine Project in 1974 to develop new energy technology. The Moonlight project was started in 1978 to develop energy conservation technology. Both projects successfully maintained R&D schedules for energy subject areas under the close cooperation of industry, government, and academic organizations. These projects have been steadily providing effective results for basic technology, practical applicants, and application of peripheral field.

The Agency of Industrial Science and Technology started the Research and Development Project on Environmental Technology in 1989.



Technology development for each of the three projects (new energy, energy conservation and environmental technology) need to be operated under a close mutual relationship based on a comprehensive viewpoint because energy utilization and environmental issues such as global warming are closely interrelated. Also, from a technological standpoint, new energy development, energy conservation, and environmental measures overlap. Consequently, flexible operation of these projects will ensure that the progress in developing these technologies will be efficient and accelerated.

Thus, the Agency of Industrial Science and Technology started the New Sunshine Programme by unifying the existing Sunshine Project, Moonlight Project, and Research and Development Project for Environmental Technology. The objective of the new programme is to develop innovative technology to create sustainable growth while solving energy and environmental issues.

2. System of the New Sunshine Programme

The New Sunshine Programme comprises the following three technological systems:

1. Innovative technology development: the development of innovative energy and environmental technology is acceleratedto implement the Global Warming Prevention Action Plan, while focusing on important subjects over the course of progress.
2. International, large-scale collaborative research programme: Promoted to implement "New Earth 21".
3. Collaborative R&D on appropriate technology: The collaborative research and accelerated development programme is promoted for fitting energy and environmental technology to the conditions of the partner county to ease energy restrictions and address environmental concerns in neighbouring developing countries.

The innovative system technological subjects were initiated with the New Sunshine Programme in addition to the continued accelerated implementation of research and development of subjects such as solar photovoltaic cells and fuel cells. These new subjects were derived from the results of the Sunshine Project and Moonlight Project and are expected to yield significant medium- to long-term benefits.

Outline of New Sunshine Project

Technological System	Outline	Project Example
Innovative technology development (For the Global Warming Prevention Action Plan)	Accelerated development of innovative energy and environmental technology to implement the Global Warming Prevention Action Plan, focusing on important subjects during the project.	- Development of innovative solar energy technologies such as amorphous solar cells; - Development of innovative geological energy technologies such as the deep geothermal resources survey; - Development of innovative coal energy technologies such as bituminous coal liquefaction; - Development of innovative fuel cell power generation technologies such as with the molten carbonate fuel cells; - Development of applied superconductivity technologies for superconducting generators; - Development of innovative technologies for ceramic gas turbines; - Development of innovative technologies for distributed cell power storage; - Development of innovative network system technologies for wide-area energy utilization (Eco-Energy City).
International large scale collaborative research programme (Promotion of the Earth Regeneration Programme)	Advancement of joint international research under Japanese leadership; Innovative large-scale research projects such as "The Earth Regeneration Programme" which have to be implemented worldwide and which are vital for the whole world.	- Development of international clean energy system for hydrogen utilization (WE-NET) and others; - Development of global environmental technologies such as CO_2 fixation and storage; - Development of waste gas denitridation catalyst technology for diluted-fuel engines (lean-burn engine technology) and others.
Collaborative R&D on appropriate technology (Support of neighbouring developing countries)	Collaborative research and development programme to provide suitable energy and environmental technology for local conditions to ease energy restrictions and address environmental concerns in neighbouring developing countries.	- Development of solar energy utilization technologies such as photovoltaic power generation and solar systems for industrial applications; - Development of coal utilization technologies such as coal liquefaction.
(Source: *JETRO*, April 1995)		

Solar energy technology

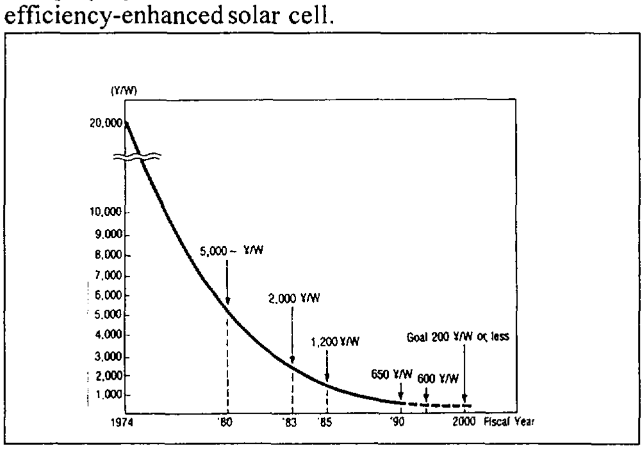
Development of solar cell production technology

1. Objectives

The solar power system using sunshine energy is a clean energy source that can generate electricity with no waste. It has thus immense value in terms of energy security and global environmental issues. Unfortunately, sunshine has a low energy density, and varies greatly with natural conditions. Another disadvantage is that the solar power system is more costly than existing electric energy sources including thermal power. A long-standing goal is to develop a novel solar power technology by which energy and environment issues are simultaneously solved.

2. Content

The New Sunshine Project has the aim of reducing the cost of a solar cell module to ¥200/W or even lower by the beginning of the year 2000. There are three current programmes for developing ways to help achieve this aim: a thin polycrystalline solar cell, a thin-film solar cell and an efficiency-enhanced solar cell.



Trend in solar cell manufacturing cost

(1) Industrial technology for manufacturing a thin polycrystalline solar cell

The programme is concerned with making cell modules more efficient and with developing an industrial method to manufacture cheaper substrates and cell modules. Specifically, to curtail the cost of a cell process, acceleration of the machining of workpiece surfaces, and facilitating the formation of the pn junction. In preparing modules, processes of cell layout and wiring are being shortened. Also under way is a study of the economical feasibility of simplifying the lamination step and using a frameless structure.

(2) Industrial technology for manufacturing thin-film solar cells

Thin-film solar cells being developed include amorphous, CdTe, thin-film polycrystalline and CIS types. The amorphous solar cell in particular promises to manufacture at much less cost, because the cell is suitable for continuous mass-production, and uses a small amount of silicon. Key technologies have been acquired for improving cells, increasing reliability, and enlarging the cell area.

(3) R&D of efficiency-enhanced solar cells

This programme investigates, among others, R&D of a crystalline-compound solar cell with the conversion efficiency greatly enhanced to allow applications to proliferate after the year 2000.

Development of solar power system technology

1. Objectives

Only improving solar cells is insufficient to promote the solar power system. It is also necessary to improve the performance and reduce the cost of the associate devices (e.g. an inverter) and the whole system.

An R&D programme on the system with completion scheduled for fiscal year 1996. The programme is described below.

2. Content

(1) Technology for estimating solar power systems

A method has been designed for estimating such auxiliary devices as inverters and storage batteries. The method is being applied to batteries so far developed. Schemes for designing and estimating the whole system are under development.

(2) Associated technologies

A solar power system is made of a solar cell module and its auxiliary devices including an inverter and a battery. Areas now being investigated are:

- *Solar cells integral with a construction component*
  A solar cell module integral to construction components (e.g. a roof and an outer wall) is being designed. The combination will make the module base unnecessary, with the installation cost reduced. The module will thus cost less. The combination should not disfigure the construction component.
- *Auxiliary devices*
  An inverter with much lower cost is being developed by not using a transformer and incorporating functions of a system interconnection protector. Batteries of a compact, high-current-density nickel-hydrogen type, and of a low-cost redox-flow type that is easy to enlarge in capacity need to be found.
- *Demonstration of a solar power system*
  The nation's biggest 750 kW solar-diesel hybrid power system was built on Miyako Island, Okinawa, and is being run for demonstrative research on an independent primarily-solar power system for a remote island.

Putting industrial solar systems into practice

1. Objectives

A solar hot-water maker and other solar systems, using sunshine as the thermal energy source, are becoming widespread or viable in Japan's consumer market. In contrast, industrial systems still present challenges to engineers, because the many heat processes range widely from low to high temperature, and the high heat consumption requires sophisticated thermal management.

2. Content

(1) Development of solar freezing/refrigeration system

By exploiting an advanced heat-process system for transferring sunshine heat with a temperature range extended at the hotter and/or the colder end, an independent solar freezing/refrigeration system using endothermic and exothermic reactions of a hydrogen-storage alloy with air or water coolant was developed. Under way are development of new hydrogen-storage alloys and packing a freezing system into a unit.

(2) R&D of advanced glazing with dimming material

Everybody wants to live in a comfortable house, and creating such an environment is an ultimate goal. In surveying passive solar systems to make better use of sunshine energy by controlling light and heat coming from the sun, and to save energy used for air conditioning and illumination, a glass with an electrochromic dimmer has been developed. The glass is now being enlarged for practical use, developing associated technologies for the product to serve as window glass.

(3) International collaboration for R&D of a solar energy utilization system

"Collaborative research of appropriate technology", a prominent feature of the New Sunshine Project, in collaboration with Republic of Indonesia is developing a dryer system with heat collected by air. A pilot plant will be subjected to design, fabrication, building, operation, and evaluation until fiscal 1997.

Wind energy technology

1. Objectives

Wind power systems are growing as the pertinent technology progresses, and now the world mainstream ranges from 200 kW to 300 kW power generation. In disseminating the wind power system, however, Japan has a serious problem with finding locations, because mountains and hills take a large part of the land area, and national parks must be protected. As long as a wind power system is noisy, it cannot be installed near, or in heavily populated areas. A goal of the programme is to invent a practical wind-driven power generator solving those problems.

2. Content

(1) R&D of wind power system of 500 kW output

Aiming at cost reduction and efficient land use, a 500 kW wind power system is being developed that is reliable and economical, and that can withstand the gusts of the typhoons which attack Japan a few times every year. Design and fabrication are under way. A nacelle is being assembled, and blades, an incorporated electric system and a tower will be completed. The system will be built at Tappi Promontory, Aomori.

(2) Developing technology to control a cluster of wind power systems

At Miyako Island, Okinawa, research and development is being undertaken to identify the best configuration (e.g. arrangement and installation) of two or more wind power systems and optimum technology to best run them. For the time being, two medium-scale systems are being operated for investigation. Another three systems will be added soon. In Japan, there are many isolated islands, including Miyako, where it is so windy that wind power seems feasible.

(3) Wind observation

To efficiently develop and disseminate wind power systems in Japan, winds have been observed over the whole country to gain data, collect existing wind data, organize and analyse the data to prepare a nationwide wind map. (Source: *JETRO*, December 1995)

Mexico

Solar thermal development rush

With Mexico and India in the lead, several countries are advancing plans for solar-thermal power plants possibly totalling more than 1,000 MWe of capacity. The Mexican national utility, CFE, has released an economic and technical feasibility report on future electric options and found the proposed 135-312 MWe worth of integrated solar, combined-cycle (ISCC) natural-gas turbine plant (which includes 40 MWe of parabolic-trough solar thermal power) to be the most "environmentally significant" electric option for Mexico.

During a World Bank (WB) mission to Mexico, the Mexican government was expected to ask the Global Environmental Fund (GEF) for $50 million to help finance the project. The GEF this month also neared approval of 140 MWe of ISCC systems for India as part of a larger aid package when the GEF Coordinating Council voted its support.

Israel is expected to issue a request for information from potential bidders on an 85-MWe ISCC system, and Egypt has recently announced plans for a 100-MWe ISCC plant.

Other major solar-thermal electric initiatives include a 100-MWe Luz-Industries-type Solar Energy Generating Station (SEGS) plant without natural-gas backup by Iran, an 80-MWe SEGS plant by Morocco, a 52-MWe SEGS plant by Crete and a 30-MWe "Phoebus" solar-thermal plant by Jordan. Not all these will go ahead as GEF does not have the funds to support every one.

Two years ago, the international solar-thermal capacity goal was 150 MWe. Today, with this significant momentum, the second wave of commercialization appears positive. (Source: *The Solar Letter*, 22 March 1996)

Morocco

Let it shine

At the beginning of June, as work in the fields gets into stride, the Moroccan village of Ighirine, in the High Atlas mountains, is bursting with light and sunshine.

You reach this community over tracks more used by mule-drivers than jeeps. Until quite recently, life in this village, totally cut off in the winter months, was governed only by the rising and setting of the sun, the weekly *souks* or markets, the *moussems* (festivals organized around a local sanctuary) and the harvests. Now, however, something new is dazzling Ighirine.

"Electricity is the light of God", exclaims one of the village's 400 or so inhabitants who are marvelling at the current which solar generators and batteries installed at the Electricity Centre have brought to their homes and streets. Today, when the muezzin summons the faithful to evening prayers, the mosque is lit up and loudspeakers lend more pomp and solemnity to the occasion. Electrification releases the villagers from their isolation. They can listen to the radio and watch television. Women can continue weaving tapestries until a late hour thanks to the new power supply.

Ighirine is one of 30 villages to benefit from a pilot rural electrification programme launched in 1993 with the aim of providing electricity for about 250 isolated rural communities in Azilal, Errachidia and Safi provinces. The village was chosen after several exploratory visits and surveys carried out by engineers and economists, helped by sociologists familiar with local habits and customs. The villagers themselves, who traditionally decide the distribution of land and water at public meetings in the main square, set up a special association led by a steering committee to handle the new situation.

Several meetings were held to explain to people who preferred the usual cable or generator supply you get in the towns that there was another way, says the head of the Electricity Centre. He is responsible for the upkeep and small repairs needed to keep the machinery running. He acquired these new skills through seminar-workshops organized during the period of installation by the National Electricity Office (NEO), local authorities and the Ministry of Agriculture.

The total investment per household only came to 9,100 dirhams (about $980). Connecting the village to the national electricity grid would have cost 30,000 dirhams ($3,200). The participatory approach of the project should ensure that it lasts. Most of the initial investment cost was picked up by the Government, with consumers contributing around 15 per cent and paying for maintenance. This arrangement won over 80 per cent of the villagers—whose incomes average between 1,000 to 2,000 dirhams a month ($100 to $220)—and made them the envy of neighbouring villages.

The pilot programme can only meet a tiny part of the demand. Only 6,000 of Morocco's 31,000 villages have been electrified. For the rest, which have little chance of ever being connected up to the national grid, renewable energy offers real hope for the future.

Work has been carried out since the 1980s. The first exploratory stage involved demystifying the technology, learning the necessary skills for its upkeep. The technology is generating higher and higher returns. Maintenance networks have had to be set up. The second stage is the pilot schemes themselves. This phase is nearly complete and will make way for the General Rural Electrification Programme (GREP), which aims at bringing electricity throughout the countryside by 2010.

At the moment, Morocco only produces 543,000 tons of oil-equivalent energy a year, about 7 per cent of its needs, and so has to import the other 93 per cent. But the country has untapped reserves, as Minister of Energy and Mines Abdellatif Guerraoui, who launched the programme, reminds us. Its geographical position, climate and terrain provides much potential for renewable energy—solar

(Morocco gets a daily average of five KW of sunshine per square metre), wind, water and biomass (through nine million hectares of vegetation).

These resources should enable about a million and a half households to be electrified over the next 15 years, at a cost of one billion dirhams (some $108 million) a year, 35 per cent of which will be financed by a levy on electricity consumption. The National Electricity Board and local authorities will provide another 20 per cent each, and the remaining 25 per cent will come from future consumers. The European Union, the World Bank and the French Development Fund will also provide funds. (Source: *UNESCO Sources No. 81*, July-August 1996)

Philippines

Photovoltaic (PV) street lights in Barangay Belance

One concrete application of photovoltaic (PV) technology is the lighting of Barangay Belance in Dupax del Norte, Nueva Vizcaya, Philippines.

The Barangay has five units of PV street lights, 100 home lighting systems connected to 300 compact fluorescent units, and a PV system to meet the power needs of the office of St. Joseph's Parish Credit Cooperative (SJPCC), the implementor of the project.

By car, Belance is at least eight hours away from Manila. The roads are rough and hilly, and landslides are frequent. But the people of Belance have prospered with their cash crops of potatoes, ginger, pepper, sweet peas and oranges.

Into this setting came ITW, a German consulting firm. They collaborated with the Alternative Energy Systems (AES) Development Specialists, a local consultancy firm, in setting up the Belance PV project at the request of St. Teresita Academy in Aritao. The company conceptualized the PV electrification project in the Barangay and helped source funds from the Dutch Government's Directorate General for Institutional Services (DGIS).

AES arranged for the supply of components, installed the systems and trained 10 members of the cooperative on maintenance. It has also taken responsibility for after-sales monitoring and trouble-shooting.

The 100 home systems installed to date were purchased by the households backed by the cooperative through a financing scheme by the Development Bank of the Philippines (DBP).

A major problem appears to be the poor capability of most of the approximately 300 households of Belance too remote to have access to public grid utilities to purchase home systems. To address this, AES hopes to introduce financing schemes for PV home lighting. (Source: *Tech Monitor*, May-June 1995)

South Africa

South African firm announces new solar water pump design

The development of a new solar-powered submersible water pump offering substantial benefits for rural areas was announced by the South African firm of Divwatt (Pty) Ltd.

The technology will set new standards in bringing a reliable and cheap supply of water to rural communities and farmers where there is no accessible electricity, according to the company.

The new pump, called SOLASTAR, is based on a new technology using an advanced linear, reciprocating floating piston design. This simple yet revolutionary design ... results in a solar pumping system that overcomes problems associated with traditional solar powered pumping, like extreme ambient temperatures, heavy overcast skies, deep and erratic water tables, high maintenance costs, labour-intensive installation, a short working life and limited water delivery.

The SOLASTAR delivers at a given head and submergence level about twice the volume of water per day per watt compared to other solar pumps currently in use and many times that of windmills.

The system can be installed by unskilled labour in less than 45 minutes, and requires no maintenance for up to 10 years. Also, SOLASTAR offers a modular system to suit different water requirements and borehole depths, ranging from 2,000 to 20,000 litres per day, using 2 to 10 solar panels at pumping depths of 10 to 150 metres.

For more information, contact Divwatt (Pty) Ltd., P.O. Box 3926, Honeydw 2040, South Africa. Tel.: +27 11 794-3825; Fax: +27 11 794-1244. (Source: *Internatinal Solar Energy Intelligence Report*, 30 October 1995)

Energy project for South African township

The US Department of Energy's Sandia National Laboratories is studying the feasibility of a possible light industrial park in South Africa that would provide goods and services relating to renewable energy.

The park, which would be located in the Gugulethu Township near Cape Town, would house several businesses. The project is designed to help South Africa develop energy technology markets in which US companies can participate.

Spin-off benefits should include the promotion of business development in South Africa, and the development of experience with and confidence in US products and companies.

Potential industries for the industrial park include both US and South African businesses providing goods and services in growing markets that are resulting from South Africa's Reconstruction and Development Programme (RDP). Goods and services to be given high priority are electrical power, both grid and modular and particularly renewable, housing and building materials, potable water supply systems and health services.

Sandia officials noted a growing interest in South Africa in developing renewable energy and energy efficiency technologies to help the nation meet energy demands and mitigate environmental and health problems. The country's abundance of solar energy and its large rural population make it an ideal candidate for the extensive use of photovoltaic technology.

An estimated two million homes, half of South Africa's 18,000 rural schools and 4,000 rural health clinics that are not on the nation's electrical grid extension plans are expected to be electrified through photovoltaics. (Source: *International Solar Energy Intelligence Report*, 30 October 1996)

Sri Lanka

Ground source energy systems (GS-systems) in Sri Lanka

The GS-system may be looked upon as a solar system using the environment, the earth and the air around us as a solar collector. The earth and the air around us continuously absorb the solar energy incident upon them. The earth also transfers this energy back into the air and maintains a constant temperature at a depth of about 10 metres. Beyond this depth, earth temperatures increase at about 25° C per kilometre depth depending on location. These properties make the earth an ideal source or sink for heat extraction or transfer. The energy stored in the earth is also available 24 hours a day.

The "heart" of the GS-system is the geothermal heat pump which works on the same principle as a refrigerator or an air-conditioner and is operated electrically. It is a device to move heat from a low temperature source to higher temperature. In moving the heat, the source from which the heat is extracted will be cooled. Therefore, the system can provide both heating and cooling of confirmed spaces where the source and sink are air.

In cold places the heat source is that stored in the earth, in hot areas the heat in the ambient air can be used. Where it is necessary to dispose of excess heat energy, the earth is used as a sink instead of costly cooling towers. GS-systems have a very wide range of applications where heating, cooling and moisture removal or control are required. The potential applications are numerous.

For Sri Lanka, some applications that have been identified are: air-conditioning, hot water, cold rooms, space heating, greenhouses, aquaculture, timber drying, tea industry, rubber industry, textile industry, grain storage, vegetable storage, produce drying, fish drying and dairy industry.

In these applications, the technology is expected to effect savings of 30 to 60 per cent in energy consumption. (Source: *Tech Monitor*, May-June 1996)

Syria

Solar power plant in Syria

The Indian public sector company, Central Electronics Limited (CEL) will put up a plant to manufacture solar panels and photovoltaic (PV) cells in Syria. CEL is one of the world's leading manufacturers of solar photovoltaic systems. The contract involves the transfer of CEL technology to manufacture a range of solar PV panels and cells, and a number of PSV application systems such as rural household and street lighting systems, water pumping systems for irrigation and drinking, SPV sources for TV and other electronic items. The company will provide technical assistance to manufacture these items (250 kW per year capacity). It will supply a complete process technology package, production and testing equipment of Indian origin, specifications and sources of various equipment suppliers. (Source: *Tech Monitor*, January-February 1996)

Thailand

Thai electronics centre, Solartron, to research PV-using equipment

Thailand is poised to begin researching and developing solar technology. The National Electronics and Computer Technology Centre (NECTEC), the nation's scientific research arm, has signed a memorandum of understanding with Solartron Co. to develop solar technology, cutting into imports of such equipment that cost more than 100 million baht ($US 25 million) each year. NECTEC and Solartron will research and develop solar batteries, controllers, inverters, pumps and other devices, but not solar cells. The technology will aid projects involving residential rural electrification. A researcher estimated that solar energy provides 2 megawatts nationally compared to 12,000 MWe from other means.

NECTEC and Solartron will equally share the research and use of Solartron engineers. Solartron, which deals primarily with government agencies, has installed 500 solar systems to generate power and pump water in remote villages nationwide. (Source: *The Solar Letter*, 12 April 1996)

United Kingdom

£2.5 million solar power offer to schools

Government and industry are to spend £2.5 million installing solar panels at 100 schools and colleges across Britain. The schools will be hooked up to the Internet so that anyone in the world will be able to see how much free energy they are collecting from the sun. The Scolar programme is the brainchild of Intersolar, Britain's only manufacturer of solar cells. It is part of the Government's Foresight Initiative to focus research on technologies that could win a significant market share in the near future. Schools wanting to take part will have to contribute £3,500 for the arrays of panels, which will last up to 30 years. Each array will generate 1 kilowatt. Larger arrays at colleges will generate up to 2.5 kilowatts—"enough to power their computer block". (Source: *International Herald Tribune*, 2 July 1996)

United States of America

SMUD about to issue RFP for 50 MWe of renewables

Sacramento Municipal Utility District (SMUD) is about to release a request for proposals (RFP) for 50 megawatts of renewable-energy-based power to be delivered in the 1988-2000 period.

The RFP includes 40 MWe of power-purchase agreements (PPAs) open to all renewables. This part of the RFP allows electricity suppliers to derive up to 5 per cent of their electricity from fossil fuels, most likely natural gas. For this bulk of the total power sought, it does not matter where the generating equipment is located, but the electricity must be wheeled to SMUD if the installations are outside of SMUD's service territory. For now, SMUD would like to limit the initial PPAs to 15 years' duration.

SMUD also is committed to PV development. A 10 MW (peak) set-aside in the RFP for photovoltaics requires bidders to offer local manufacturing and jobs. Unlike the 40 MWe general-renewable portion, this part of the RFP is offered with the expectation of equipment purchases although PPA proposals are permitted. The PV set-aside is intended to provide a transition from a yearly PV programme to long-term commitments. SMUD would like to add 800 kilowatts (peak) in 1997 and 10 MWp in the 1998-2002 time frame.

Deliberation on the proposals begins by subjecting all bids to a pass-fail test to weed out any inappropriate offers. Then, the board will evaluate the bids according to cost in terms of dollars per watt. This criteria, worth half of the total evaluation points, will cover the cost per peak Watt on a total (10-MWp) and average (year-by-year) basis if the bid includes a declining-block price offer, as expected. The other criteria are: local manufacturing content (20 per cent); technical merit (15 per cent); equal business opportunity programme, or the ability to include women- and minority-owned partners (10 per cent); and environmental benefits (5 per cent).

SMUD is requesting separate 5 and 10 MWp prices in the bid, and could be interested in supporting more than one supplier. As production ramps up from the local factory, prices are expected to drop and local employment is expected to rise.

The city is offering a host of benefits to the winning bidder. Economic development funds and defence conversion assistance will be available. The municipality has a building left over from the Rancho Seco nuclear power plant that was shut down in the 1980s. The building, needing additional investment to be made ready for use today, will be written off by SMUD. It is large enough to accommodate more than the space needed to manufacture 10 MWp per year and could be used by several PV companies or a PV company and its balance-of-system (BOS) partners. In return, SMUD is expecting low prices.

The utility has purchased small PV systems at record-low prices and has received record low-priced bids for larger systems in the hundreds-of-kilowatts range as well. Now, SMUD expects much more as it launches its tens-of-megawatts programme looking for long-term commitments.

Two older SMUD RFPs about to close

SMUD still has two other RFPs available. The first is for PV materials—modules and inverters for rooftop applications under the utility's PV Pioneer programme of load management PV, under which customers pay a premium for the right to avoid future rate increases.

The second open RFP is for turn-key systems in a substation, parking lot, building-integrated PV or PV demand-side management mode. Bid analysis on this RFP will occur simultaneously to that of the PV-material RFP. The two sets of bid awards are expected to be announced at the same time. (Source: *The Solar Letter*, 22 March 1996)

Solar energy 24 hours a day

Generating electricity from the sun at night is what the Solar Two power plant is doing. It soaks up the sun's heat during the day, then releases it at night—or over the course of several cloudy days. If Solar Two keeps on working as designed during its three-year shakedown, solar power could become far more dependable.

Solar Two is a $40 million refurbishment of Solar One, a 10-megawatt power plant that operated from 1982 to 1988 near Daggett, California. Solar Two uses heliostats, or sun-tracking mirrors, to focus sunshine on the top of a central tower. There, the concentrated sunlight heats a mix of sodium and potassium nitrate to 1,050° C. That melts the salts, and the steamy liquid flows down into a giant thermos bottle, which is tapped to boil water and produce the steam that drives a generator. Originally, Solar One used rocks submerged in oil, but this mixture cooled off quickly, and the plant had to shut down when the sun was not shining. Sandia National Laboratories developed the new salt mixture.

Even if Solar Two, which is funded by the Energy Department and an industry group headed by Southern California Edison Co., is scaled up to 100 megawatts or more, it probably will not compete with coal-burning generators until 2005. Its near-term outlook could be brighter in countries that have to import oil to generate electricity. (Source: *Business Week*, 17 June 1996)

Zimbabwe

Solar PV project in Zimbabwe

Jointly funded by the Global Environment Facility (GEF) and the Government of Zimbabwe, the Zimbabwe Global Environment Facility (GEF) Solar PV Project is expected to install about 9,000 solar lighting systems during the period 1993-1996. The expected lifetime of the project is three years (field installation) with another two years for maintenance, technical reviews and report writing.

The objectives of this project are to: address the problem of global warming by substituting fossil fuel-based energy for lighting with a renewable energy source, the sun; help raise the standard of living amongst people in rural areas; upgrade indigenous solar manufacturing and distribution infrastructure; develop a sustainable market for PV systems in rural areas through a revolving fund; and integrate solar electric lighting activities with other related activities such as health and education programmes. (Source: *Tech Monitor*, March-April 1996)

Cultivating the Green Carrot. A market stimulus for photovoltaic technology

Overview

The goal of the *Green Carrot* is to significantly accelerate the commercialization, market penetration and financial viability of photovoltaic (PV) technology in the developing world, and provide a window for promoting large-scale use of photovoltaics as one of the best long-term prospects for a low carbon energy future. The *Green Carrot* will take the form of a total fund of approximately $60 million contributed by the Global Environment Facility (GEF), providing $5-20 million rewards for each of three to six companies or consortia with the most innovative proposals for accelerating PV technology development and expanding commercial applications in the developing world. This initiative is fundamentally different from a donor designed and implemented programme in that the primary innovation and activity will come from the private sector. The "reward" in the programme is expected to be used to address obstacles and opportunities in three key areas: market development, manufacturing and country partnering.

The programme will be managed by the International Finance Corporation (IFC), the private sector affiliate of the World Bank Group. Management through the IFC will gain greater speed and flexibility in implementation, increase potential leverage, and create movement towards wholly private sector financing windows at the IFC and elsewhere. In order to avoid inadvertent exclusion of potential innovative approaches and to provide adequate time for the required business arrangements to be made, a broadly defined "early opportunity notice" (EON) will be issued to outline the programme structure and provide an opportunity for information exchange.

Green Carrot: the problem and the opportunity

In its efforts to address greenhouse gas emission (GHG) problems, the Global Environment Facility has provided technical assistance and pilot project development support to a range of efficiency, conservation, carbon sequestration and emission avoidance approaches. While these approaches were akin to "buying time", GHG accumulation continues because net emission rates in the industrial countries remain large and those in developing countries continue to grow.

In terms of addressing the immediate goal of keeping year 2000 GHG emissions to the 1990 level, GEF pilot phase projects have addressed less than 0.4 per cent of required emission reductions. Consistent with revised draft operational strategy, the GEF is now reallocating its resources to new "technological lifeboat" solutions—technologies that have high present costs but enormous future potential (including PV, solar thermal-electric, wind, biomass gasification, and fuel cells). Zero emission technologies such as PV have a particular benefit as "decumulator" technologies should atmospheric concentrations of CO_2 trigger environmental consequences that can only be addressed by reversing emission rates. Also, in a departure from previous World Bank designed PV programmes implemented through country governments, *Green Carrot* projects will be designed and implemented largely by the private sector. Rather than a "top down" approach that might expire when funds are exhausted, this use of GEF funding through the IFC can stimulate PV players to stretch their technological and marketing capabilities in pursuit of their own long-term private interests.

The *Green Carrot* is fully consistent with the GEF's lead role in funding the implementation of the Framework Convention on Climate Change (FCCC). During the Conference of the Parties (COP) meeting in Berlin in March 1995, the *Green Carrot* was offered to the FCCC by the World Bank as one of several options available to support clean technologies and address climate change. It received positive commentary from both governmental and non-governmental organizations and delegates.

This initiative is affiliated with the World Bank's *Solar Initiative*, which is intended to develop internal commitment and project development capability within the World Bank as well as provide an external liaison role in coordinating strategic activities in accelerated research, development and demonstrations of renewable energy technologies. The *Green Carrot* also represents ideals of the emerging *Climate Technology Initiative*, a linked set of unilateral and multilateral programmes designed to accelerate the development and diffusion of technologies with global benefits through joint government and private sector activities.

The *Green Carrot* adopts a fundamentally different approach to previous World Bank and GEF approaches. Rather than pursue one-time emission reductions through technical assistance or pilot projects, the *Green Carrot* entails a moderately large intervention (relative to existing markets) to initiate long-term GHG avoidance and reduction. The flow of business deals and technology transfer resulting from the *Green Carrot* is intended to complement these initiatives, not by changing World Bank Group investment policy but by advancing PV to the status of a sound, bankable investment in a broader range of conditions than is now the case. (Source: *Global Environment Facility, International Finance Corporation,* 11 October 1995)

A difficult coming of age

The oil crisis of 1973 made the world uncomfortably conscious of its dependence on fossil fuels and the fact that they were available in limited supplies largely controlled by a limited few.

This realization opened the way for the research and development of alternative energy options, culminating in a related UN conference held in Nairobi in 1981. That conference called for an orderly and peaceful energy transition from an international economy based primarily on hydrocarbons to one based increasingly on new and renewable sources of energy. The year 2000 represented a magical milestone heralding a new millennium. It was still two decades away, which seemed long enough to prepare for entry into the solar age.

But today, just four years from that fateful date, how far are we from this goal? Where are all those solar powered gadgets that were expected to become part of daily life? Why is natural gas becoming more popular for heating water and buildings?

The fact is that world oil prices have remained stable for nearly 15 years. New reserves of oil and gas are discovered regularly, and, along with coal, will continue to provide for the bulk of our energy requirements for several decades. Then, there is the relatively slow progress of renewable energies, the reasons for which are more varied and complex, ranging from purely economic to technical, social and cultural factors. Renewable energies do have their drawbacks. They are diffused and thinly distributed. They vary with day and night and with the seasons. All require large surface areas, storage systems and/or use of multiple energy sources. The lack of suitable terrace space, for example, prevents the use of solar hot water systems in many urban areas.

However, the main barrier is the user's perception of the relatively high cost of these devices and their economics. Conventional energy products are subsidized. Renewable energies, to a large extent, are financed by the consumer, who must pay for the equipment to produce them. It could be argued that there are no running fuel costs in the case of solar, wind or small hydropower systems, making them cheaper in the long run. But this is true only under certain conditions.

There is a greater benefit to national economies through use of renewable energies, but unless this benefit is passed on, users are unlikely to invest in them. This is a matter of national policy, requiring, in some countries, legislative measures. Governments that tend to allow market forces to determine the relative economics of different energy sources may be reluctant to introduce such measures. The interests of traditional energy suppliers can also contribute to the political inertia.

In the late 1970s and early 1980s, the US Department of Energy forecast that photovoltaic module prices could fall to one dollar per watt and below that by 1985. But this is now unlikely before the next decade. Part of the slowdown is due to funding cuts in the 1980s for related research and development. The pace has now picked up again, but it would be unwise to overstate what a renewable energy device, such as a solar cooker, can do.

To buy a conventional device such as an electric fan or kerosene stove, we know where to go and how to acquire the product. Renewable energy products, on the other hand, are unknown in the marketplace. After-sales service is virtually non-existent. Even community installations are not maintained. India's solar street lights, or China's biogas plants are but two examples of large-scale failures. Often this is a chicken and egg situation. Unless there are a sizeable number of devices to maintain, a servicing network does not grow; without such a network it is hard to instill confidence among users.

People have proved time and again their capacity for change. The move from firewood to coal and kerosene and then to gas for cooking has been achieved in a single lifetime. However, each change was motivated by convenience or economics. Solar cookers do not yet offer the convenience and speed demanded by today's consumers. Neither can they prepare certain foods commonly used in some communities. Likewise, solar pumps have smaller discharge rates than conventional electric or diesel pump sets and do not fit in with the watering practices of farmers. Considerable education is needed to assure farmers that when properly used, solar pumps can meet their needs.

Despite the numerous technical, economic and attitudinal barriers, some renewable energy systems are already well established and are making progress. Propelled by environmental considerations, renewable energies are likely to begin making an impact on the global energy situation in the next 15 to 20 years. We can foresee solar energy in the near future as the main source of energy for millions of rural homes, or wind energy lighting the homes of coastal or mountain dwellers. Further along, renewable energy sources could be used widely for grid-connected power. And in say 100 to 300 years from now, when most of the fossil fuel reserves are likely to be exhausted, humanity will have adjusted its energy consumption to within the thousand watts or so per square metre provided by the sun every second to the Earth's surface. An eventual balance of the energy received and the energy used will alone ensure our survival on this planet. (Source: *UNESCO Sources No. 81*, July-August 1996)

The Solar Summit: overcoming the obstacles

Imagine a developing country, essentially rural as most tend to be, where the majority of the population (worldwide about 2.4 billion people) live without electricity. Imagine trying to equip these regions with "modern" energy. What follows is fairly predictable: the light—if there be light one day—would only be found at the end of a very long tunnel.

This scenario is based on the proviso that such an undertaking is necessary and that there is sufficient will to carry it through. There are no doubts as far as the future consumers are concerned: they dream of the day electricity will arrive, and with good reason, as traditional energy sources—almost always wood—are particularly burdensome. On the other hand, the decision makers—thinking of the next election—usually take a short-term view. Yet a project of this scale requires at least 10 years before it will bear fruit. And, even if the well-being of the rural world is a "*must*" in the politician's rhetoric, it is rarely given priority treatment.

Extending national grids to thinly spread, sparsely populated, low-income rural communities would be prohibitively expensive. The "*beneficiaries*" would find themselves paying exorbitant prices for their energy to cover the costs of construction and installation of plants that would be used for only a few who could afford to pay. The alternative would be to sell the electricity produced at a loss.

Imagine then that, in the name of generalizing public services, these same political authorities decide to go ahead anyway, but opt instead for renewable energies. Once again, they would have to seek out the same big utilities, who would once again declare that the task was simply beyond their capabilities.

Their economic capabilities to start with: at present, only wind energy is price competitive with classically produced energy used in normal conditions. Energy produced from photovoltaic cells and biomass is much more expensive. Then comes the know-how and structure of these utilities, which are not geared to conceive, sell and maintain simple yet viable minipower plants based on renewable energy. Yet another obstacle is the "*threshold effect*". For public utilities even more than private ones, the sale and maintenance of these types of installations would only be profitable in an economy of scale. Heavy losses would have to be carried until a sufficient number of plants had been installed, creating the critical mass needed to make them profitable.

Finally we will have understood: the canons of liberalism and the rules of politics work hand in hand to brake a resolute and rapid transition to renewable energy, despite its obvious environmental, societal and economic benefits.

Integrating renewable energies into the system, an exercise that would take between 10 and 20 years, requires a strong dose of political will—a real commitment to promote sustainable development—supported by national and/or international funding than can only come from the public purse.

The Solar Summit, to be held in Harare (Zimbabwe) over 16 and 17 September, at the invitation of President Robert Mugabe, will see the affirmation of this political will. Organized with technical support from UNESCO and other international bodies such as the European Union, the International Energy Agency and UNIDO, the Summit is the culmination of a long process started more than two years ago and marked by a succession of preparatory regional meetings. The World Solar Commission, made up of 16 Heads of State and government leaders, has also played a key role in its organization, and will advise the Summit on the best possible strategies to be pursued for the large-scale development and deployment of renewable energy technology.

The Summit will launch the World Solar Programme 1996-2005, comprising some 300 "*highest priority*" renewable energy projects.

But above all, it is expected to adopt the Harare Declaration. The start of the draft version could not be more explicit: "*We, the Heads of State and Government,... recognize the significance of the role that solar energy (which includes all sources of renewable energy) should play in the provision of energy services and in the sustainable use of environmental resources for the well-being of mankind*". (Source: *UNESCO Sources No. 81*, July-August 1996)

Why promote renewable energy

All the member countries of the International Energy Agency (IEA) promote renewable energy in some form or other, although its relative importance, the type of energy targeted, and the strength of promotion varies from country to country. Some variation is also seen in the mix of promotional policies employed by different countries, although particular policy types—such as financial incentives and a guaranteed market for renewable electricity—are more prevalent than others. But despite recent reductions, the cost of renewable energy is relatively high and will have to fall further if it is to become fully competitive with alternative forms of supply.[1]

Renewable energy can be derived from a variety of sources—geothermal, wind, solar, tidal, wave, biomass, municipal and industrial waste. Renewable energy has been promoted in some OECD countries since the 1970s. But although the concerns for energy security and the heavy dependence on oil—the main initial stimulants for develop-

[1] *Policy Aspects of Renewable Energy in IEA Countries*, IEA/OECD Publications, Paris, forthcoming 1996.

ment of renewable energy—still have relevance today, the world has changed radically. The IEA countries have moved from an era of high prices for energy and concern over energy (and particularly oil) supplies to one of relatively low prices and more transparent global energy markets. Moreover, one of the most important aspects of "renewables", electricity generation, is undergoing a period of rapid change as electricity markets are liberalized.

The environmental concerns that emerged in the 1980s (acid rain) and 1990s (climate change) are now the most commonly cited reasons behind the promotion of renewable energy, although issues of flexibility and diversity in the supply of energy, economic concerns such as regional development and the export potential of renewable-energy technology (such as "standalone" photovoltaics to help meet electricity demand in Asia) are also important.

Renewable energy is often more expensive than more traditional sources, and the higher costs of harnessing it have prompted government intervention to promote it, often through government expenditure on R&D and/or by introducing favourable economic or fiscal measures such as capital or output subsidies, tax breaks, and so on. Technical improvements and larger markets for renewable energy have indeed succeeded in lowering costs, sometimes dramatically, over the last decade. But low energy prices mean there is still a price differential between most forms of renewable energy and other energy sources, especially the low cost and flexibility of electricity production from combined-cycle gas-turbines.

The use of renewable energy and the relative importance of different renewable sources varysubstantially between countries, the main influences being:

- The domestic availability and cost of non-renewable energy sources—coal, oil, gas and nuclear power, as well as hydropower;
- The rate of growth of demand for electricity and other energy sources;
- The national policy framework for renewable energy;
- The physical, economic and market potential of renewable energy (in turn related to country size, climate and geography).

Since the beginning of the 1990s many IEA governments have introduced policies intended to create a more favourable climate for renewables. Although the mix varies (the following table gives examples of policies used to promote wind and solar electricity), some are more widespread than others. In general, measures taken to promote renewables fall into eight categories.

A range of economic and fiscal incentives aims to stimulate markets for renewable energy, either by making its economics more favourable for investors or by encouraging consumers to buy it by keeping the price low. These are the most common measures used by governments to promote renewable energy in the short term; indeed, experience to date has shown than they can have a significant short-term stimulus on the amount of renewable energy harnessed.

FOCUS
Encouraging Wind and Solar Electricity
Austria Photovoltaic systems benefit from a subsidy of 80,000 schillings per installed kW (from 1992) and premium buy-back rates in some areas of Austria.
Denmark Capital subsidies of 15 per cent (capped at 200,000 crowns) are available to replace obsolete wind-turbines. An output subsidy of 0.27 crowns per kWh is paid for all wind electricity.
Germany Buy-back rates of 90 per cent of average consumer end-prices are available for wind-energy installations below 500 kW. The rates for larger installations are 65 per cent.
Italy Premium buy-back rates (varying by renewable energy source) are available for the first eight years of operation. Guaranteed minimum rates are subsequently available.
Japan Rooftop photovoltaic systems up to 4 kW benefit from a capital subsidy of 50 per cent for residential buildings and 67 per cent for commercial buildings (up to a maximum of ¥900,000 per kW). Guaranteed buy-back rates for photovoltaic electricity are set at consumer end prices. Ambitious targets for renewable energy use in the years 2000 and 2010 have been set out by the Government.
The Netherlands Two pilot projects for "green electricity" have been set up, and the Government has set ambitious targets for future use of renewable energy.
Sweden Wind-energy systems benefit from a capital subsidy of 35 per cent (up from 25 per cent in 1991-1993) for turbines of less than 60 kW. There is an output credit of 0.09 crowns per kWh and guaranteed electricity tariffs (not yet fixed).
United Kingdom Renewables orders under the Non-Fossil Fuel Obligation pay premium rates for a guaranteed period. (Rates vary for each project but ranged from 3.98-5.29 pence per kWh in the latest order).

Capital subsidies on the purchase and installation of renewable energy systems are available in some IEA countries, frequently set up as a capped percentage subsidy—50 per cent of rooftop photovoltaic systems in Japan, for example, and 35 per cent of wind turbines in Sweden. Some governments have used capital subsidies as a means for "pump-priming" specific technologies and have discontinued this incentive after a period of time (as with wind energy in Denmark, where capital subsidies were phased out a decade after their introduction).

Other financial incentives including tax exemptions, credits and deferrals, are in common use in several IEA countries (not least Canada and Japan). Some countries also provide incentives for feasibility studies for renewable-energy projects.

Second, favourable and/or guaranteed electricity markets are also important. Buy-back rates—the tariff that independent power producers obtain for sales of electricity to the grid—and the regulations governing these rates have a major influence on development of renewable electricity markets. How high (or low) payment for renewable and other electricity is varies between countries (and sometimes within a country). Some countries guarantee a market for a certain amount (up to 100 per cent) of renewable-generated electricity at a minimum rate, sometimes the "avoided cost" when utilities do not have to produce electricity themselves. Other countries pay a subsidy per kilowatt hour produced, as well as offering guaranteed markets for the electricity produced (as in some parts of the United States, for example). As a result, some countries guarantee premium rates for renewable electricity, others only parity with prices for electricity generated from other sources, or less. Germany, for example, pays premium prices for wind electricity, under the Electricity Feed Law (EFL), as does the United Kingdom, where the Non-Fossil Fuel Obligation guarantees predetermined electricity prices for certain government-selected renewable-electricity projects. Recently, for example, electricity from small wind turbines was guaranteed a market until 2014 at a price that averaged 5.3 pence/kWh. Unsurprisingly, premium prices have proven effective in increasing the interest of independent producers in such projects. But the cost can be high: the EFL in Germany was estimated to cost utilities DM 170 million in 1994 and DM 225 million in 1995 for wind-electricity payments alone.

Third, "green" pricing schemes, whereby consumers can opt to pay more for renewable electricity, are being set up in Australia, the Netherlands, Switzerland and the United States. This is obviously a financially attractive measure for governments and utilities, as it involves only limited financial commitment on their part. The Netherlands has reported genuine interest in the pilot schemes set up, even though the financial implications for consumers are substantial. None the less, since all these projects are relatively new and, moreover are available only in parts of a handful of IEA countries, their global impact on the uptake of renewable energies is likely to be limited.

Regulations, standards and planning measures are a fourth means of encouraging increased use of renewable energy. For example, deregulation of the electricity industry has facilitated access for independent producers of renewable power to the distribution grid, which is a prerequisite to encouraging renewable-electricity production through favourable buy-back rates. Some countries (Italy and Japan, for instance) have also initiated measures to facilitate the planning/siting of renewable-energy systems, since the absence of standardized planning requirements can mean that each turbine has to be approved individually, resulting in lengthy procedures and discrepancies in standards.

Fifth, voluntary actions (VAs) can range from formalized and binding negotiated agreements between government and industry or utilities to more informal approaches aimed at encouraging renewable energy and are increasingly being used as part of the mix of measures in place to promote renewable energy. The range of VAs is extremely diverse: some emphasize increased dissemination of information; others take the form of more formal or binding agreements (such as the requirement of the Dutch electricity companies to produce 3 per cent of electricity from renewable sources by the year 2000).

Sixth, information and education programmes to promote renewable energy have been initiated by more than half of the IEA countries. But the scale of such campaigns varies enormously, and most are either general in nature or aimed at domestic uses of renewable energy, such as solar water-heaters or heat-pumps.

A seventh policy measure is found in the use of targets for future renewable-energy use and have been set by over half of the 23 IEA governments. The targets vary in nature and can be expressed in terms of renewable energy use (as in Greece), relative importance (in the Netherlands the percentage of renewables in the total energy supply, and in Japan the total fuel used in transport), generating capacity (Japan) or number of units installed (Switzerland). The presence of a centralized plan and/or target for many renewable sources may in itself encourage increased use of renewables, by (for example) centralizing sources of information on financing, and may also help to coordinate public and private decision-making on renewable energy. Targets may indirectly help renewables by raising general awareness (of the public or of financiers) towards renewable energy.

Lastly, national R&D programmes for renewable energy are in place in all IEA countries except Luxembourg, although wide disparities exist between countries both in the extent of funding and the energies supported. In 1994 the total of national R&D for renewables in the IEA countries stood at $700 million (almost 8 per cent of total energy R&D), the majority of which was spent on solar energy applications.

The largest barrier to increased use of renewable energy is its cost, despite the reductions achieved over recent years. But other obstacles, particularly for renewable electricity, include subsidies and other support for competing conventional fuels (especially coal and nuclear power). Lack of full-cost pricing when determining the cost of competing energy supplies also hinders the development of renewable energy since the cost of environmental impacts are usually not included in energy prices. High discount rates disadvantage projects with high capital costs but low running costs (such as renewable electricity schemes). And the increasing deregulation of the electricity industry in many of the IEA countries is stimulating competition between electricity suppliers, sometimes on a short-term price basis. Since renewable electricity is often more expensive than electricity from other fuels, that could hinder its development (unless, of course, governments set up other schemes, such as protected market shares). And there are costs from system integration and capacity back-up. Other, non-cost barriers, especially the imperfect flow of information and the lack of integrated planning procedures and guidelines, also inhibit the uptake of renewables.

The contribution of renewable energy to the total primary energy supply of the OECD is small, but the amount of renewable energy harnessed has been growing over recent years to stand at 155.2 Mtoe (million tons of oil equivalent) in 1994 (3.6 per cent of total energy supply). This amount is made up mainly of biomass, wastes and geothermal energy. Wind and solar energy currently account for only a tiny proportion of it, but are the fastest growing renewables in the IEA area.

Some policies, particularly premium prices guaranteed over several years, have succeeded in increasing renewable-electricity production and capacity rapidly, showing that investors will invest in such projects under favourable economic conditions, despite regulatory barriers. Recent policies have also demonstrated that competition can bring down the costs of renewable electricity substantially over a short period of time. But sharp increases in electricity production from renewables have, to date, been achieved only at a cost and often with distortions to energy markets.

Governments have to improve the environmental performance of the energy sector while maintaining a low-cost and reliable energy supply. Whether the newer policy approaches to promote renewables can help achieve this aim in an era of increasing pressure on national energy budgets has yet to be determined. But the impetus for more widespread use of renewable energy may increase if new commitments to limit or reduce greenhouse-gas emissions beyond the year 2000 are introduced. In that event, governments may choose to accelerate or strengthen policies that promote renewable energy. (Source: *The OECD Observer*, No. 201, August/September 1996)

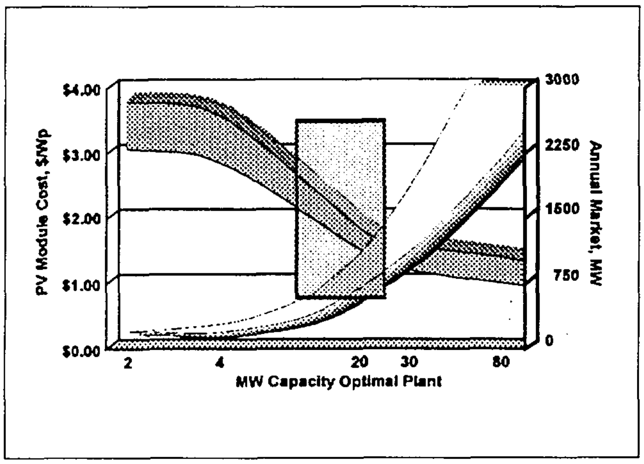
E. POTENTIAL MARKETS

Cultivating the Green Carrot
A market stimulus for photovoltaic technology

Market development potential

Each layer of cost reductions from manufacturing improvements enables tremendous market growth. The near-term area of opportunity for the PV industry, and the "zone of influence" for the GEF, is indicated in the shaded area in figure 1, where simultaneously increasing investment and commitment to market development can accelerate access to expanded markets.

Figure 1: Module Cost and market expansion



Electricity demand for the developing world overall is projected to increase at 7 per cent per year, with growth rates for the more industrialized of these countries in excess of 10 per cent per annum and those of some South-East Asian countries exceeding 15 per cent per year. The financial requirements to meet growing energy demand in the developing world (mostly with fossil plants) are estimated to be at least $100 billion per year. Currently, $50-60 billion is spent each year in this sector leaving an annual deficit of as much as $50 billion. This cumulative deficit poses a significant bottleneck for economic development in the developing world.

In the urban areas of the developing world, marginal costs of electricity are around $0.10 per kWh, while in rural areas it is often $0.20-40. Still, customer prices tend to fall short of costs (around $0.04 to $0.05 in 1990), and peak-load pricing is rarely charged. Failure to account for the cost of line extensions in areas of low customer density, usage, and connections has resulted in enormous financial and technical losses in many developing country utilities, and has failed to deliver the expected benefits. In India, for example, nearly 80 per cent of villages have been connected to the grid, but the number of *households* connected is just 22 per cent. Grid power under these circumstances is often unreliable and/or of poor quality, with very low load ratios and high losses. Even without considering the subsidized tariffs which exist in many countries as an element of social policy, revenue collection does not cover actual costs.

Opportunities in rural and off-grid markets

While not necessarily a requirement of the initiative, it is generally expected that some *Green Carrot* proposals will address off-grid rural markets. These rural applications—where grid connections are unavailable or unlikely to be available within the next few decades—are the fastest growing niche and represent over 50 per cent of the market for PV. These markets are expected to offer the best potential to mainstream PV technology as an alternative to grid extension.

These unelectrified customers account for 300-400 million households in the developing world. While massive efforts to electrify rural areas have resulted in an increase of rural electric coverage from 18 per cent in 1970 to about 33 per cent in 1990, the overall rate of connections has just kept pace with population growth, leaving the estimated number of unelectrified people constant at about 1.7 billion.

Nearly 1 billion people in the developing world lack access to safe water supplies; combined with a number of other small- and medium water pumping applications for agriculture, this represents another important market where the PV option is a least-cost solution. In addition, there are hundreds of thousands of off-grid schools and health clinics throughout the developing world where PV can provide small amounts of power through government and donor financed programmes.

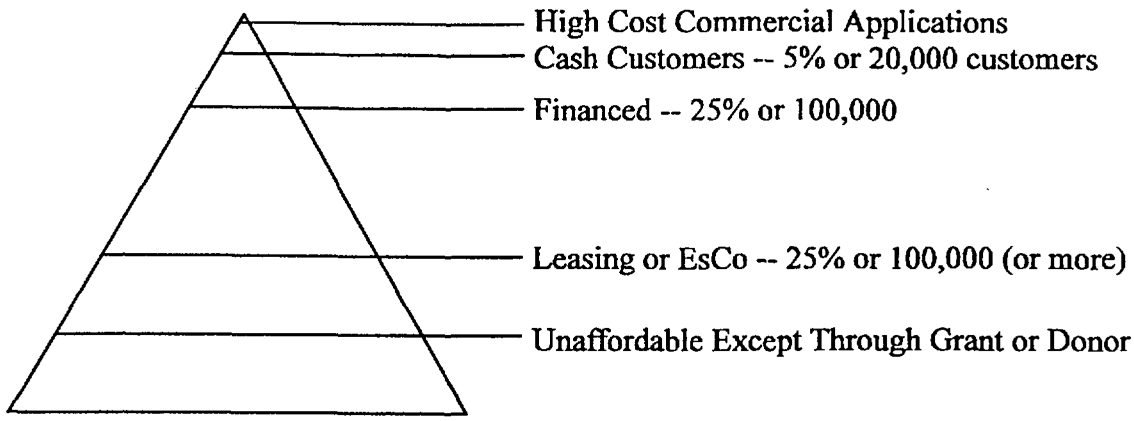
As developing countries grow and become more integrated with the world economy, the costs of poor quality grid service become an obstacle to development. A variety of applications exist in transmission, distribution support, and baseload and peak power to supply commercial operations that place a premium on dependable electrical power. PV can be an important part of an integrated, least-cost utility strategy to meet such requirements. The *Green Carrot* is thus a step towards a new paradigm for electrical power development that places greater emphasis on decentralized, environmentally superior energy services rather than central station grid connected supply options.

The nature of the rural market

In the absence of government or multilateral initiatives to promote renewable energy dissemination, PV commercialization efforts will tend to focus on a "cream-skimming" approach targeting a relatively wealthy minority customer base. Enersol Associates, an NGO and affiliated commercial companies performing PV installations in the Dominican Republic and Honduras, has described a pyramid structure for the larger number of off-grid rural customers that can be served through additional financial services.

In figure 2, the top layer represents the relatively high cost and high value commercial applications in telecommunications, water pumping, and specialized applications; this niche market is small but continues to grow. Below this, there are several layers of customers included within the approximately 400,000 households in the off-grid market. The first 5 per cent, or approximately 20,000 households, are either unserved or dissatisfied with grid service and are able to pay cash for small PV systems. Below this, approximately 25 per cent, or 100,000, can afford systems financed with a down payment and time

Figure 2: Rural market pyramid structure



payments. Lease financing (or Energy Service Company approaches) with no significant down payment can address another 25 per cent, or 100,000, of the household customer pool, while the remainder will generally find PV unaffordable without significant grant contributions. Commercial service to each of these layers builds the sales, technical, and financial infrastructure that supports expansion in each successively larger layer. While these percentages cannot be casually extrapolated to all developing countries, they are an indicator that large, attainable PV markets exist. In poorer countries, the bottom of the pyramid will be larger; in more affluent countries there will be higher levels of affordability.

The "ability to pay" of rural people in the developing world is often higher than average income of GDP figures might suggest. Cyclical farming income and cash remittances or gifts by relatives in urban areas often provide a surprisingly high ability to pay cash for PV systems, evidenced by widespread purchases of motorcycles, televisions, and other consumer durable goods. For those unable to pay cash, amortizing costs through private or public utility service or leasing plans can effectively channel existing expenditures for lighting fuels and batteries to support PV systems. Many rural area households remain poor by definition and cannot afford PV, and no degree of innovative financing or institutional arrangements can address this without a grant component. In many cases, however, a PV approach can still help utilities minimize subsidies already being paid by utilities.

The largest obstacle to widespread PV dissemination is not capital constraints on system purchases or even the price of systems themselves; it is the hesitation of relatively small industry players to commit to investing in and maintaining far-flung sales, distribution, and financing networks when only small and dispersed levels of sales opportunities exist. While 1.7 billion people without electrical services represents an enormous latent market, the mere fact that they remain unelectrified indicates how rural they are, and how difficult they may be to reach through conventional market pathways. This does not mean that these markets should be ignored.

There are numerous opportunities to serve off-grid applications not addressed by country utilities. In addition, there are emerging opportunities for private energy companies to offer services on a franchise basis, with benefits to both customers and the utility that is relieved of the responsibility to serve customers far off the grid. In order to organize markets and bring the required financing to dispersed rural customers, the objective is to catalyze the nascent network of intermediaries in the private, NGO, and government sectors to establish lasting reductions of transaction costs for PV systems. Success in these efforts will signal the commercial viability of PV throughout national and world markets, and spur incorporation of PV projects and applications into normal financial channels.

PV market barriers

Current world PV production (approximately 75 MW), associated balance of systems equipment, and design and installation services, is valued at $1 billion annually. Private investment in PV is estimated at over $2 billion, and has been supplemented with like amounts of government investment, but only a few companies are considered profitable. Cumulative installations of over 300 MW remain but a small fraction of the approximately 2.6 million MW of installed electric generating capacity world-wide, and the technology is in many ways contrary to established patterns of centralized generation and grid distribution of electricity.

While essentially a commercial technology, costs remain high, and the industry is only now making the jump from R&D level production to one of large scale manufacturing. Incremental development of far-flung niche markets is difficult and expensive. A number of PV companies still do direct sales; even those that have a widespread world distribution network and use in-country distribution channels have not made the large commitment to broadening distribution in the developing world for a number of reasons:

- **Investment:** While there is not a macro-level capital constraint on PV, and a number of PV companies have partners or parent companies with significant financial resources, it has been difficult to mobilize capital for manufacturing investment without reasonable assurances that the market will absorb output and that the returns with such investments will be competitive with other investment opportunities.
- **Financing:** Even when cost-effective on a life-cycle basis, PV represents a high front-end capital investment. This increases financing requirements from commercial or private sources, and more difficult to organize on a dispersed basis for individual PV customers. Financing institutions tend to be conservative and most still view PV as unproven or non-commercial and are unwilling or unable to provide innovative or alternative financing mechanisms for PV sales.
- **Subsidies:** Grid power and diesel generators benefit from significant tariff support, tax and investment policy, and fuel subsidies. In both the developed and the developing world, conventional power generation technologies enjoy well-established patterns of investment and institutional support, and have had 50-75 years to diffuse into the market. Unless efforts to rationalize energy systems take hold, market distortions will continue to negatively impact *all* renewable and many energy efficiency technologies.
- **Transaction costs:** Low customer density in a given service territory makes sales, installation, service, and payment collection expensive and difficult, resulting in transaction costs that are about 30 per cent of total system costs. This reduces affordability, undermines sustainability of systems, and reduces the market impact of even dramatic cost reductions in modules.
- **Customer awareness:** There is often a lack of knowledge of PV's capabilities among end-use customers, and utilities remain conservative in regard to all small, decentralized technologies and departures from standard practice.

In spite of these institutional and market barriers, PV cells and modules are taking on the characteristics of a commodity market. A broad array of systems integrator companies has formed to distribute and install completed systems, and there are emerging companies providing a variety of consumer and energy services. Such companies source cells and modules from the least-cost supplier on a competitive bid basis. (Source: *Global Environment Facility, International Finance Corporation*, 11 October 1995)

Photovoltaic applications in rural areas of the developing world

Identifying the niche for photovoltaics (PVs)

The potential niche for PVs in the rural areas of the developing world can be simply defined; it is where satisfactory grid supplies are not available and are unlikely to be available within the next 5 to 10 years. The size of the niche is thus about 300 to 400 million households. But this is a purely theoretical figure that takes no account of the problems, limitations, and priorities of the real world. Identifying a practical niche for PVs means identifying the range of applications for which PVs are technically suitable, affordable for their potential users, and the least-cost solution compared with all the relevant alternatives.[1]

PVs versus the grid

Much attention has been given to financial and economic comparisons between PVs and grid-based power. It has been demonstrated numerous times that running an 11-kV line a distance of 10 kilometres to provide a village with electricity for lighting is far less cost-effective than supplying the same load with PV household kits. But it does not necessarily follow that the PV solution is therefore justified or practicable or that PV systems are affordable or attractive to potential users.

The service provided by PVs is more limited than that provided by the grid in that PVs are essentially confined to lighting, with a few additional low-load uses such as cassette players or small TVs used for a few hours in the evening. PVs are appropriate here because they are free-standing; a long grid extension makes neither economic nor technical sense for such small loads, unless consumer density is extremely high. If a grid extension is provided where the density is low, the cost of the electricity will far exceed what can be recovered with locally acceptable tariffs, and the grid extension cannot be justified economically. The same arguments apply to isolated grids supplied by diesel generators; if the loads could be adequately supplied by PV systems, the diesel supply is almost certain to be economically unviable.

Where a genuine prospect of substantial load growth exists, however, the grid connection is technically the ideal way to provide electricity. Once the main feeder line is in position, no significant constraints remain on the number of consumers that can be connected or the loads they can impose on the system. The grid connection, therefore, opens the possibility of substantial growth in domestic, commercial, and small industrial consumption of electricity at low marginal costs. Hence, where it is economically justifiable, the grid is the first-choice option, and PVs are not likely to be competitive. It might even be taken as a rough guiding principle that the two options are sufficiently different to be mutually exclusive. Thus, the proper role of the grid extension is to provide electricity to areas where a substantial load already exists or is likely to develop in the reasonably near future. PVs are not a technology of choice here because they cannot provide the level of service required in such areas.

The present-day limitations of PVs are accurately, if rather irreverently, portrayed in one of the papers from a recent photovoltaic conference. Describing a rural consumer with a PV system, the paper asks:

> What does the solar "customer" get in this deal? A limited time of use every day for the few lamps he has. Affordable DC appliances? If he finds more than a black and white TV, radio cassette and a car ventilator he is lucky indeed. His city comparison usually has a colour TV, a mixer, an electric iron, and even a fridge...It is not much that the guy from the village sees in the workshop of his brother in the town: a

[1] PVs have a variety of well-proven uses in providing power for telecommunications, remote signalling, and other such applications. These specialized uses, in which security of supply generally takes precedence over cost and the technically qualified staff of the implementing agencies are available for repair and maintenance, are not considered here.

drill, a grinder, maybe an old air compressor. But even those few things are still ages away from his new and modern PV installation... So all is gloom? We might as well give up on PV electrification? Of course not; this paper just wants to stress the need to clearly identify the problems, set priorities, and admit the limitations of the PV technology presently available. (Kusche 1994: 1991)

Any neat division between areas in developing countries that are suitable for grid supplies and those that are not is largely vitiated by lack of investment funds, financially and managerially weak utilities, and a variety of other factors that are preventing the extension of electricity networks, even into areas where they are economically fully justified. This problem is especially apparent in many urban and peri-urban areas. Although such areas should be natural priority targets for expansion of the electricity supply, the run-down condition of the distribution system, lack of generating capacity, and shortage of funds mean they will not acquire a supply for years, or even decades. Although the grid connection may represent the technical and economic optimum, it may not reach many places for a considerable time.

Another factor indicating the need for care in assessing the kind of electrification that is most appropriate is the fact that in many regions the quality of grid supplies provided is extremely low. Breakdowns in generating equipment and distribution systems mean that supplies are only intermittently available. Reductions and fluctuations in voltage are so severe that customers either cannot use equipment or run the risk of having it damaged. Where such problems are already evident or are likely to be prevalent if the grid is extended, the attractions and advantages of connection to the grid are greatly diminished. Under these conditions—when the utility is unable to provide a grid supply or its quality is unacceptably low—people have to meet their energy needs as best they can from the sources available. PVs may be one of the options available. The question for energy consumers is whether PVs are preferable to non-grid alternatives.

Another possible niche for PVs is where, for social or political reasons, utilities are providing electricity supplies to areas in which these are not economically or financially justified. This lack of economic or financial justification may be the result of national tariffs that are set below the necessary level, or a relationship between the costs and likely load in an area that makes it fundamentally uneconomic to serve it with the grid. In both cases, providing PV kits to households may be a less uneconomic option for the utility. The question will then be whether it is technically and institutionally feasible, as well as acceptable to consumers.

The pre-electrification concept

The term *pre-electrification* is sometimes used to describe the use of PVs to supply electricity to an area in advance of full grid electrification. Pre-electrification, in this sense, is not seen as a substitute for a full-scale conventional supply but as a complementary or interim approach. The idea is that it may meet small electricity demands in an area at a stage when providing a grid connection is not economically justifiable. In time, the people in the area can proceed to a full-scale grid supply.

Pre-electrification is something of a misnomer, however. The process envisaged is one of real, although limited, use of electricity. The question is whether, as conventionally assumed by advocates of the approach, the promotion of PVs as a preliminary form of electrification helps or hinders the move to a grid supply.

One of the problems with PV pre-electrification is that once a household has made its investment in a PV system, the type and magnitude of the electric load that can be supplied is largely fixed because of the high marginal cost of providing additional capacity. Even with increased capacity, the use of conventional appliances such as electric irons, kettles, cookers, power tools, and colour TVs is excluded. If a grid supply becomes available, the PV panels, support system, battery, and load controller, which together account for around 80 per cent of the cost of the installation, are no longer relevant. The investment in the PV system therefore does nothing to build up a conventional electricity demand. It also does not make families more able or willing to invest in a grid connection when it arrives, since doing so involves scrapping the greater portion of their investment in the PV system.

At the commercial level, the use of PV installations, however common, does not act as a first step towards large-scale productive electricity uses such as grain milling, metal working, or other small industrial or artisanal activities. Indeed, it can be argued that a large-scale investment in the provision of PVs in an area will slow rather than advance conventional electrification because it absorbs a large amount of the available investment capital for infrastructure. Some commentators have even alleged that PV electrification retards the development process itself:

> First, the community can no longer expand demand to new processes, locations and applications at low marginal cost. The market cannot rationally increase or be allowed to increase beyond the volume indicated by the high marginal cost of a photovoltaic system. Second, the installation of photovoltaics has preempted classical development... The village is trapped at a subsistence level of electricity consumption. (Lucas; no date)

Although this undoubtedly overstates the case in relation to solar home systems (SHSs), it points to a real danger if a centralized, village-level PV power station is being considered. It must also be kept in mind if large-scale government or donor investments are being considered in the provision or subsidization of PVs for social purposes. Although some degree of salvage of sunk costs may occur, investments in PV pre-electrification are highly unlikely to be repaid by savings in the subsequent costs of providing a grid supply.[2] The value of PV systems lies in the immediate satisfaction of small-scale electricity demands they provide. It is on this basis—in their own right rather than as a step towards a quite different form of electricity supply—that PV programmes need to be considered.

[2] In Sri Lanka, suppliers buy back modules at prorated prices if the user obtains a grid connection. Similarly, in Indonesia, a secondary market for PV modules and controllers has emerged. Rural electrification cooperatives in the Philippines rent the modules and controller to the consumer and use them elsewhere when a grid connection is provided. PV owners in the Dominican Republic have kept their PV systems operational for their TVs because of the poor quality of grid supplies (M. Cosgrove-Davies, personal communication, 1994).

Where do PV systems fit?

PV systems provide small amounts of electricity. Finding where they fit in the provision of rural energy supplies involves identifying where such amounts of electricity are required to provide the services that rural people demand.

Solar home systems

In rural areas without an electricity supply, people use candles, kerosene, and car batteries to provide the lighting and other services they want. Most, if not all, of these demands can also be met by using SHSs.

Table 1 breaks down "typical" expenditures on kerosene, dry cells, and battery recharging by rural socio-economic group with the monthly amortization payments that would be payable on a range of PV household systems. The intention here is not to provide a definitive statement on the commercial competitiveness of PV systems in each case but rather to obtain a broad impression of how their cost and level of service compare with what is happening at present in each socioeconomic group.

The most interesting point revealed by the table is that the PV systems are generally financially competitive in providing the services demanded in each socio-economic group. This is a considerable change from even a few years ago. but again, the figures must be viewed with caution—they certainly do not apply in all countries because of the wide variations in prices and expenditure patterns. It also must be borne in mind that the amortization payments are somewhat artificial because payments for PV systems are rarely spread over 10 years. Where credit schemes are available, the repayment period is more likely to be 3 years, at an interest rate considerably higher than 10 per cent.

Other practical considerations come into play when comparing the existing costs incurred by families with those of the PV systems. For the lowest-income group, which spends $2.30 a month on candles and kerosene, the monthly amortization of the cheapest PV system, a lantern, is about half this figure. But the purchase price of $70 for a single item is a considerable deterrent for poor families—the risk of breakage or theft, with the complete loss of such a major investment, is likely to be a major consideration. Perhaps most important of all is that the PV lantern, although it supplies much higher quality lighting than a kerosene wick lamp or a candle, is only a single lighting source. To provide the flexibility the family currently enjoys, the lantern must be supplemented with additional candles or kerosene, thus reducing or nullifying its cost advantage.

For the lower-middle-income household, the initial purchase price of the PV system is also a major hurdle; for many families, it would represent up to 50 per cent of their annual income. Even if extended credit arrangements are available, a rigid commitment to monthly repayments is involved, as well as a need to purchase replacement batteries. This is quite different from the present pattern of expenditure of small amounts of money on a completely discretionary basis. If money is scarce, the family can cut down their purchases, or even do without. Although the PV system provides a higher standard of lighting, it is difficult to see it as an attractive proposition to many families in this income group.

For groups in the middle and upper income range, the purchase price of the PV system is still a significant obstacle. Nevertheless, disposable incomes and expectations are higher in these income groups. These families are not averse to making considerable investments—for example, to improve the quality of their dwellings. They tend to be prepared to incur substantial expenditures for a variety of other reasons as well. For middle-income families, who are spending considerable amounts of money on relatively poor lighting and large numbers of dry cells, a PV system that provides them with a substantial improvement in their living conditions can begin to look very tempting. For the upper-income family already using a car battery, the 100-Wp system would provide a more comprehensive electricity service of considerably higher quality, and at a lower cost than they are presently paying.

Table 1
Comparison between "typical" family expenditures on energy and monthly amortization of PV household systems (US dollars)

Socio-economic group	*Appliances*	*Monthly expenditure*	*PV system*	*Price*	*Monthly amortization*[a]
Low-income	Kerosene lamp Candles	2.30	Lantern	70	1.49
Lower-middle income	Kerosene lamps Torch	3.95	20 Wp	300	4.42
Middle-income	Kerosene lamps Radiocassette Torch	8.00	50 Wp	750	10.81
Upper-income	Kerosene lamps Radiocassette Torch TV and car battery	17.6	100 Wp	1,500	18.98

[a] At 10 per cent; lantern life, 5 years; other systems, 10 years overall life; 5-year life for batteries.

The comparisons shown in the table are, of course, arbitrary in many ways and are purely for illustrative purposes. A middle-income or upper-income family could easily buy a rechargeable lantern to supplement their present sources of lighting, for example. Similarly, an upper-income family may feel that a 20-Wp system to provide good lighting for one room and help economize on their use of a car battery is their best option.

A Zimbabwe report noted the use of 10-Wp systems by mining families living near Harare and commented on the management of these to provide electricity for TV:

> As the energy available is small, there are sometimes conflicts between the husband wanting his light and radio at night and the family wanting the radio during the day. The users were otherwise very adept at load management to achieve their ends. One owner wanted to use the system to power a television set. This is a huge load for such a small system. He discovered that if he used power sparingly, he could watch television all evening every third day. This met his needs and he was very happy with the system. (Zimbabwe Energy Programme 1992)

In summary, table 1 supports the obvious point that the main market niche for SHSs is most likely to be among middle-income and upper-income families in rural or peri-urban areas. The PV option is particularly likely to be attractive to families that currently use car batteries for their electricity supply. For poor and lower-income families, the financial commitment and risk involved in the PV investment are hardly likely to be outweighed by the improved service it provides. In broad terms, this means that the present market niche for SHSs is likely to be in the top 10 to 15 per cent of the rural and peri-urban population without a grid supply or an early prospect of obtaining one.

PV water pumping

It is widely agreed that safe, reliable, and accessible water supplies are critical to rural development and economic progress in developing countries. The United Nations, in cooperation with the World Bank and other development organizations, launched the International Drinking Water Supply and Sanitation Decade (1981-1991) with the goal of providing safe drinking water and sanitation to all people in the developing world. Although progress has been made, it is estimated that nearly a billion people in the developing world still lack access to safe water supplies (Cabraal and others 1987).

Experience with rural water supply programmes demonstrates that they are fraught with difficulties, and a large number of donor and government programmes have fallen far short of their targets or failed completely. The main problems are usually social, cultural, and financial rather than technical. They also vary considerable depending on social conditions and the economic level and expectations of the target groups.

Water, an unconditional necessity of life, is available wherever people live. The minimum amount required for survival is small, considerably less than one litre per person per day, and the actual quantity used depends almost entirely on its local availability. In dry-land agricultural communities, outside the rainy season, for example, people generally rely on the amounts that can be carried in jars from the nearest available water source. These quantities are often far less than needed for hygiene and sanitation; the sources are frequently polluted; and the labour involved in water carrying is excessive and diverts time and energy from more productive, or more pleasant, activities. But, crucially for poor people, the supply is free.

It is easy to specify the ideal amount of water that should be made available to people—the WHO figure is 40 litres of clean water per head each day. What is difficult is translating this ideal into an affordable and sustainable programme. In practice, this means finding communities prepared to commit themselves to the effort and financial expenditures involved in financing, operating, and maintaining a rural water supply to deliver these quantities of water.

Once water supply programmes move beyond the provision of wells and hand pumps that can be maintained by the local community, the question of finance arises. Because of the large numbers of people to be served and the poor state of government finances in most developing countries, the provision of totally free, mechanically pumped supplies to everyone is impractical. Schemes must therefore be designed to gain at least partial cost recovery and local payment for operation and maintenance. Where water is supplied directly to households, this may be in the form of a charge for the metered amount supplied; otherwise people collecting water may be charged a fee by the pump operator.

Such payments conflict directly with the widespread conviction of rural people that water is a free good, for which they should not have to pay. Experience with water programmes shows that a high proportion of rural people, faced with payments in cash, or even in kind, for a high-quality pumped water supply will opt instead for their traditional free source, however unsatisfactory it may be. This is particularly true of the poor, but also for women in general because they are commonly responsible for water supplies and often have limited access to cash. What outsiders may believe is appropriate does not necessarily coincide with the priorities people have for themselves. The provision of a high-quality, mechanically pumped water supply, for which people have to pay, as a replacement for a poor-quality but free system of wells or hand pumps, can have extremely regressive social effects, for example. Contrasting the views of the UN Decade shortly after its inception and those of the village, two Indian writers commented as follows:

- The decade view: Clean water and adequate sanitation are basic needs for life, and these needs are overwhelming for humanitarian purposes.
- The village view: In an acutely water-scarce situation, a convenient water supply is an important priority—not just for drinking and domestic purposes, but also for irrigation. When some water is available, regardless of its quality, other priorities are overriding. (Chauhan and Gopalakrishnan 1983)

The results of the Decade seem to bear out the reservations of these commentators. It appears that just as families and communities climb an energy ladder as their incomes and aspirations grow, they make a similar progression with regard to water. Thus, at the subsistence level, people rely on their traditional free supply sources no matter how inadequate these are, as long as they yield enough for survival. As people become better off, their view of what constitutes an acceptable water supply changes, and they begin to demand higher standards of quality and greater quantities. With this may emerge a willingness to pay at least something, making it feasible to consider more powerful and sophisticated supply systems.

Comparisons between different kinds of supply service are thus difficult to make satisfactorily. Just as families do not attempt to match the level of service provided by an electric light by using vast numbers of candles, they will not expect a hand-pump supply system to deliver the quantities of water they obtain from a diesel or PV system provided by the Government or a donor agency. Attempts to compare water supply technologies by normalizing the supply sources on the basis of a uniform level of water supply will therefore produce misleading results.[3] Rather than comparing systems on the basis of costs per litre delivered, people at the village level are more likely to judge the acceptability of a particular supply system on the basis of the contribution they are asked to make to its operation. This means that low-cost bucket-and-well or hand-pump systems that deliver relatively small quantities of water are likely to be the only practical options in low-income areas.

In higher-income areas, where a reasonable level of cost recovery is acceptable, motorized pumping is more likely to be a financially and socially viable option. It will also be possible in higher-income developing countries where the Government is able and willing to subsidize rural water supplies as part of its rural development activities. In these cases, PV pumping systems come into direct competition with gasoline or diesel engines. Because the service provided—quantities of water pumped into a storage tank—is virtually identical regardless of the motive power used, the comparison hinges primarily on costs.

To illustrate the possible applicability of a PV pumping system in comparison with a diesel system, a water supply system with a daily electricity requirement of 5 kWh, whether for a village or for irrigation, can be used. For the purpose of the discussion, the pump and all the ancillary equipment, including the water tank, can be assumed to be identical for the two systems. Attendance and maintenance will be required for the motor and pump, and general supervision of the system will be needed in both cases.

To provide this amount of electricity in an area with a daily insolation of 4 kWh/m^2 in the worst month, an array with an output of 1,400 Wp would be required. If the installed cost is $10,000, assuming no additional charges for repair or maintenance of the array, a lifetime of 15 years for the system, and an annual interest rate of 10 per cent, the annualized cost is $1,314.

The same water supply service could be provided by a 2.5-kW diesel system operating for two hours each day. The investment cost would be about $1,800. Assuming a fuel consumption of 1,000 litres yearly at $0.50/litre, annual repairs and maintenance at 15 per cent of the capital cost, additional attendance beyond that required for the pump at $500/year, and a 10-year engine life, the annualized cost works out at $1,560. Under these assumptions, the PV system is about 16 per cent cheaper than the diesel.

As the pumping energy requirements become larger, the competitiveness of the PV option is reduced. This is because the marginal costs of the increased supply capacity for the PV systems are so much greater than those for diesel. Suppose the pumping requirement is 10 kWh/day. The size of PV system required becomes 2,800 Wp, with an installed cost of $20,000 and an annualized amortization of $2,628. The same diesel generator as in the previous case can be used, running for four instead of two hours daily, with an additional cost of $500 a year for fuel.

The above calculations are presented for illustrative purposes. The actual availability of solar energy, the water requirements, and the investment and running costs of PV and diesel systems differ widely among countries and locations. In some cases, the niche where PV pumping is economically competitive may be relatively wide; in other countries, it may not exist at all. Only a careful local analysis will reveal which is the case.

Where fuel supply or skilled maintenance are problematic, a weighting may be given in favour of the PV system, but care must be taken to ensure that the necessary skills and spare parts are available for the repair and maintenance of the motor and pump. Inability to obtain reliable supplies of diesel fuel may be symptomatic of deeper problems that will make the operation and maintenance of the PV system equally problematic. Other factors may also have to be taken into account. The small gasoline engines used for irrigation pumping in some countries may have a variety of other uses during the rest of the year. In Bangladesh, for example, many of the engines used for water pumping in the dry season are used as outboard motors for boats in the flood season. Finding the niche for PV pumping, in short, requires a careful assessment of local costs and conditions.

PV refrigerators for health clinics

PV refrigerator systems are considerably more costly than kerosene or LPG units. A typical PV refrigerator system, including the PV array, battery, load controller, and refrigerator, costs from $4,000 to $10,000 before installation. Typical annualized costs are in the range of $800 to $1,500.

Typical costs for comparable kerosene or LPG refrigerators are in the range of $1,100 to $1,500, and installation costs are negligible. An analysis carried out by the EPI in Uganda found that the annualized cost of LPG refrigerators, at a 3 per cent interest rate, were about half those of the PV model—$453 a year in comparison with $939 a year (Rovero 1991). An EPI review in Indonesia found that the annualized cost of kerosene refrigerators was $366 a year, compared with $922 a year for the PV model (Larsen 1992).

An analysis by the EPI (Zaffran 1992) of the conditions that justify use of PV refrigerators concluded that the following would apply:

- No other fuel supply is available.
- Other fuel supplies are unreliable, and shortages are likely to disrupt immunization activities.
- A private fuel distribution system or one managed by the national EPI cannot be envisaged.

More recently this last item was amended after further experience with kerosene refrigerators. It is now thought that the unreliability and difficulty of operating these appliances makes them a generally unsatisfactory option. The present policy of the EPI is to select LPG refrigerators wherever possible because of their low costs and simplicity and reliability of operation. Otherwise, PVs are the system of choice, provided satisfactory arrangements can be made for regular maintenance and for carrying out repairs promptly when required.

[3] This is done, for example, in Cabraal and others (1987), which compares hand pumps, diesel, and PV pumping systems and states that "A key feature of the analysis is that technologies are compared when they are providing the *same level and quality of service.*"

PV battery charging

Car-battery charging services are found throughout the developing world. Technically suitable PV systems can be designed to fill this function, but the economics are highly problematic. With customary costs of about $2.00 for each charge, before profit, it is generally impossible to compete with commercially available services that use diesel generators or the grid. The commercially viable PV car battery charging niche in a given country, if indeed it exists, is thus likely to be small and specialized and can only be identified through detailed local investigation.

Centralized PV power station

The progress that has been made in PV technology means that the costs of the centralized stations built in the 1980s would now be lower. Nevertheless, the inherent disadvantages of high capital investment and the lack of flexibility in meeting load growth of these stations remain.

Another major problem with centralized PV stations is that the equipment is extremely sophisticated, and repair and maintenance are costly, especially when technicians have to be flown in from the country of origin of the equipment. There also tends to be a high level of consumer dissatisfaction, because households connected to what *appears* to be a conventional grid expect the same level of service.

Interest in centralized PV systems has declined in the light of the experience gained to date. They do not appear to have a niche in the developing world, at least in the coming decade. A GTZ review stated, "Central-station village systems do not today constitute a viable alternative to diesel-based isolated grids, and not even a dramatic decline in the price of solar cells would alter this" (Biermann and others 1992).

Centralized PV systems

Instead of separate PV kits in individual households, centralized PV electrification systems or "power stations" parts of the developing world. These centralized systems generally have outputs in the range of 10 to 30 kWp. They are usually designed to provide a 220-volt alternating current supply through a village distribution grid. The power station itself consists of a large area of PV modules; a control room housing the electronic load controllers, inverters, and switch gear; a battery store; and a backup diesel generator.

Box 1.1 Indicative costs of a PV battery charging system

Assume a maximum of 8 batteries charged each day.
Electricity output required = 320 Ah.
Required daily input at 70 per cent overall system efficiency = 457 Ah = 5,500 Wh.
Assuming 4.5 kWh/m^2 in the worst month, number of 50-Wp panels required = 25.

Item	**Cost ($)**
50-Wp panels, 25	12,500
240-Ah battery	300
Load control system	1,500
PV support structure, wiring, charging bay, fence, and so forth	2,500
Installation	2,000
TOTAL	18,800
Repair, maintenance, and attendance @ 10 per cent	1,880
Assume 10 year overall system life	
Monthly amortization at 10 per cent interest	165
Repair, maintenance, attendance	156
TOTAL MONTHLY COSTS	345
Total number of batteries charged per month at 75 per cent utilization of system capacity, 180	
Cost per charge	$1.92

Source: Author estimates.

(Source: *World Bank Technical Paper Number 304, Energy Series, Energy Sector Management Assistance Programme*)

Business opportunities abound in Latin America, Asia, Southern Africa, ECRE

The renewable-energy community has a considerable international business opportunity although it faces some clear challenges, according to the US Export Council for Renewable Energy. Energy growth and interest in renewables are high in developing countries at a time when renewable-energy technologies are becoming mature, environmental pressures are mounting and there is a shift toward privatization.

Among the obstacles are lack of awareness of renewable energy, a bias towards conventional-energy solutions, uncertain financing, uncertain geographic access, lingual and cultural differences, strong competition, a lack of solid partnerships and local presence, and the political and legal environment.

Currently, the US Government and industry focus on Latin America and the Caribbean (LAC), southern and western Africa, and Asia. Within a decade, Latin America will require a 90-gigawatt, or 50 per cent, increase in installed electric capacity. Private power is the key for providing electricity to the 30-90 per cent of the rural populations of the region without access to the grid.

Selected highlights include:

- **Argentina**—has a $300-million rural electrification programme in place; is seeking a $100 million World Bank loan for off-grid rural electrification based on renewables; and has two project concessions due out this spring.
- **Chile**—has launched an off-grid electrification programme and has about $100 million for photovoltaics and wind.
- **Mexico**—offers one of the world's largest PV markets; has a mature lighting market that is shrinking due to the national economic crisis; and is seeking market expansion of productive uses.
- **Caribbean**—depends heavily on imported oil; and has a large untapped "eco-tourism" market that could be tapped by photovoltaic and solar-thermal companies.
- **Brazil**—has launched a renewable-energy policy that calls for the installation of 50 peak megawatts of PV and 3 million square metres of thermal collectors by 2005; and has a $50-million PRODEEM Project promoting PV for community services, and offering loans, a diesel-substitution programme and a PV-installation programme.
- **Costa Rica**—has set aside 35 per cent of total installed electric capacity for private-power development based on renewable energy.

Several key activities of the US ECRE under way for 1996 are:

(1) Policy support: policy-reform workshops were held in Bolivia, Nicaragua, Mexico and Brazil, and policy technical assistance has been extended to Guatemala, Nicaragua, Honduras, Bolivia and Brazil, resulting in laws and regulations favourable to renewables in at least two countries.

(2) Financing support: technical support has been offered through World Bank and International Development Bank; innovative financing sources have been identified; and support for prefeasibility funding has been offered. As a result, renewable energy project sponsors leveraged financing, assisted in creating at least two new renewable energy funds with more than $50 million available, and conducted at least seven prefeasibility projects.

(3) Training: ECRE provided training on productive uses of renewable energy equipment in Mexico and planned training programmes in Ecuador, the Caribbean, Nicaragua and Brazil. This work led to increased decision-maker awareness early in project development.

(4) Project facilitation: ECRE is leading trade missions to Peru (in April), Bolivia, Brazil (in August), Argentina, Chile and the Caribbean (in September). In addition, projects are being identified through in-country project facilitators; in-country partners are being identified; the second Renewable Energy in the Americas Conference will be held; and the tourism-industry-related renewable-energy market is being assessed and developed. The outcome has been the identification of at least 30 new project opportunities; announcement of 30 new projects; holding of a project exposition among 20 companies; training of 50 people; and matching at least 10 renewable-energy project suppliers with tourism opportunities in Brazil and the Caribbean.

(5) Hemispheric Energy Symposium (HES)/Summit of the Americas support: ECRE participated on the HES steering committee and continues working for clean-energy options and rural-electrification outcomes. As a result, the efforts have led to identification of at least five grid-connected fast-track projects for the HES process and identification of one renewables project in each HES-participating country.

Asia is the fastest growing region in the world with more than 460 gigawatts of new capacity expected to be needed within a decade at a cost of $460 billion.

In India, ECRE said it found a strong solar resource and renewables-incentive structure. In addition, there are plans to install renewables capacity of 2 GWe in the current five-year plan, including 30 MWe of solar thermal and 25 MWe of PV. India plans to install 16,000 MWe by 2015 and has 200,000 PV systems installed with a cumulative capacity of 14 MWp and an annual manufacturing capacity of 12 MWp.

Opportunities include $195-million from WB for a renewable-resource development project involving 187 MWe, including 2.5 MWe of PV; a $30-million grant from Global Environmental Fund to finance an integrated solar combined-cycle facility; a $150-million line of credit for renewables from Asian Development Bank, including $5 million for solar-thermal electric; plans by Rajasthan state to create a 35,000-square-kilometer Solar Enterprise Zone to develop 10,000 MWe of solar by 2010; and a renewables credit line from Indian Renewable Energy Development Agency.

In Indonesia, total capacity is 17,000 MWe and another 12,000 MWe are planned. Only 42 per cent of the villages and 26 per cent of the rural homes have grid access. The Government has plans to electrify 80 per cent of the villages by 1999. The country has 2 MWp of PV installed, and the Government plans to install 600 kWp of PV pumping and 190 PV systems for rural medical centres.

Among the opportunities foreseen by ECRE are a WB $50-million small-scale system PV project; a $105-million WB Renewable Energy for Small Power Generation Project using biomass, small-hydro and geothermal energy; and opportunities being explored with non-energy ministries.

China plans to install 100-130 GWe of new generating capacity within 7-10 years, mostly in coal. Currently, the country has 1.5 million sq.m of solar water-heating collectors and 5 MWe of installed PV capacity. China also plans to add 35 MWp of PV capacity by 2000. Current manufacturing capacity is about 4.5 MWp per year although actual production is only about 1 MWp/year. Planned installed capacity for solar thermal is 35 MWe and there are 70 MWe of long-term projects approved.

In southern Africa, the market and opportunities consist of more than 14 million rural households and 85 million people; more than 10,000 unelectrified clinics, schools and larger loads; potential renewables sales exceeding $10 billion; high levels of direct normal solar radiation; a Government undergoing economic trade liberalization; several countries with renewable-energy programmes; and emphasis on rural electrification and PV/wind systems for water pumping. (Source: *The Solar Letter*, 12 April 1996)

Solar technologies for future buildings

Abstract: An increasing demand for integrated building concepts to reduce energy consumption exists. Building design, construction and heating, ventilation and air-conditioning (HVAC) technologies are the decisive elements in this respect. By increasing the energy efficiency, the total energy demand can be reduced to the point that solar energy becomes the dominant source. An "active building envelope" assumes the task of controlling energy flows between inside and outside. The paper reports on new components, system concepts and planning tools for solar buildings.

1. Introduction

Solar energy already occupies an important position within building energy balances. Windows, components found in every type of architecture, reduce the amount of artificial lighting needed and the energy demand for space heating. If we take into account that we spend more time than ever in indoor environments—be it a residential or a working environment—a buildings orientation towards the sun makes the chance for improved living quality as well as energy saving and environment protection.

These planning criteria lead to numerous approaches to integrate solar energy supply components into the building envelope and building services. The palette ranges from so-called passive systems—windows, atria, transparent insulation, etc.—through the application of solar collectors for heating or cooling, to the generation of solar electricity with photovoltaic systems. Recently constructed buildings have proven that a building envelope used in this way can be of high architectural and technical quality.

Further developed and new components and system concepts, combined with improved planning and design tools, lead to buildings which provide a pleasant indoor climate with the aid of increasingly simple building service technology. This is the crucial point in achieving financial viability with the new approaches.

2. New components

2.1 Windows and glazing

Windows provide visual contact to the outside environment. At the same time, they are the components in the building envelope with the highest energy transfer in both directions. With regard to the winter energy balance of fenestration, both a low heat loss (described by the heat transfer coefficient, U) and a high transparency for solar radiation (solar heat gain coefficient, SHGC) are desirable. Starting from insulating glazing technology, there are different approaches to meet these requirements, used separately or combined:

- Selective coating of the glazing
- Selective films in the cavity between the panes
- Rare gas fill
- Evacuated glazing
- Transparent insulating materials.

Primarily due to progress in coating technology, glazing products are now available which satisfy the rising demands on building thermal insulation and thermal comfort.

The coatings are usually tuned for high visible transmittance. The transmittance for the entire solar spectrum—including the non-visible range—is somewhat lower. If transparency and object recognition is not decisive (roof glazing, skylights, transparent insulation of walls), better properties for the total energy transmittance are achieved with transparent insulating (TI) materials between the panes. These consist of open-celled structures made of plastic or glass, which suppress convective heat transport and absorb thermal radiation.

With regard to indoor temperatures in summer and daylighting conditions in buildings, the facility to "switch" the transparency becomes very important. In addition to the well-known stationary and mechanical sun-shading systems, new approaches are opened by so-called "smart windows". They are distinguished according to the underlying physical principle into the following categories:

- Thermotropic
- Thermochromic
- Electrochromic
- Photochromic.

At present, thermotropic switching is the most interesting with regard to production possibilities and price. Thermotropic glazing consists of a hydrogel, a mixture of water and a polymer, which is sandwiched between two glass panes. The switching is passive, depending on the temperature, and is based on reversible mixing (clear state) and separation (diffusely reflecting state) of the polymer and water.

Advances in the glazing itself mean that the energy deficits in the glass edge sealing and the window frame now become significant. Window properties are increasingly determined by these components. Current development is concentrating on components with improved thermal insulation.

2.2 Daylighting systems

Energy savings and visual comfort are the arguments for making better use, qualitatively and quantitatively, of daylight to illuminate rooms. Apart from measures affecting the building form, such as facade contours and atria, the design of the building envelope is primarily responsible for the lighting conditions.

2.3 Transparent insulation

With transparent insulation of the outer walls, passive use of solar energy also becomes feasible via the non-transparent surfaces of the building envelope. Incident sunlight is absorbed by the dark wall surface behind the TI material. The resulting heat is released to the room behind, with a time lag and attenuation determined by the material and thickness of the wall. Increased thermal comfort due to the warm walls and the simple operating principle are the advantages of this approach. The solar thermal efficiency values for these systems lie between 25 and 50 per cent.

The transparent exterior insulation and finish system is the most interesting economically at present. The highly efficient glazed TI facade will profit significantly, both in its construction and in its price, by the anticipated integration of a thermotropic glazing cover to switch the transmittance.

3. Innovative system concepts

3.1 Solar thermal systems

District heating networks with a central heating plant have a long tradition in Sweden and Denmark. The first demonstration projects with large integrated collector arrays (2,000 to 5,000 m^2) and reservoirs (2,000 - 350,000 m^3) for heat production throughout the year started in 1982. Recently, the experience has been transferred and adapted to Central European conditions, leading to the first pilot systems with collector areas of up to 1,000 m^2. In most of them, large flat-plate collector modules with an area of about 10 m^2 were mounted on the roofs of individual buildings to avoid occupying additional ground area. Further development aims towards prefabricated roofing sections including collectors, in order to improve the architectural integration and the financial viability.

With heat generation costs of 0.2 - 0.3 DM/kWh, the price for using solar energy in district heating networks is lower than for decentralized domestic hot water heating. In settlements of low-energy houses, up to 50-70 per cent of the heating demand can be met in this way for an acceptable price.

Because of the temporal match of energy supply and demand, the use of solar energy for active air-conditioning in buildings is especially advantageous. This is of most interest for Southern European countries. Besides the well-known sorption techniques, today desiccant cooling systems (DCS) are being intensively investigated, particularly when high air exchange rates are required. In both cases, thermal energy is the source to drive the cooling process. The lowest possible temperature level is advantageous for applying solar thermal energy. A desiccant cooling system can already use heat at 60° C for the drying process and completely avoids the need for fluorinated hydrocarbons. Fossil-fuelled desiccant cooling systems represent the state of the art. The first solar-supported systems are being constructed at present. The required collector arrays can be used throughout the year to generate hear.

3.2 Photovoltaics

Photovoltaics in buildings now represents the state of the art. Because of the fluctuation in the solar radiation, European systems are generally connected to the grid via inverters. Standalone systems to supply isolated buildings are the exception, for example in rural areas. An array of about 10 m^2 (crystalline silicon cells) is needed for a rated generator power of 1 kW_p. Depending on the amount of solar radiation available (primarily determined by the latitude), optimally orientated, roof-integrated systems can supply an annual yield of 700 kWh (60° N) to 1,500 kWh (40° N) per kW_p. The yield from wall-mounted modules is 20-30 per cent lower.

Assuming the highest energy efficiency (an advanced low-energy house, energy-efficient appliances, solar domestic hot water), a PV generator area of about 30 m^2 (3 kW_p) is sufficient to meet the total energy demand of a single family house in the annual primary energy balance. The electricity grid acts as the energy storage unit.

In contrast to earlier installations, the constructive and architectural integration of modules into the building envelope is treated as a high priority. This applies particularly to prestigious commercial and industrial buildings. The market offers numerous possibilities:

- Variable module sizes and forms
- Opaque and semi-transparent modules
- Flexible modules
- Coloured cells and modules
- PV in multi-functional insulating glazing (heat mirror, acoustic glazing,...)
- PV in ventilation facades
- Shading devices with PV
- PV roofing tiles.

4. Conception, simulation, analysis

Improved properties of the building envelope with respect to energy reduce the need for supplementary "artificial" energy flows. "Passive" control of the temperature and lighting conditions in buildings is becoming increasingly popular. Dialogue between architects and energy planners at the earliest possible stage is essential for success. The dedicated application of computer-supported planning tools can already provide detailed information in the early planning phase. Here, it is decisive, not only to calculate individual numerical values (e.g. heating or cooling demand), but above all to analyse the results of parameter studies and compare variations.

Whereas questions relating to the thermal energy balance are usually treated with dynamic building simulation, the simulation of lighting conditions is usually limited to selected instantaneous situations because of the computing time needed at present (e.g. for ray-tracing). However, these instantaneous situations can be visualized in photo-realistic illustrations or combined to give animated sequences. The primary question is that of the illumination quality. In order to evaluate the energy savings resulting from increased use of daylight, these instantaneous situations can be employed in quasi-dynamic annual simulations and combined with cooling load calculations.

Experience from completed projects demonstrates that economically favourable results are best achieved when a solar system is not simply added on but is thoroughly integrated into the building and its service technology.

5. Conclusions

The presented concepts show how high living quality can be achieved with low exploitation of resources. It is decisive for the success of these strategies that buildings, which have been planned and constructed along these principles, become widely known and thus deepen the knowledge on the subject. Analysis of everyday reality in the completed buildings is thus an important contribution. If we ignore this, complicated system concepts to correct faulty building designs will still dominate future buildings. (Source: *(Paper presented at the fourth European Conference on Solar Energy in Architecture and Urban Planning, Berlin, 26-29 March 1996*, J. Luther, K. Voss, V. Wittwer; Fraunhofer Institute for Solar Energy Systems ISE; Oltmannsstr. 5, D-79100 Freiburg i. Br., Germany)

Major development funding sources for renewable energy projects

The World Bank and related multilateral development banks

World Bank
Energy Development Division
1818 H. Street, N.W.
Washington, D.C. 20433, USA
Tel: 202-473-3266/477-1234
Fax: 202-477-6391

United Nations Development Programme (UNDP)
One United Nations Plaza,
New York, NY 10017, USA
Tel: 212-906-5000
Fax: 212-906-5364

Global Environmental Facility (GEF)
(see the World Bank)
The GEF was established by the World Bank in 1990 to support energy-efficiency and new and renewable energy activities that developing countries would otherwise have too little incentive to undertake. It is a cooperative venture between the World Bank, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and national Governments.

Energy Sector Management Assistance Programme (ESMAP) (see the World Bank)
Established in 1983 as a joint programme of the World Bank and UNDP. Provides technical assistance on a range of energy issues to recipients of World Bank loans.

Financing Renewable Energy for Small-Scale Energy-Users (FINESSE) (see the World Bank)
The FINESSE project was created by the World Bank's Energy Sector Management Assistance Programme (ESMAP) to provide workable approaches to address the financing and infrastructural problems that hinder the spread of the renewable technologies.

International Fund for Agricultural Development (IFAD)
107 Via del Serafico,
00142 Rome, Italy
Tel: 39-6-545-91
Fax: 39-6-504-34-63
Since 1974, IFAD (specialized agency of the United Nations) has made low interest loans available directly to poor, small-scale farmers, and to small-medium scale agricultural development projects. Their goals include promotion of food-based rather than export-driven agriculture, and to improve living conditions in rural areas.

International Finance Corporation (IFC)
(See the World Bank). A World Bank private sector affiliate.

Inter-American Development Bank (IDB)
1300 New York Avenue, NW
Energy Division
Washington, D.C. 20577, USA
Tel: 202-623-1963
Fax: 202-623-3096
A regional branch of the World Bank.

Asian Development Bank
P.O. Box 789
Manila, Philippines 2800
Tel: 834-444 or
63-2-711-3851 (international calls)
Fax: 632-741-7961
A regional branch of the World Bank.

African Development Bank
01 B.P. No. 1387
Abidjan 01, Cote d'Ivoire
Tel: 225-32-07-11
A regional branch of the World Bank.

Caribbean Development Bank
Wildey St. Michael
Barbados
Tel: 809-431-1600
Fax: 809-426-7269
A regional branch of the World Bank.

International Fund for Renewable Energy and Energy Efficiency (IFREE)
Suite 805,
777 North Capitol Street, NE,
Washington, D.C. 20002, USA
Tel: 202-408-7916
Fax: 202-371-5115
IFREE fosters environmentally-sound energy projects in developing countries. IFREE was established in 1992 by the US Export Council for Renewable Energy, in cooperation with the USAID, US Department of Energy, US Environmental Protection Agency and the Rockefeller Foundation.

German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit — GTZ)
Postfach 5180
D-6236 Eschborn 1, Germany
Tel: 49-6196-790
Fax: 49-6196-791115

Japan International Cooperation Agency (JICA)
Shinjuku Mitsui Bldg, 2-1-1, Nishi-shinjuku,
Shinjuku-ku,
Japan
Tel: 03-3346-5311-5314
A government sponsored agency which implements a wide range of programmes which contribute to the economic and social progress of the developing world. JICA specializes in technical training, consultation, and supplying equipment for technical cooperation internationally.

Swedish International Development Agency (SIDA)
S-10525
Stockholm,
Sweden
Tel: 46-8-728-5100
Fax: 46-8-673-2141

F. PUBLICATIONS

World Bank Technical Paper Number 304
Energy Series
Photovoltaic Applications in Rural Areas of the Developing World
ISSN No. 0253-7494
Gerald Foley
The World Bank, Washington, DC

Solar Cells and Their Applications
Edited by Larry D. Partain
Edward L. Ginzton Research Center
Palo Alto, California
A Wiley-Interscience Publication
John Wiley & Sons, Inc.
ISBN 0-471-57420-1

This book covers a broad range of applications including: Solar cell fundamentals, cell technologies, module technologies, system technologies and other aspects, i.e.

Silicon Cells: Single Junction, One Sun, Terrestial, and Single and Multiple Crystalline
Martin A. Green and Stuart R. Wenham

Terrestial Silicon Concentrator Solar Cells
Silicon, Gallium Arsenide, and Indium Phosphide Cells: Single Junction, One Sun Space
Status, Prospects, and Economics of Terrestial, Single Junction GaAs Concentrator Cells
High-Efficiency III-V Multijunction Solar Cells
a-Si:H-Based Solar Cells
$CuInSe_2$- and CdTe-Based Solar Cells
Silicon One Sun, Terrestial Modules
Silicon-Low Concentration, Line-Focus, Terrestial Modules
Silicon and Gallium Arsenide Point-Focus Terrestial Concentrator Modules
Thin-Film Terrestial Modules
Silicon and Gallium Arsenide, Single Junction Space Modules
Concentrator Modules Using Multijunction Cells
Terrestial Off-Grid Photovoltaic Systems
Terrestial, Grid-Connected Systems: Field Experience, Status, Needs and Prospects
Silicon and Gallium Arsenide Space Systems
An Overview of Environmental, Health and Safety Issues in the Photovoltaic Industry
Photovoltaic Market Analysis
Solar Resource Characteristics
Future Space Program Plans, Needs and Potential
Government Terrestial Acceleration Programs
Status, Potential, Conclusions

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The **International Solar Energy Society (ISES)** is the older solar energy organization in the world. ISES has two major publication *Sun World*, a quarterly non-technical report of activities world-wide, and *Solar Energy*, a technical journal published monthly.
ISES Headquarters (NEW—January 1995)
Villa Tannheim, Wiesentalstrasse 50
D-79115, Freiburg, Germany
Tel.: +49 761 45906 50
Fax: +49 761 45906 99
E-mail: HQ@ISES.ORG

The **American Solar Energy Society** (ASES) publishes *Solar Today*, a bi-monthly magazine of happenings in solar energy in the US.
2400 Central Avenue, Suite G-1
Boulder, CO 80301, USA
Tel.: (303) 443-3130
Fax: (303) 443-3212

Institute releases 40 reports on its solar research innovations

The Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany, has released its latest annual report listing 40 innovations.

Among the innovations described in the recently released report are:

- A compact fuel cell reformer that makes long ranges possible for electric vehicles;
- Thermoelectric converters that reduce storage problems in photovoltaic (PV) systems;
- Convert unused radiation in thermo-PV applications to electricity; and
- "Favourably priced" multicrystalline silicon solar cells that achieve efficiency values of 16 per cent.

Contact: K. Heidler, Fraunhofer Institute for Solar Energy Systems ISE, Oltmannstr. 5, D-79100 Freiburg, Germany

Dower, Roger and Keith Kozloff.
A New Power Base, Renewable Energy Policies for the Nineties and Beyond.
World Resources Institute, 1993

This book includes solar energy in its discussion on revised policies utilizing renewable energy sources for a national energy source. This source includes several tables relating the projected benefits of renewable energy sources. These include some that compare solar power economically to fossil fuels in the future.

American Solar Energy Society.
Economics of Solar Energy Technologies.
Boulder, CO: American Solar Energy Society, 1992.

This source about solar energy provides useful economic comparisons with other forms of energy. Its appendixes provide cost tables including one for photovoltaic systems.

Web sources/links

http://www.sandia.gov/ttrans/facilities/abstracts/photovoltaic.html/(26January 1996)

This Web site describes the Sandia National Laboratory's facilities and projects that are geared towards the developments of competitive photovoltaic cell electricity systems.

http://www/rain.org/solarpv/utilgrid.htm

This site is Siemens Solar Industries' presentation of its projects in the development of solar power systems to support the power grid.

G. CALENDAR OF EVENTS

The Solar Energy Calendar

14-17 April: Fourth International Conference on Applications of Solar and Renewable Energy, Cairo, Egypt.
Contact: International Solar Energy Society, Conference Secretary, ASRE '96, Box 487, Doki, Egypt

13-17 May: 25th Photovoltaic Solar Energy Conference, Washington, DC.
Contact: Eldon Boes, National Renewable Energy Laboratory, 409-12th St., S.W., Ste. 710, Washington DC, 20000 USA. (202) 484-1096

27-30 May: 19th International Conference of the International Association for Energy Economics: Global Energy Transitions with Implications for Central and Eastern Europe, Budapest, Hungary.
Contact: International Association for Energy Economics, 28970 Chagrin Blvd., Ste. 210, Cleveland, Ohio 44120-4630 USA. Fax: (216) 464-2737; or Magyar Energetikai Tarsasag, Professor T. Jaszay, Foutca 68, H-1027, Budapest, Hungary. Fax: +36-1 201-7937

29 May-1 June: International Symposium for Thermal and Photovoltaic Energy Utilization, Gleisdorf, Austria.
Contact: Arbeitsgemeinschaft Erneubare Energien, Gartengasse 5, A-8200, Gleisdorf, Austria. Fax: +0043 3112-5886-18

3-7 June: Sixth International Energy Forum: Energy Strategies in Developing Countries in the 21st Century—Challengesand Opportunities, Beijing, China.
Contact: International Conference Centre for Science and Technology, Attn: Mr. L. Feng, 44 Kexueyua Rd., Shuangyshu, Beijing 10086, China. Fax: +86 1257-5691

15-21 June: 4th World Renewable Energy Congress, sponsored by United Nations Educational, Scientific and Cultural Organization, Commonwealth Science Organization, DOE. Topics will include renewable energy, global warming and the environment.
Contact: World Renewable Energy Network, A.A.M. Sayigh, 147 Hamilton, Lower Early, Reading, RG6 4HN, UK. Fax: +44(0) 9240 4991

25-29 August: Biennial Conference of the International Solar Energy Society, Taejon, South Korea. Sponsored by International Solar Society.
Contact: ISES, P.O. Box 124, 26 Railway Ave., Caufield East 3145, Australia

2-6 September: International Symposium on Solar Energy Materials, Marriott Casa Magna Hotel, Cancun, Mexico.
Objectives and Scope:
The purpose of the Symposium is to provide an opportunity for scientists, engineers and technologists, to present the State of the Art, discuss new developments and exchange ideas in the area of materials as related to solar energy systems and their applications. Invited lectures and contributing papers will be presented by researchers and practising scientists and engineers from around the world.
Topics to be included in the symposium:
Photoluminescent materials
Photosensitive materials
Composites
Selective reflecting and absorbing materials
Photocatalysis materials
Chromogenics
Photovoltaic materials
Hydrogen production electrolyzers
Fuel cells
Thermodynamic working substances
Energy storage materials
Other related topics

World solar summit scheduled for September in Zimbabwe

Harare, Zimbabwe, will be host to a world solar summit to be held 16-17 September, the United Nations Educational, Scientific and Cultural Organization (UNESCO) announced.

The conference is expected to be attended by officials of some 40 countries, along with representatives of non-governmental organizations and industry, said Luis Marques, special adviser to the UNESCO director-general.

The purpose of the conference is to enhance the understanding of the role that renewable energy sources can play in protecting the environment and in meeting the energy needs of the world's population, particularly those living in remote, undeveloped areas.

"Fossil fuel sources, especially oil, will dwindle and become more expensive in the years to come, and the world needs to prepare for that eventuality", Marques told a session of the UN Energy Committee.

The summit would be preceded by a 14 September meeting in Harare of the World Solar Commission, chaired by Zimbabwean President Robert Mugabe. The commission was established as part of the summit process.

Preparations for the conference were discussed at a 26 February meeting in Harare, where Mugabe said Governments need to adopt policies that will encourage the use of renewable energy resources. Mugabe said his Government is actively promoting the use of solar energy, but he complained that international financiers are not investing enough money in solar energy projects.

He urged those attending the planning meeting to develop recommendations for "innovative funding mechanisms" that can be used to support solar energy projects.

16-19 September: DGS International Solar Forum — Euro Sun '96, Freiburg im Breisgau, Germany.
Contact: Deutsche Gesellschaft für Sonnenenergie e.V., Augustenstrasse 79, D-80333, München, Germany; +49-0 89-521668. Scientific Contact Intl. Solar Energy Society e.V., Wiesentalstrasse 50, D-79115, Freiburg im Breisgau, Germany.

September: Third Annual Renewable Energy Asia Pacific '96, Jakarta, Indonesia.

Contact: Alternative Development Asia Ltd., 5F, 3 Wood Rd., Wanchai, Hong Kong. Tel.: +852 2574-9133; Fax: +852 2574-1997.

6-11 October: 8th International Symposium on Solar Thermal Concentrating Technologies, Cologne, Germany. Sponsored by Deutsche Forschungsanstalt für Luft und Raumfahrt e.V. Topics will include solar thermal power stations and solar chemistry.

Contact: Herr Becker, Linder Höhe, D-51147, Köln, Germany. Fax: 02203 66100

11-15 November: 9th International Photovoltaic Science and Engineering Conference, SEAGIA Convention Complex, World Convention Centre Summit, Miyazaki, Japan. Sponsored by The Japan Society of Applied Physics, The Institute of Electrical Engineers of Japan and Nagoya Industrial Science Research Institute.

The PVSEC-9 will be held at SEAGIA Convention Complex, Miyazaki, Japan in November 1996. The conference will cover the entire aspects of photovoltaic devices, materials and systems. The major area includes:

- I Fundamentals and New Approaches;
- II Crystalline Si Solar Cells and Materials (including single, polycrystalline and thin-film cells);
- III Amorphous Si Solar Cells and Materials;
- IV Compound Semiconductor Solar Cells and Materials (including III-V, II-VI and CIS cells).
- V Modules and System Components (including reliability, BOS components and concentrators);
- VI System Applications (including terrestial and space systems)
- VII National Programmes and Economics

The conference will provide excellent symposia on the prospect for future PV devices and systems through invited and contributed papers.

Announcement

30 June-4 July 1997: 14th European Photovoltaic Solar Energy Conference and Exhibition, Palacio de Congresos, Barcelona, Spain. Supported by the European Commission.
Chairman: Dr. H. Ossenbrink.
Organizer: WIP-Munich, Germany. Tel.: +49-89-720-1232.

29 September-3 October 1997: The 26th IEEE Photovoltaic Specialists Conference,
Anaheim, Marriott Hotel
Anaheim, California
Abstracts due 5 May 1997

Contact: Paul Basore, conference chairperson, Centre for PV Devices and Systems, University of New South Wales, Sydney NSW 2052, Australia. Fax: +61-2-666-4079; e-mail: p.basore@unsw.edu.au;

Ajeet Rohatgi, programme chairman, Georgia Institute of Technology, Atlanta, GA 30332. Tel.: 404-894-7692; Fax: 404-853-9171. E-mail: ajeet.rohatgi@gatech.edu/

H. UNIDO NEWS

UNIDO at the World Solar Summit

The World Solar Summit was convened in Harare, Zimbabwe 16-17 September 1996. A series of preparatory meetings at regional level had been undertaken over the last two years. The Summit agreed on the Harare Declaration on Solar Energy and Sustainable Development. The Heads of States and Government committed themselves to:

(a) Work towards wider use of solar energy, to enhance the economic and social development of all people....;

(b) Work towards policies and effective mechanisms that will speed up and facilitate the use of solar energy, avoiding duplication and administrative delays, and the encouragement of international cooperation; and

(c) Work towards the greater use of solar energy through the provision of adequate technical assistance and funding.

In pursuit of these objectives, the Summit called on all nations to join in the development and implementation of the World Solar Programme, 1996 to 2005; invited the World Solar Commission to continue to provide high level political leadership and guidance; and invited the Secretary-General and Heads of specialized agencies and programmes of the United Nations to join in the implementation of the World Solar Programme, 1996 to 2005.

The Managing Director of UNIDO's Human Resource, Enterprise and Private Sector Development Division (HEPD) made a statement to the World Solar Summit outlining UNIDO's programmes on solar energy. He indicated that UNIDO and the International Centre for Application of Solar Energy (CASE) are ready, in cooperation with other organizations, to assist developing countries in the formulation and implementation of renewable energy projects, including those within the framework of the World Solar Programmes (WSP). In particular, UNIDO will take the lead responsibility for one of the key areas of the programme namely, industrial policy, market penetration and technology transfer for renewable energy.

The Perth International Centre for Application of Solar Energy (CASE)

Operating under the patronage of the United Nations Industrial Development Organization (UNIDO), the Perth International Centre for Application of Solar Energy (CASE), has as its charter the aim to promote the application of solar energy technology in developing countries. Solar energy encompasses all forms of renewable energy. The Centre is funded by both the Government of Western Australia and the Commonwealth Government of Australia and is currently located in the Central Business District of Perth, the capital city of Western Australia.

The Centre aims to undertake a wide range of renewable energy technology-related services, including:

- Carrying out externally funded project definition studies;
- Arranging consultants to carry out feasibility studies;
- Assisting in preparing applications for project financing;
- Organizing contractors to implement projects;
- Managing projects;
- Ensuring local people are trained effectively to operate and maintain renewable energy systems.

CASE is a project oriented organization which draws together expert teams for individual projects. A typical project could include:

- Standalone photovoltaic (PV), wind and mini-hydro systems;
- Hybrid diesel, PV, and wind systems;
- Bio-mass energy systems;
- Solar thermal systems;
- Education and training;
- Technology and skills transfer seminars and workshops.

In collaboration with UNIDO and the recipient country, CASE aims to: define the project; carry out a feasibility study; assist in securing finance and finally to implement the project.

Projects should generally be initiated by an organization in a developing country, which formally requests UNIDO or CASE for assistance. Potential projects may be informally discussed at any time with CASE, or UNIDO, to ascertain their appropriateness, and will be judged on their own merit.

At the conceptual stage, potential projects may lack definition, scope and specific outcomes. The formulation of this information and the preparation of a project definition document, incorporating a preliminary system proposal and cost estimate is essential before the feasibility study can be carried out. This feasibility study is aimed at the objectives outlined in the project definition document. The study generally includes:

- Analysis of energy requirements and resources;
- Technology and equipment options, cost estimates;
- Economic and financial evaluation; site location studies;
- Analysis of cultural and social issues;
- Environmental considerations;
- Training requirements;
- Preliminary work schedules.

This feasibility study should provide the information required to support a request for project implementation funding. It is expected that where such a study indicates a viable project, the Government of the recipient country will formally make a request for such funding. CASE and UNIDO assist in the application for national or international funds to implement viable projects. once funding has been obtained, project implementation can proceed where usually UNIDO, or CASE are appointed as project managers. The objective of this project management is to ensure that the project is completed on schedule, within budget limitations and meeting technical specifications. The project ensures that local people are trained in the operation and maintenance of the renewable energy systems so that the system will provide long-term satisfactory operation.

For more information, contact:

Programme Coordinator
Technology Service
UNIDO
Vienna International Centre
P.O. Box 300
A-1400 Vienna, Austria
Tel.: (+43 1) 21131 5158; Fax: (+43 1) 2113 6805

Managing Director
Perth International Centre for Application of Solar Energy (CASE)
Level 3,81 St. George's Terrace
Perth, WA 6000
Australia
Tel.: (+619) 321 7600; Fax: (+619) 321 7497

TECHNOLOGY AND INVESTMENT OPPORTUNITIES

TECHNOLOGY OFFERS

AMORPHOUS SILICON SOLAR MODULES

Company offers amorphous silicon solar modules which are manufactured using 9-layer structures of amorphous silicon deposited from a gas phase. The layers have different properties and are deposited on top of each other on to a stainless steel substrate in a patented roll-to-roll process. The design allows the utilization of a wide spectrum of solar radiation, thus increasing the efficiency of the energy conversion. The face of the module is coated with a durable and long-lasting polymeric material. Reliable operation is ensured even if only partly illuminated.
The company also offers a variety of equipment for solar energy use and claim to be of use even in the most remote places. The company also offers technology for other renewable energy sources.

For more information, contact: Mr. A. Volchov, Atomenergoexport, Ovchinnikovskaya nab. 18/1, 113324 Moscow, Russia. Fax: (+95) 230 21 81.

ELECTRICALLY CONDUCTIVE ADHESIVE

The adhesive is based on an electrically highly conductive filler mixed into a resin matrix. Two kinds of adhesive are offered: a two component adhesive based on reactive resin which have to be mixed before application and showing excellent adhesion to metals with hardening within four hours. Conductivity is in the order of 10^3S/m. The one component adhesive shows same conductivity and requires no mixing before application. Adhesion is achieved shortly after application; however the adhesive strength is somewhat lower than that of the two component glue.
Degree of development: In current production.
Type of Offer: Joint venture; manufacturing under licence or patent.

For more information, contact: Slovak Chamber of Commerce & Industry, Regional Chamber Trencin, Dolny Sianec 1, 91101 Trencin, Slovakia. FAX: (+42) 831 521 023. Please quote Ref.: 7.27

HIGH TEMPERATURE, HEAT RESISTANT, NON SHRINKING DRESSED SILICA THREADS

The technology for making these silica threads is offered by a Russian company for high output production (up to 300t/year). The threads have uniform strength characteristics better than those of silica threads made from E glass. The threads are made by way of chemical leaching and subjected to heat treatment and dressing.
Technology offers production of packs with a weight of 1.5 kg, with linear density of up to 250 tex.

For more information, contact: InterTec, Brahmsplatz 8/3, A-1040 Vienna, Austria. Fax: (+43) 1 504 4094. Ref: Na-01-048.

WIND PUMPS

Company offers proven design of low-cost wind-pumps (water pumping windmills). It offers high standards of reliability and robustness, easy installation, automatic storm protection with minimal maintenance. Suitable for pumping heads up to 90 metres. Technology is offered for manufacturing under licence.

For more information, contact: Mr. T.A. Polak, 43 Downing Street, Farnham, GU9 7PH, United Kingdom. Fax: (+44) 1 252 737 106.

SOLAR HEATING SETS

Company offers small solar boilers on light-weight concentrators (aluminized plastic film technology) for a fast heating system, as well as portable solar boilers and solar kitchens (1kWt power range). Peak power achieved is 800W, working volume 300 cm^3, focal temperature 300°C with a clock-drive tracking system. Manufactured from stainless steel and aluminium.

For more information, contact: Institute of Nuclear Power Engineering (INPE), 1, Studgorodok, Obninsk 249020, Russia. Fax: (+7095) 255 22 25. OR Volna Ltd., RIARA, Kievskoe Shosse, Obninsk 249020 Russia.

SOLAR ENERGY ACTIVITIES

Institute offers assistance in solar energy activities, with particular emphasis on small-scale power range systems (1 - 100 kW) and heat and power generating systems for agricultural applications. These include: combined solar-fuel electricity generating sets and stretched membrane concentrators; heat-power co-generating systems using combined solar, wind energy and domestic fuels; seasonal water heaters and portable solar douches; portable water desalination sets; portable solar boilers and solar kitchens.

For more information, contact: Mr. A. Trofimov, Research Leader, Institute of Nuclear Power Engineering (INPE), 1, Studgorodok, Obninsk 249020, Russia. Fax: (+7 095) 255 22 25.

SOLAR PANELS FOR DRYING BARNS

Company manufacturers, delivers and installs custom-made solar panels for tobacco drying chambers. Suitable for upgrading any type of drying chamber, tests have shown a reduction in organic fuel consumption and can save up to two hectares of forest per annum. Can also be used for drying tea leaves, timber and other products. Approximately 100 panels would be required to upgrade a barn drying 300 kg of green tobacco leaves.

For more information, contact: NPO Machinostroyenia, Gagarin Str., 33, Reutov, Moscow region 143952, Russia. Fax: (+095) 302 2001.

PORTABLE SOLAR POWER PLANT

Company offers a portable solar power plant intended for DC supply of household appliances (radio, lighting etc.) requiring up to 40W. During day time the plant operates from solar betteries, at night from accumulator batteries enclosed in the plant casing and which automatically recharge during operation. Manufactured in the form of a case, it is equipped with a device for sun-tracking at the required angle, is simple to use and requires no special maintenance. The solar battery modules are hermetic.

For more information, contact: NPO Machinostroyenina, Gagarin Str., 33, Reutov, Moscow region 143952, Russia. Fax: (+095) 302 2001.

SOLAR WATER HEATING PLANT

Technology offered for a solar water heating plant for use in farms and cottages, etc. Dependant on the intensity of the sun, it is connected to the water supply. Water is heated due to heat transmission from the surface of the collector panale, raised to the tank. Natural circulation occurs.

For more information, contact: NPO Machinostroyenina, Gagarin Str., 33, Reutov, Moscow region 143952, Russia. Fax: (+095) 302 2001.

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TECHNOLOGY REQUESTS

ELECTRICAL INVERTERS

A company wishing to diversify plans a new project to import and assemble inverters to provide electricity to rural areas and small towns where the national power grid is not present. The current supply of electricity only meets 5% of rural demand. Initially, the company wishes to assemble 1,000 inverters to test the market. In addition, they wish to import solar panels. The estimated total project cost is US$2,319,800.
Specification of technology requirement: Product/process know-how, training, managerial skills, technical services and equipment.
Preferred mode of cooperation: Joint venture, equipment supply and technical services.
Year established: 1992
No. of employees: 30

For more information, contact: Mr. P.A. Lyatuu, Executive Chairman, Environment Press Foundation, P.O Box 246, Arusha Tanzania; Fax: (+255) 57 8170

COAL DUST FUEL BRIQUETTES

Simple machinery is required for the production of coal dust based fuel briquettes for use on domestic customer stoves. The coal dust is a waste product of coal mining and when mixed with soil, can produce a burnable briquette. The new project should run in collaboration with an existing mining operation. Prototype stoves have been successfully tested, the manufacture of which can be done locally. The company hope that the briquettes will provide a viable alternative to tree removal for charcoal production.
Preferred mode of cooperation: Joint venture, turnkey project and equipment supply.
Year established: 1992
No. of employees: 18
Annual turnover: US$60,000

For more information, contact: Mrs. Bisama, Director, Eddy Co., P.O.Box 3072, Mbeya, Tanzania; Fax: (+255) 65 4137.

ELECTROSTATIC COATING

The technology for electrostatic coating by powder epoxide enamels is sought to also include pre-treatment and calcining furnace. The technology should be able to create surface imitations of "ancient brass and copper". Parameters: dimensions for finished surface approximately 2m; approximately 1,000 m^2/year; correspond to environmental and hygiene legislation of Slovak Republic.
Preferred mode of cooperation: Joint Venture and production equipment.

For more information, contact: Slovak Chamber of Commerce & Industry, Regional Chamber Trencin, Dolny Sianec 1, 91101 Trencin, Slovakia. Fax: (+42) 831 521 023. Ref.: 1.44

MINING EQUIPMENT

A gold ore mining operation currently using primitive hand tools for open pit extraction and ore processing, requires modern technology and equipment. The equipment required includes: earth moving; mining; panning; crushing; generators and chemicals for testing and cleaning gold. The estimated total project cost is US$3 million.
Specification of technology requirement: Equipment
Preferred mode of cooperation: Joint venture, equipment supply and technical services.
Year established: 1994
Annual Turnover: US$300,000

For more information, contact: Mr. A. Lauingia, Director, Lauingia Mining Co. Ltd., P.O.Box 2060, Dar-Es-Salaam, Tanzania. Fax: (+255) 51 116.515

FOR MORE TECHNOLOGY OFFERS AND REQUESTS, VISIT UNIDO'S INTERNET HOME PAGE! ADDRESS: HTTP:// WWW.UNIDO.ORG AND CLICK ON 'BUSINESS'.

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