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(1of 2)

Proceedings of

*Expert Group Meeting on "Networking of PV Systems and Applications"*
*Photoenergy Center, Faculty of Science, Ain Shams University,*
*Cairo, Egypt 26-28 April 2000*

**Organized by ICS in collaboration with the Photoenergy Center**

**Expert Group Meeting Directors**

**Mr. Anthony Bromley, Senior Officer, UNIDO/IEE/SES**

**Prof. Dr. Sabry Abdel-Mottaleb, Director, Photoenergy Center**

**Organizers**

**Mr. Gordon Thompson, ICS High Technology Consultant**

**Mr. Tatsushi Kurobuchi, ICS Programmer Officer, High Tech and New Materials area, Trieste, Italy**

**Prof. Dr. Sabry Abdel-Mottaleb, Director, Photoenergy Center**

## Collected Papers and Presented Materials

**Prepared by**
**Professor Dr. M. S. A. Abdel-Mottaleb**

**May 2000**

**Cairo, Egypt**

CONTRACT NO. 2000/062

**PART (3) <u>ANNEX B</u> (PROCEEDINGS OF THE EG MEETING): 3.1**
TWO PARTS IN TWO SEPARATE BOOKS
IT CONTAINS PAPERS AND MATERIALS PRESENTED

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*Expert group Meeting on"Networking of PV Systems and Applications"*

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**Representations of Participants and Collected Materials**

## PART ONE



## PART TWO

ICS-UNIDO Expert Group Meeting on PV, 26-28 April '00

**Outline of PV activities in participating nations in Cairo meeting**

| | Morocco | Algeria | Tunisia |
|---|---|---|---|
| PV programmes<br>Organizations<br>Activities<br>Collaboration links | Several demonstration and pilot projects since 1970.e.g. PPER (Pilot Rural Preelectrification Program) | National projects<br>1st 1985-1989<br>2nd 1995-<br>Only post-graduate studies | ANER (National Agency for renewable energy), ENIT, INRST<br><br>Neither regular nor intensive training<br>EU Labs in advanced PV materials |
| Existing applications | Installed PV capacity is over 5MWp.<br>*Rural electrification *Water pumping *Telecommunication | Installed PV power since 1985: Total 1MWp<br>*Water pumping *Refrigeration<br>*Rural electrification *Telecom.<br>*Cathodic protection | *Rural electrification *Telecom.<br>*Water pumping *Mobile Health carravan |
| Market size<br>Industry capacity | 1 MWp/y<br>200,000 housefolds in five years.<br>Several attempts for PV module lamination without success. | 2Mwp/year<br><br>One unit of encapsulation of modules | 100,000 households, 10,000 schools<br><br>Foreign investment and JV has not been successful |
| Needs | Better access to financing<br>Different cyclic training programs and the increasing involvement of the private sector | Investment from demonstrate stage to large scale projects | Thin film silicon<br><br>Specialized master linked with the professionals of PV issue |
| General remarks | Much experience through demo and pilot projects.<br>Needed to continue efforts for further development | Possible applications are identified through a couple of field tests.<br>Standstill before further step to mass diffusion due to the lack of investment. | Situation is almost the same as Algeria. |

ICS-UNIDO Expert Group Meeting on PV, 26-28 April '00

**Outline of PV activities in participating nations in Cairo meeting**

| | Egypt | Saudi Arabia | Yemen |
|---|---|---|---|
| PV programmes<br>Organizations<br>Activities<br>Collaboration links | EREDO (Egyptian Renewable Energy Devel. Org. )<br>Photoenergy Center<br><br>R&D of inexpensive PV cells and PV purity Si. | KACST-ERI, PV Lab.<br><br>Feasibility study for PV cells manufacturing<br>Hybrid systems, battery in PV communication systems | Sana'a Univ.- Electrical Engineering Dep. |
| Existing applications | *Transportation roads lighting<br>*Lighting for camping | Total installed capacity-1.3 MWp<br>*Water desalination<br>*Grid connection *Hydrogen production plant (350kw)<br>*High way lighting, traffic monitoring systems | *Rural electrification<br>*Water pumping *Telecom.<br>*Power source for remote switching substations |
| Market size<br>Industry capacity | Roof top applications<br><br>Few private companies<br>Home assembled PV arrays and systems | Capacity will increase 0.8 MWp/y | |
| Needs | BIPV (Building Integrated PV)<br>Thin film Si<br><br>Professional training | Suitable process of PV Si production | Mechanism enabling the necessary coordination of all national and international efforts. |
| General remarks | In advanced stage.<br>Attempts enabling PV systems to be economically viable have been carried out. | Proper applications are identified and feasibility study of PV Si production has been pursued. | Introductory stage |

ICS-UNIDO Expert Group Meeting on PV, 26-28 April '00

## Outline of PV activities in participating nations in Cairo meeting

| | Jordan | Syria | Palestine |
|---|---|---|---|
| PV programmes<br>Organizations<br>Activities<br>Collaboration links | RERC (Renewable Energy Research Center)<br>Installation, maintenance, testing and evaluation of water pumping systems<br>GTZ, FIZ, SIJ, DLR, Siemens | HIAST( Higher Institute of applied science and Technology)<br>Atomic energy commission<br><br>UNDP, JAICA | PEC<br><br>EC projects (iresmed, intersudmed)<br>Baden Wuerttemberg (Germany) |
| Existing applications | *Water pumping *Stand alone for remote clinics, schools and police stations | *Rural electrification (48kw)<br>*Water pumping | *Rural electrification for schools, households (>60 systems) |
| Market size<br>Industry capacity | | 8,000 off-grid small villages | 1,000 Bedouin families<br>60 villages (1.2 Mwp)<br>40 public stations<br>22 water pumping<br><br>SIEMENS & SOLNUR Co. |
| Needs | | Up date old testing equipment<br><br>Intensive technical training | Applications development for storage batteries, water pumps and telecomm. |
| General remarks | Efforts have been concentrated on "Water Pumping" application | In initial stage | In initial stage |

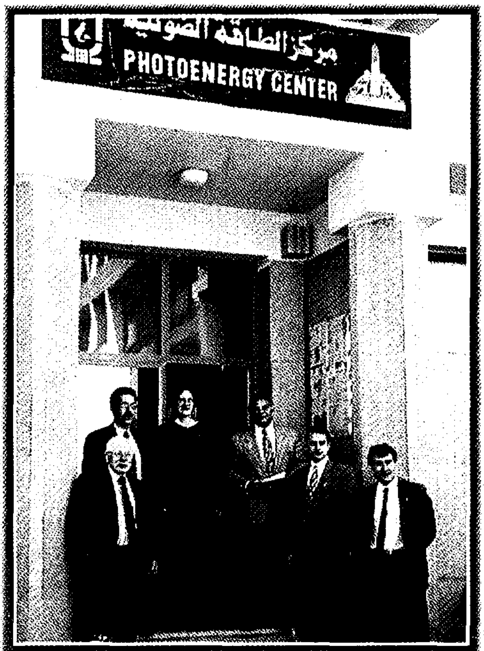
مركز الطاقة الضوئية

Photoenergy Centre

# PHOTOENERGY CENTER

## FOR TRAINING, RESEARCH & DEVELOPMENT

Faculty of Science, Ain Shams University,
Cairo, Egypt



## Why Photoenergy Center ?

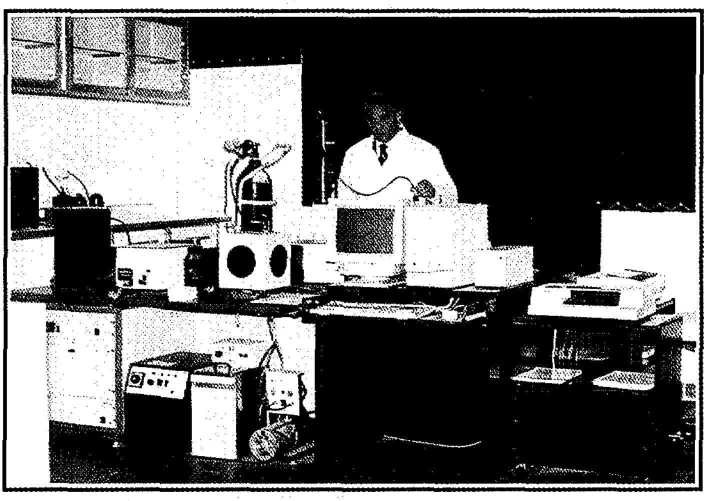
*Egypt* realizes that it is of importance to establish modern laboratories where young scientists and technologists in major industries and research institutions have access to advanced techniques and to the frontiers of science development in the field of Photosciences. For this reason, and because of the successful international activities in the field of Photochemistry, the Egyptian Government responded favorably to the proposal from Ain Shams University (ASU) based on the project document submitted by Sabry Abdel-Mottaleb and offered financial grant through the Ministry of International Cooperation to establish a science and technology center of excellence for PHOTOENERGY.

## What for ?

For education and training as well as for pure and applied research and problem solving in photochemical processes and Solar Chemistry, their industrial applications and their environmental and health implications.

## What Objectives?

- to support industries by training, research and development programs aimed towards an understanding of the aspects of the realistic applied photochemical research activities in main areas of importance to sustainable development.



## What Specific tasks?

- to conduct realistic applied Photochemistry and Photophysics research as well as advanced spectroscopic techniques to develop solar energy storage and conversion systems and to assist industries in solving production problems. Specifically, clean energy sources like sunlight or artificial light are used for:

1- photodegradation of toxic substances and pollutants using sunlight. This includes wastewater treatment as well as industrial inorganic, organic pigments and textile dyes.

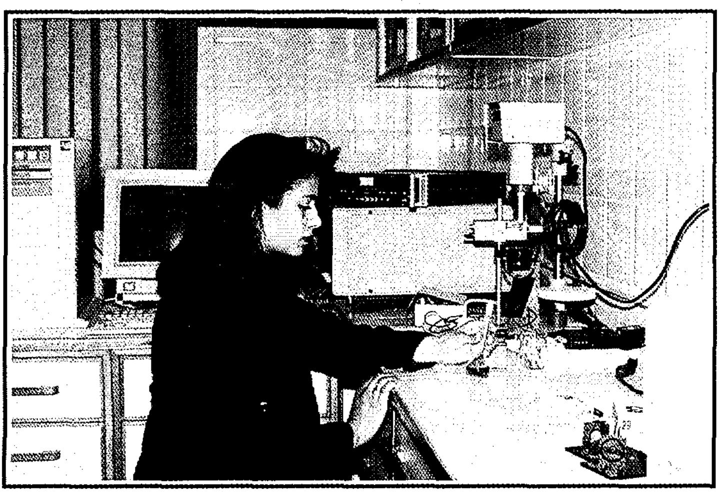
2- testing photostability of pharmaceuticals(light stress testing) and drug products, and production of valuable chemicals, and hydrogen fuel.

3- photovoltage generation- solar energy conversion, hydrogen production, etc.

4- analysis of petroleum products.

5- production and testing of solar energy materials: solar collectors, concentrators e.g. luminescent solar concentrators "LSC".

6- Solar thermal applications in chemistry, power generation, ... etc.



## Infrastructure (Facilities Available)?

[A] Fast Kinetics: (I) LIFETIME-TIME RESOLVED SPECTROSCOPY SYSTEM. (II) DIODE ARRAY SPECTROMETER

[B] Photochemical Reaction Efficiencies and Stability of Pharmaceuticals, Toxic chemicals and New Materials and Laser Dyes:

(III) LIGHT SOURCES. (IV) MONOCHROMATORS.

(V) QUANTUM YIELD DETERMINATION SYSTEM- QUANTACOUNT.

VI) PHOTOREACTORS (*ACE GLASS*) and PHOTOSTABILITY TESTING EQUIPMENT (FOR PAINTS, DRUGS ETC)

[C] Photodynamics & Electrochemistry of Semiconductors and New Materials:

(VII) POTENTIOSTATE/ GALVANOSTAT (Electrochemical Analysis). (VIII) PHOTOCONDUCTIVITY SET-UP.

[D] Analytical Tools: (IX) Total Organic Carbon (TOC)

(X) Spectrofluorometer.

(XI) UV-VIS Spectrophotometers. (XII) Standard lab facilities: pH-meters, viscometer and Radiometer.

[E] Educational-Aid Tools:

(XIII) LAN-a server and 8 workstations,

(XIV) Electronic library (Current Contents with Abstracts).

(XV) PV System for Training (Water Pump, Hydrogen Production, Lighting).

## Organs?

- a) International Advisory Board (Eminent Professors and Researchers from Developed Countries: Ahmed Zewail (USA), V. Balzani (Italy), Frans DeSchryver (Belgium), M. El-Sayed (USA), A. Gilbert (UK), J. Kossanyi (France), R. Loutfy (Xerox research Center, Canada), H. Scheer (PM, Bundstag, Germany)).- b) The Steering Committee - c) Associate members; Faculty members and postgraduates; Ph.D. and M.Sc. researchers.

## International Relationships

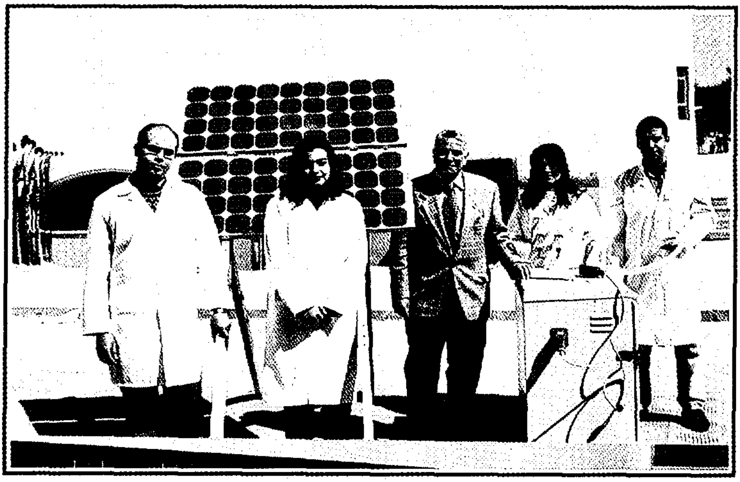
The Center has established excellent relationships with several international laboratories and institutions all over the world. Furthermore, the Center is exploring further possibilities to initiate more collaborative links.

## Research Activities?

Different applied research projects concerned with chemical of potential applications and pharmaceutical treatments are being carried out. Partners are: Departments of Analytical Chemistry, Faculties of Pharmacy (ASU, Cairo and Helwan Universities), Departments of Chemistry and Physics, Faculties of Sciences. The Ministry of Environmental Affairs agreed to sponsor one of our major program for clean technology of light utilization for the treatment of different industrial wastes. This will help different industries for implementing the laws of the Environment protections and Regulations.
The center accomplished with other international partners (two labs in France (CNRS and Ecole Polytechnique - Paris), one Lab in UK (Bath University)) a research project on Silicon optoelectrodes (Corrosion and optostability) for solar applications and electronic fabrication; financed by European Community.

## Funding Sources?

- The Egyptian Government: through Ministry of International Cooperation (USA - Sector), Ministry of Planning and ASU offered ca. LE 3.4 millions (about one Million US$).
- Equipment Donation from FRG, Ministry of Foreign Affairs;



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# *Part 1*

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *Algeria*

# An Outline on PV Systems and Applications in Algeria

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## INTRODUCTION

The potential solar energy in Algeria is very important with an average sunshine of about 3000 hours per years. The total area of the country is more than 2 millions $km^2$. The respective percentage of the total area and the yearly average irradiation for the three specific regions of the country are illustrated in table 1. The yearly average of solar irradiation on optimal tilted surface is very interesting. It ranges from 5 to 7 kWh/m2/day (figure1).
The research and development in the field of solar energy have existed since fifties, the first solar furnace which was built in the site of Bouzaréah (Algiers) in 1954. But the applications in situ of solar energy and especially photovoltaic were initiated only in 1985.

Table 1
Sharing out of area and irradiation between coastline, high-plateau and Sahara.

| | Coastline | High-Plateau | Sahara |
|---|---|---|---|
| Area (%) | 4 | 10 | 86 |
| Irradiation (hours/year) | 2650 | 3000 | 3500 |

## EXISTING PV APPLICATION

The PV applications are particularly used for water pumping, rural electrification, telecommunication, refrigeration and cathodic protection. Table 2 summarizes the rate and the installed PV power of the three specifics regions in Algeria from 1985 to 1990. The total installed PV power is 274.2 kWp for which than 58% are installed in the Sahara region. Table 3 shows the detail of the assessment of photovoltaic realization such as the number of signaling beacon, health refrigerators, water pumps and PV power installed for rural electrification.

Table 2
Rate and the installed PV power in Algeria from 1985 to 1990.

| | Coastline | High-Plateau | Sahara | Total |
|---|---|---|---|---|
| Installed power (kWp) | 42 | 71.9 | 160.3 | 274.2 |
| Rate (%) | 15.32 | 26.22 | 58.46 | 100 |

There are 297 pathway beacons, 28 health refrigerators and 61 PV pumps to supply water for drinking and irrigation [1]. The PV pumping systems are installed with a peak power between 1 to 5 kWp. Since 1985 the total value of PV power installed in Algeria as estimated to about 1 MWp.
Following is a survey of some photovoltaic applications in the field of water pumping, rural electrification and environmental protection and pollution control:

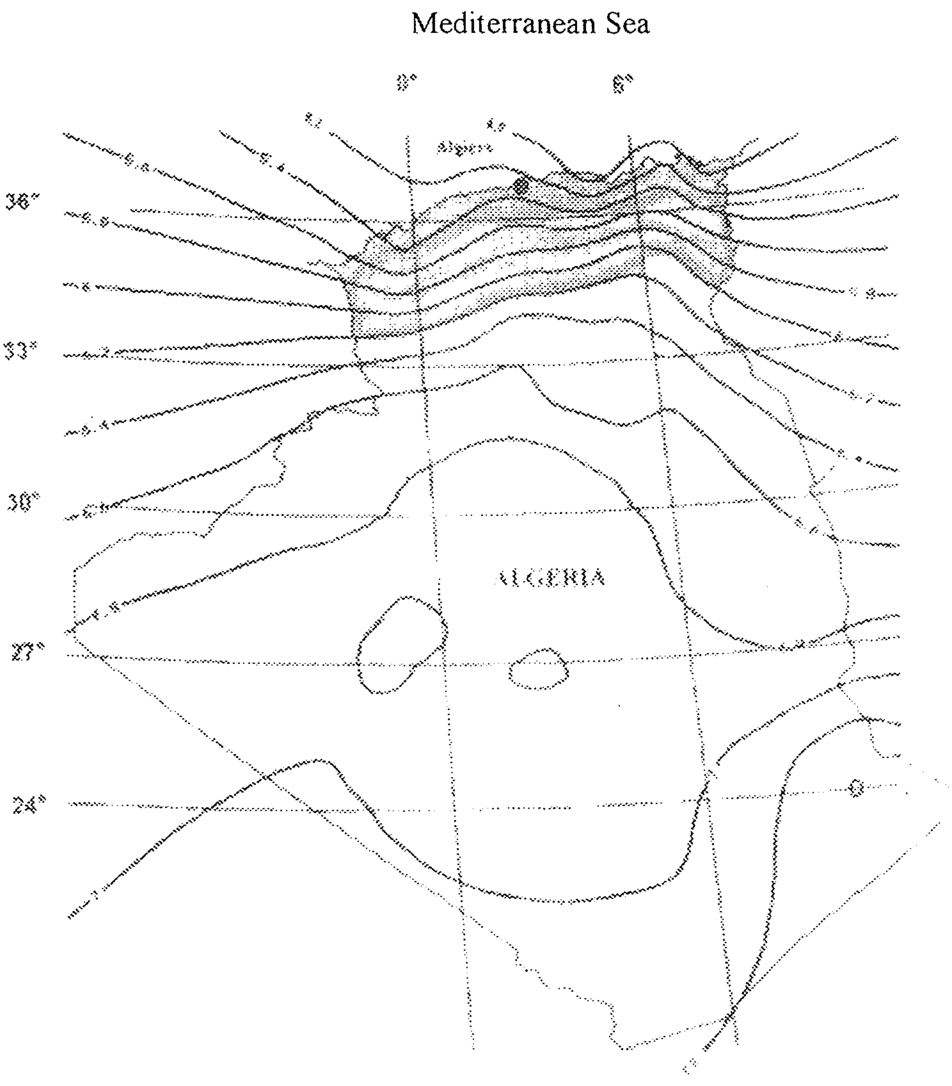


Figure 1 : Daily irradiation and three specific regions of Algeria

Table 3
Assessment of photovoltaic realization in Algeria from 1985 to 1990.

| | Nbr of Signaling | Nbr of Refrigerator | Nbr of Pumps | Electrification (kWp) |
|---|---|---|---|---|
| Coastline | 16 | 6 | 4 | 4.1 |
| High-Plateau | 6 | 12 | 23 | 25.5 |
| Sahara | 275 | 10 | 34 | 83.8 |
| Total | 297 | 28 | 61 | 113.4 |

- **Photovoltaic pumping system in El-Golea site:**

This PV water pumping system was installed in 1992. It is designed to irrigate 1 ha of agricultural crop with a daily of 60 $m^3$/day of water flow. The components of the PV installation are the PV array (1.5kWp), the pumping subsystem which are the DC/AC inverter, the surface pump-motor unit and the water tank (Figure 2 and 3).
The PV array is constituted by 30 UDTS-50 modules type which are constituted by 36 squares monocrystallines solar cells. The inverter is designed specifically for PV pumping and it is operated by a pulse width modulation (PWM) circuit which is controlled by a frequency control circuit [2][3].
The surface motor-pump consists of an asynchronous motor (1.1kw) directly coupled to a centrifugal pump. The capacity of the traditional water tank is about 35 $m^3$.

- **Tin Zaouatine Photovoltaic system:**

In 1990, two stand alone photovoltaic systems were erected by the Center of Development of Renewable Energies (CDER) in the southern part of Algeria at 2600 kms from Algiers in a village called Tin Zaouatine (Lat: 22°47'N; Long: 5°31'E). The first PV system is used to supply electric power for lighting houses. The population is around 1500 Algerian nomads and more than 1000 refugees from Mali [4].
The 110 houses of the village are very widespread so the adopted solution it was to use 8 small PV installations ranging from 1 to 1.7 kWp combined with an appropriate external grid so that each PV installation supply the maximum of houses around (figure 4). Table 4 shows for each PV installations the peak power, the number of connected houses and the number of lamps. The PV arrays are used to operate 172 low consumption lamps (18W).
The second PV system is constituted by two PV pumping systems to supply population with drinking water. Each pumping system consists of a PV array of 15 modules (33 Wp), a DC motor and a pump.

- **Matriouane Photovoltaic system:**

The Matriouane Photovoltaic system was installed in 1990 and it is one among several projects of cooperation between Algeria an Spain. Matriouane village (Lat: 27° 53'N , Long 0°17'W) is located in the central part of the Algerian Sahara at 1543 km from Algiers. The PV system is used to electrify this remote village and to pump water from wells for drinking and irrigation [5].
The PV array consists of 135 PV modules with a total peak power of 6.7 kWp (figure 5 and 6). The loads consist of 6 vapor sodium lamps (35W) for public lighting, 161 lamps (18W) for home lighting and two pumps.

Table 4
Peak power, number of connected houses and number of lamps of Tin Zaouatine PV system

| Number | Array power (kWp) | Number of Connected houses | Number of lamps |
|---|---|---|---|
| 1 | 1.6 | 8 | 18 |
| 2 | 1.2 | 8 | 12 |
| 3 | 1.7 | 13 | 30 |
| 4 | 1.4 | 21 | 28 |
| 5 | 1.0 | 10 | 13 |
| 6 | 1.0 | 8 | 18 |
| 7 | 1.0 | 14 | 24 |
| 8 | 1.4 | 18 | 29 |
| Total | 10.3 | 100 | 172 |

♦ **Photovoltaic system of Assekrem research station:**

The World Organization of Meteorological has appointed Assekram montain to build a research station for measuring reference of a Global Atmosphere Watch and pollution control. The Assekrem site (Alt:2710 m; Lat:23°16'N; Long:05°38'E) is located in the southern part of Algeria inside Africa. Thus it is so far away from human activities and biomass. The photovoltaic system aims to electrify this remote station and to supply the instruments of measurement by a clean power (PV power).
The photovoltaic array consists of 100 PV modules with a total peak power of 5 kWp and a nominal operating voltage of 48 Vdc (figure 7). The daily average consumption of both the instruments of measure and lighting of the station is about 2.5 kW [6].
The instruments installed in this remote station are the instruments for measuring the Ozone, the black carbon and radiance.

## SIZE OF MARKET

The value of the installed PV power (1MWp) is far away from a full exploitation of the solar resources and the real potential of local the market. In remote area they are many fields and sectors which need PV power such as agriculture, telecommunication, transport cathodic protection. The 1994 census has estimated more than 260 000 homes remaining to be electrified in Algeria. These homes are shared out between 6250 localities through the country [7]. Thus in the field of rural electrification the PV power needs are evaluated to no less than 20 MWp. For the other PV applications such as water pumping, pathway signaling of pathway and refrigeration plants, the market needs are evaluated to 2 MWp per year [8].

## PV SYSTEM PROGRAMS

Two nationals programs have been undertaken and funded by the government. The first one is "the solar energy great south program" with an aim to install stand alone PV systems for different applications as the water pumping and electrification. It was started in 1985 and ended in 1989. The second one is "the south rural electrification program" for which the aim is to supply rural houses and agricultural sites. It started in 1995 and is still in progress.

Figure 8 : PV array (5 kWp) of Assekrem research station

♦ **The solar energy great south program:**

The aims of this program is to install stand alone PV systems for different applications as water pumping and electrification. This program is achieved by the Centre of Development of Renewable Energies (CDER). A summary of the program outline is as follows:

- Photovoltaic water pumping system, total power installed is 85 kWp
- Electrification of small village in the Sahara desert and in rural houses, total power installed is 97 kWp
- Telecommunication repeaters in remote site, total power involved is 80 kWp
- Pathway signaling in the Sahara desert (figure 8).
- Photovoltaic power for refrigeration system.

♦ **The south rural electrification program:**

The aim of this program is to supply 216 000 rural houses shared out in 4000 localities. The achievement of this program is assigned to the National Company of Electricity and Gas (Sonelgaz). In the framework of this program, twenty isolated villages in the southern part are supplied by PV power until 1997. The PV electricity is used for home lighting, radio and television, refrigeration and ventilation.

## RESEARCH AND EDUCATION

In the field of research and education they are only post-graduate studies in Algeria. The students receive theoretical courses and practical training in photovoltaic laboratories. The actual needs are overseas training and advisors for students registered in the doctorate level.

## INDUSTRY CAPACITY

The PV modules are not manufactured in Algeria in spite of big efforts made to set up this kind of industry. Only one unit of encapsulation of PV modules came into operation in 1985. Recently new laws have been applied to incite investment of private companies.

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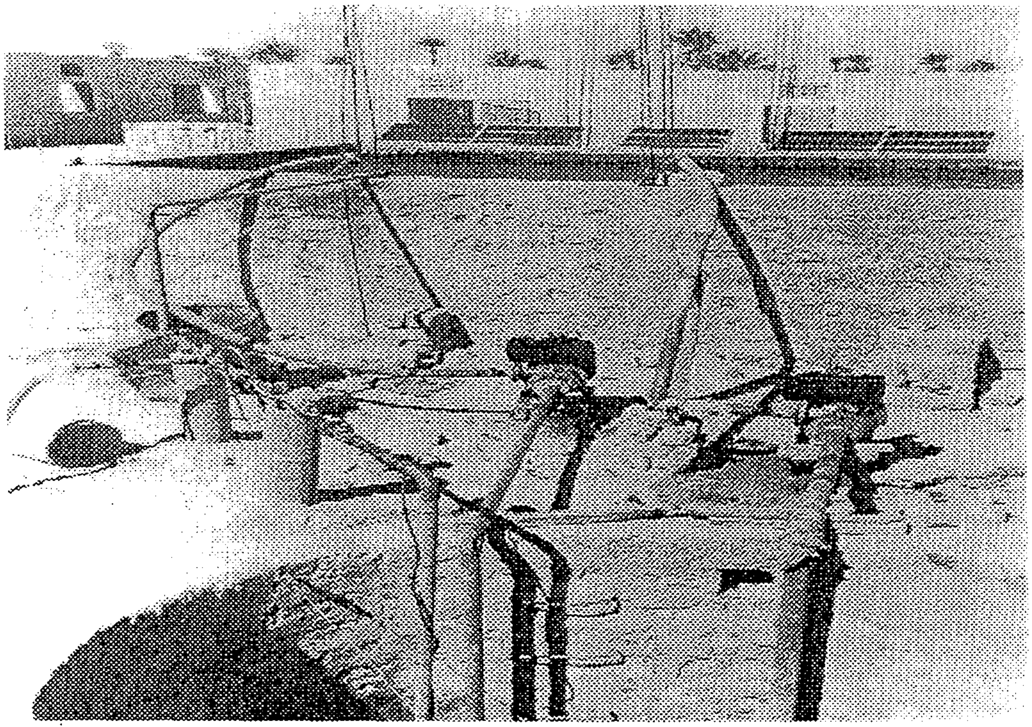

Figure 2 : Photovoltaic water pumping system of El-Goléa (1.5 kWp)

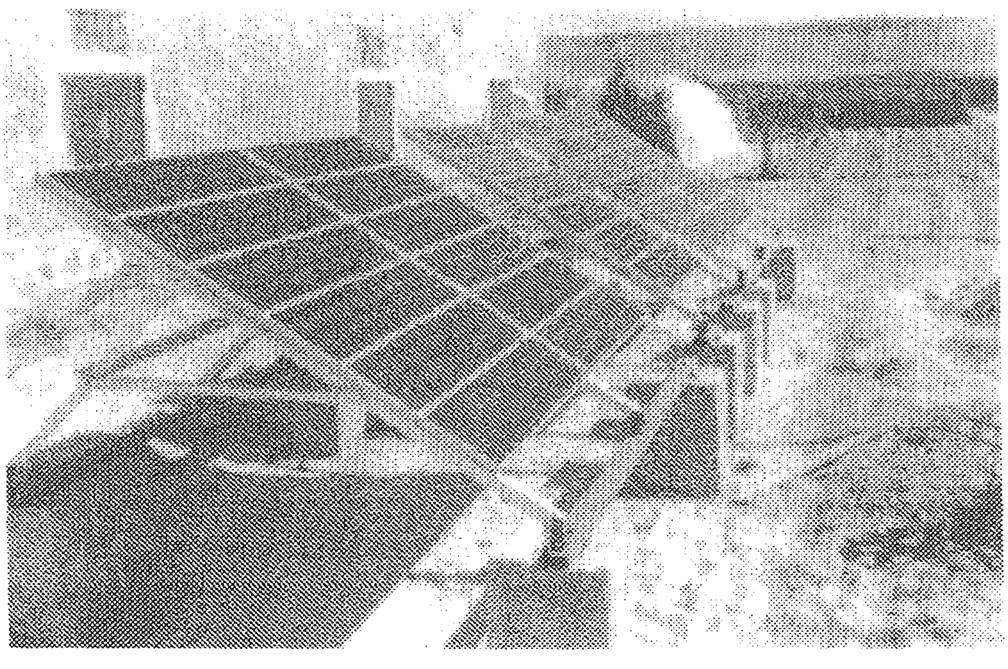

Figure 3   View of (1.5 kWp) PV array, cultural field and greenhouse of the PV pumping system of El-Golea

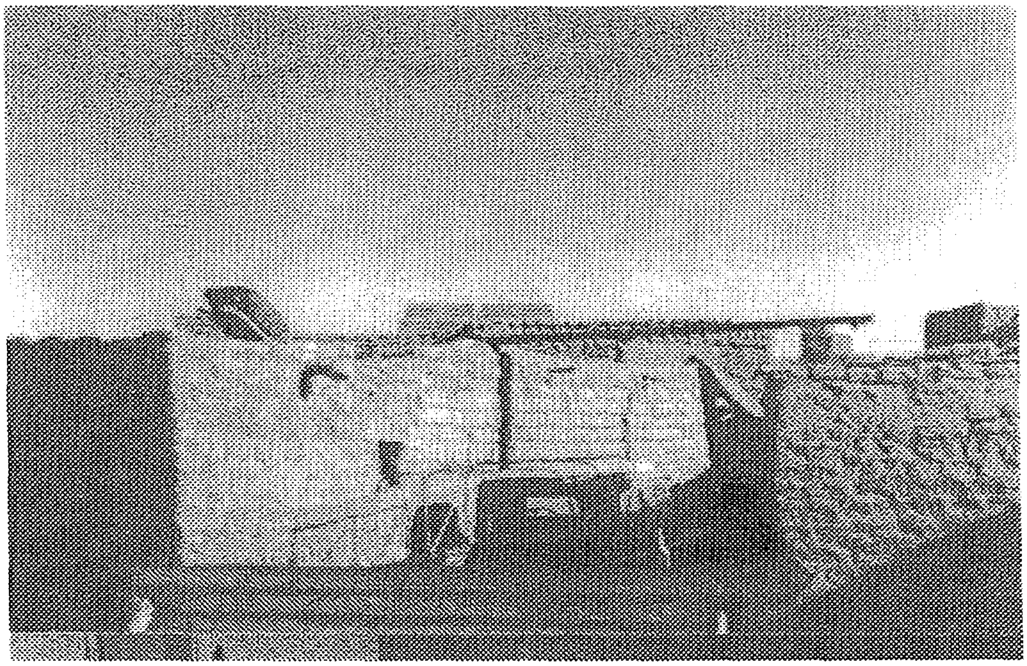

Figure 4 : Elecrification of Tin Zaouatine village

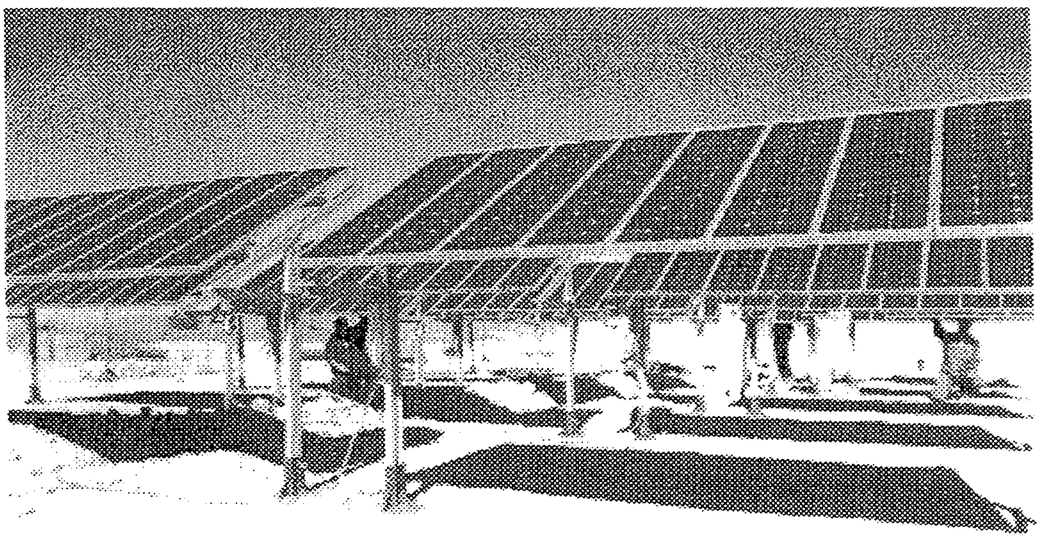

Figure 5 . PV array of Matriouane system

*Expert Group Meeting*
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*Cairo, 26-28 April 2000*

# ***Egypt***

# Photovoltaics For Efficient Solar Energy Conversion

*Draft paper (merged with a Project Proposal)*

**Submitted by:**

*Professor M.S.A. Abdel-Mottaleb*

Director, Photoenergy Center, Ain Shams University, Cairo, Egypt

Solar@photoenergy.org

To: The PV Expert Group Meeting (*ICS - UNIDO Project, Trieste, Italy*)

Cairo, Egypt, 26 - 28 April 2000

This draft paper (merged with a project proposals) deals with supporting applied studies, technology transfer, marketing and development of PV products and systems in Egypt that could be very fast produced on industrial level for immediate application as a clean, reliable and duarable source of energy needed for sustainable and global development process in Egypt.

## Background and Target Formulation.

In short, I will give here an outline of a prelimenary draft for the Project Proposal. I will try to concentrate on what I consider to be important elements for drafting a project proposal and an action plan for developing, applying and marketing PV systems in Egypt.

## International Situation and Market Potential

First of all, I believe it is important to note, that there is a wide agreement (on national as well as on the international levels) on the need for developing rapidly the technology and utilization of PV especially in sunny developing country like Egypt.

This realistic technology subject can be very fast transferred into industrial potential products by cooperation with small or medium enterpris industry companies in Egypt. The project aims at making a more significant progress in the transfer and development of technolgy of PV (low cost and more efficient) that should fulfil its potential in securing Egypts's long term clean energy supply and in contributing to its environmental protection.

Market situation in Egypt is still very young and of very high potential. To the best of my knowledge, no considerable amount of PVs are produced on an industrial scale. Few private companies are working in the production of home-assembled PV arrays and systems. Almost all applications and PV systems marketing are limited to street (transportation roads) lighting systems and in some touristic villages for camping and yachting. As a first approximation, one can say that production of PV in Egypt is limited to research and testing purposes as well as the above mentioned few applications.

Moreover, another potential activity in Egypt is the successful attempts of Metallurgy Institute of the Academy of Science and the National Institute of Solar Energy Research to produce very pure silicon (99.999% Si) that is needed internationally for producing efficient silicon based PVs. This is a long term plan that needs a lot of capital investiments.

Furthermore, the Ministry of Military Production has recently announced a program for PV production. It will start production in the coming few years.

The following facts are in favor of global PV:

. PV is now being widely used in some countries to convert light to electricity.

. PV proved to be one of the most reliable clean energy source.

. Job Creation: As a result of the market penetration and utilization, too many opportunities for job creation will be opened.

However, there is still an urgent need for production and test of cost/effective consistant PV systems that based on new materials (new semiconductors, new forms of already existing semiconductors -nanoparticles, amorphous, polycrystalline forms - or like organic PV materials that mimick the nature (as in plants which use light harvesting organic molecules around us).

*Action Plan (Joint Venture to be Supported) :*

- Market study that aimes at increasing market potential will be one important element of this project. The need for a level playing field is important : Internalisation of external costs and benefits must be a guiding principle for future energy pricing. The creation of guarantee funds could be helpful for applied research needed for development. It is encouraging to see that international donor institutions like the ICS-UNIDO are increasingly involved in the financing of renewable energy projects such as this proposed PV one. PV have to be considered in the wider context of energy savings and energy efficiency. It should be considered in all sectors, like fore example in the building and housing and health and environment protection sectors.

## - *Technology Transfer and Development:*

The ultimate goal is:

- to produce (with the collaboration with small or medium industrial factories) and
- to test cost effective high quality PV solar cells (already available in the international market) based on new materials and/or new composite of semiconductos.

PV already exists in the market had very few product standards and no systems standards existed, which means that manufacutrers especially in developing countries had no guidelines to produce a reliable product, how to install them and how to serivce them. The lack of accredited testing laboratories made testing difficult for producers especially in the developing countries. However, in Egypt and within the framework of the programs of the ministry of electricity and energy for development and localization of renewable energy technologies, the Egyptian Renewable energy Development Organization (EREDO) has been established as a specialized center within the New and the Renewable Energy Authority (NREA). It has Photovoltaic laboratories:

*Outdoor photovoltaic laboratory*

The outdoor PV Lab. has two main sections:

1-Testing units for measurement and the evaluation of photovoltaic modules.

2-Demonstration Units for photovoltaic applications, household and pumping equipped with measuring instruments for testing their performance. The laboratory is also equipped with a data acquisition system and a meteorological station unit.

*Indoor photovoltaic laboratory*

The lab. can perform R&D studies on PV cells, as well as testing and certification of PV modules. It has two main separate facilities;

The PV cell testing facilities with pulsed solar simulator, monochromator and four points prob systems.

photovoltaic modules testing facility, with mounting twist tester and insulation tester.

## The Role of the Photoenergy Center:

*The Center has established a small PV station for training and demonstration. It consists of PV arrays, Battaries and Charge regulators for different applications. Namely, lighting, water pumping and hydrogen production are among other important applications demonstrated at the Center .*

The Photoenergy Center of Ain Shams University is a package that satisfy creteria to be approved research and development organization that strives:

- to develop new PV products and systems
- to promote and maintain a set of quality standards and certification procedures for the performance of PV products and systems, to ensure high quality, reliability and durability.

Promising achievemnets would be expected by using the facilities available at the Photoenergy Center and its staff members as well as making use of National and International Cooperation with specialized laboratories in Europe (Italy, Germany, France,...., etc.), Japan, USA, Australia to be specified in the final project document). The Center is well connected with the leading research institutions all over the world. The Center shall make use of its scientific connections in realizing and complementing the research to be carried out in order to develop new low cost and more efficient PV products and systems.

[Related International Research Activities Carried out by the Photoenergy Center ? The center accomplished with other international partners a research project on n-Silicon optoelectrodes for solar applications and electronic fabrication; financed by European Community (Partners were: two labs in France (CNRS "Professors Etman and Gorochov" and Ecole Polytechnique "Ozanam and Chazalviel" - Paris), one Lab in UK "Professor L. Peter" (Bath University))].

On the domestic level; the Center has also very good contact with national industries (Public and private sectors) that will enable finding industrial partners for close collaboration in the project. In spite of the high level of technology already achieved in Europe and other industrialized countries, it was general agreed that a continued effort on domestic levels for research and technological development will be needed also in future, if the present level is to be maintained or improved. Technological development can only be considered to be successful, if it results in a good market product, and if it has been correctly integrated and adapted to market conditions. Finding new economic applications is very important.

An example for the urgently needed new applications of crucial importance is in the field of Building integrated PV.

On January 1, 1997, IEA's (International Energy Agency) PV Power Systems Program welcomes a new task: Task VII – PV in the Built Environment.

The objective of Task VII is to enhance the architectural quality, the technical quality and the economic viability of PV systems in the built environment and to assess and remove non-technical barriers for their introduction as an energy-significant option.

Primary focus of Task VII is on the architectural design of (roofs and facades of residential, commercial and industrial) buildings and other structures in the built environment (such as noise barriers, parking area's and railway canopies), and on other market factors, both technical and non-technical, that need to be addressed and resolved before wide spread adoption of PV in the built environment will occur.

- *Knowledge Transfer*

This is another area of need. Information dissemination and awareness creation at all levels is another priority area for a faster penetration of PV. The Center through his continuous activities (and this project) is trying to put in place a comprehensive information system (data base establishment) and knowledge transfer (desingning training courses, creating fellowships program, etc.). Moreover, increased efforts in form of consultation for example are also needed at national ,regional and local levels , if the still existing information gap is to be bridged.

Education and training, especially professional training, is occupying a prominent position in our PV Action Plan. Professional training (for scientists and researchers) in other Developing Countries (Arabic countries as well as south coast countries of the Mediterranean sea, where prospects for developing solar technologies are particularly good) is also essential, if similar PV projects investiments are to be implemented successfully in these countries. This will also create a strong domestic market that would be successful in producing and utilizing the clean technology needed for development.

Specifically, the action plan will focus on the following:

- Holding Training Courses.
- Organizing scientific specialized meetings.
- Fellwoship position opening (4 - 6 qualified scientists mainly from Egypt).

- Consultancy (Experts from industries at both National and International levels).

Economic Aspects: Funding PV projects? This is one of the major problems that need to be solved to overcome the barrier for marketing PVs.

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*[Egyptian Market - Technological needs: Building Integrated Photovoltaics*

Solar PV energy is the only renewable energy form, which can be readily integrated into the urban environment and is particularly suited to roof tops and building facades.
Some companies have developed a cost-effective production technology for the manufacture of high efficiency laser grooved buried grid (LGBG) crystalline silicon solar cells that deliver 16 - 18% photovoltaic (PV) conversion efficiency on large area substrates.

The cells and modules give high performance and are ideally suited to applications which require reduced space and balance of systems costs, in particular in the growing market for grid-connecting PV solar energy.

Furthermore, there are some companies offering coloured solar cells, thereby allowing architects greater flexibility for integration of solar cells into buildings.

Grid-connect PV systems offer the opportunity to generate significant quantities of commercially valuable electricity, operating in parallel with existing electricity grid and allowing interactive exchange of electricity to and from the grid. This is a rapidly growing market in which three main applications are evolving: residential PV for the domestic sector (1-5 kWp), centralised PV for utility generation (100 kWp – 5 MWp) and building integrated PV for the commercial and industrial sector (10 – 250 kWp).

Solar PV energy is the only renewable energy form, which can be readily integrated into the urban environment and is particularly suited to roof tops and building facades. Building facades should be attractive as well as functional and the option to offer solar cells in a range of colours is considered an asset to the market acceptance of the technology by architects and designers.

Although photovoltaic systems have been used to power building loads, particularly for remote dwellings, for around twenty years, there has been a considerable increase in interest since 1990 and many countries now have significant programmes in building integrated photovoltaic systems (BIPV). The main difference in today's systems is that the PV array forms part of the building envelope, both generating electricity and performing the job of the roofing or cladding material it replaces.

The BIPV system has many advantage for use in urban environments. Not only is the generation of the electricity more environmentally benign than conventional methods, but the use of the electricity within the building on which it is installed also reduces the environmental impact of distribution. The BIVP system uses existing façade or roof area, without requiring additional land which is very valuable in most urban centers. The fact that PV systems generate electricity without any noise or emissions means that the building inhabitants are not disturbed by the presence of the system.

An additional benefit, whilst capital costs of PV systems remain high compared to conventional generation of electricity, is that some financial offset can be allowed with respect to the building material replaced by the PV system. This reduces the effective cost of electricity produced by the system.

BIVP systems can have many designs and applications and recent systems have also demonstrated a multifunctional approach. In these cases, the PV system also acts, for example, as a shading device or is designed to assist in natural ventilation of the building. Especially for commercial buildings, each system is designed to meet the needs of the architect and user. Issues which must be considered are the performance of the PV system, how the output matches with the electrical loads of the building, the aesthetics of the design and, of course, the costs.

At present, only a few BIPV systems are cost effective in terms of electricity generation, although they also have value in terms of environmental considerations and the image of the building owner. However, as the capital costs of PV systems decreases due to increasing market size, the generation of electricity by BIPV systems is expected to become increasingly attractive in urban centres around the world.

The technical potential for BIPV is very large, even in high latitude climates, and several countries have announced large development programmes to stimulate the market and hence increase the rate at which the capital costs are reduced. If all these programmes are realised, the installed BIPV capacity will grow to around 4GW in 2010, over 40 times the current annual market for PV systems in all applications.

Furthermore, the technology of Thin Film Silicon is architecturally attractive. It looks like tinted glass and replaces prime time tariff day-time electricity with power generated by light. In older buildings and homes solar roof tiles are the ideal way to generate power. Sunslates blend visually with the roof material and are simple to install and wire by hand. For prestige corporate or public buildings thin film silicon makes a strong visual and environmental statement, whether used as an entire façade, or as architectural detail. TFS is laminated into 1sq m and 1.5sq m panels of toughened glass - each with a single electrical connection – reducing the handing and wiring needed on site. Thin film silicon laminated are more cost-effective than expensive cladding materials and can make an important energy contribution especially in a building designed for energy sustainability.
Suitable for new-build projects, as well as retro-fitting onto existing structures, TFS is ideal for the urban environmental where other renewables are inappropriate.

# Appendix

Details of the Action Plan
PV Systems: Development and Utilization
Project Proposals; Submitted to ICS, UNIDO "Trieste - Italy"

Egyptian Contribution: Establishment of Photovoltaic Test and Training Facilities.

The Center has already some PV systems for demonstration and training. However, more facilities should be added for short and long term's activities. The Center together with the Egyptian Partners from small private enterprise companies will contribute to add and establish a fully equiped test and training facility.

Test Facility (could be considered as "Study Cases") will be established at the Photoenergy Center.
This facility is designed for:
Testing of PV systems for industrial companies in Egypt (long term activity) for several training courses (short term activities) Extensive monitoring of PV Systems (long term activity) This will serve in the development of field testing procedures for solar energy systems.

## Facilities

The Testing and Training Center incorporates working reference or demonstration systems which use state-off - the-art components:
Pumping system: this demonstration system is a highly efficient system using a submersible brushless DC motor driving a progressive cavity pump.
Battery system: the second demonstration system is a stand-alone PV system with battery storage comprising a PV array, charge controller, battery bank and an inverter. This system is used to power lights, computers and other appliances at the Center.

The Test and Training Center has the following purposes:

- Provision of PV training courses for key decision makers, engineers, installers, students etc. (short term activities)
- Testing of stand-alone PV systems and components and the development of standards. (Long term activity)
- Demonstration of stand-alone PV systems. (Short and long term activities)

**Consumer's products:** a range of products is available for demonstration purposes. Other products should be added.

Needed are several PV arrays with a total of 3- 10 kWh power output.
First array: The first array consists of 1-3 kWp of certain company's modules, using cadmium telluride (CdTe) thin film technology. This array is normally connected to the pumping reference system, but can also be used for the other tests.
Second array: the second array comprises 1- 3 kWp of amorphous silicon modules. The array is normally connected to the battery system.
Third array : the array consist of 1- 3 kWp modules which are made with high-efficiency laser grooved buried-grid mon crystalline silicon cells. This array can be easily configured to any appliances which are to be tested. If the array is not needed for tests, it is connected to the battery system.

## Further requested facilities are:

Data logging facilities: The Test and Training Center should offer a fully automated Data Acquisition System cable of monitoring climatic data and performance of the demonstration systems as well as the performance of any components or complete systems under test.
Pumping testing rig: a pumping test rig must be available for testing solar pumps (involving PV pumping laboratory tests).
Facilities for training courses: including on-site lecture rooms and audiovisual equipment.

# Services

The Test and Training Center will offer the following service:

Testing of individual components, including qualification and acceptance testing. PV system, component and appliances for PV systems can be tested using PV power sources. It is also possible to substitute components of demonstration systems with component to be tested. Components, which can be tested, include solar pumps, charge controllers, batteries, inverters, etc.

Testing of complete systems. Complete stand alone PV systems of any size can be tested. Performance monitoring over a period of time can be carried out.

## Demonstration of PV systems and products.

In addition to the demonstration systems described above, a display of various PV products will be also available.

These systems and components to the Test facility will be used for training courses and demonstration to decision-makers in industry, governments and non-governmental organizations and others.

**Work on norms and standards for PV systems.**
At present, there are few standards for balance-of-system components for PV systems. We are going to use the experience gained from testing and our international contacts to work towards internationally recognized standards for PV systems to be appreciated in the Egyptian market.

**Training courses.** A leaflet on training courses offered will be prepared. Specifically designed courses for small groups can also be offered on request.

## Detailed Plans:
## Short term activities
## General Title: Effective Photovoltaic Systems: Development and Utilization

Photovoltaic (PV) is the direct conversion of sunlight into electricity. PV provides a reliable source of power in areas remote from electricity grid. It is ideal for lighting systems, remote communication, water pumping, refrigeration, monitoring, and much other application. The power produced can be used directly or to charged batteries.

Photoenergy Center is a renewable energy consultancy with experience in training, testing, R&D, and marketing (in collaboration with Arabian Solar Energy and Technology Company, ASET and GMC Company). Photoenergy Center has been undertaking PV projects for more several years.

Applications suggested range from professional systems to health care and rural electrification. It is expected to execute PV training courses, seminars and workshops for decision-makers in industry, governments and non-governmental organizations and other people.

# Training courses [for 15 to 20 persons]
# International Seminars [40 - 60 persons]

Training courses which cover different aspects of PV systems, technology, installation etc. are organized and held at the Test Center for small groups of up to 20 persons from different countries in the region as well as from abroad {international Seminars and Workshops will be organized for about 40 to 60 persons}. Training courses are tailored to cover essential and practical aspects of PV systems that should meet the needs of the participants will be ready to receive participants from around the world.

Seminars and training courses are designed to meet the needs of the key decision-makers in governments, NGOs, installers, development workers, post-graduate students and private individuals.

Courses vary from general introductory courses for those with little knowledge about PV to more specialized courses on specific topics.

The Test and Training Center has three purposes:

Provision of PV training courses for key decision-makers, engineers, installers, students etc.

Testing of stand-alone PV system and components and the development of standards.

Demonstration of stand-alone PV systems.

All courses contain some theoretical work as well as practical hands-on-training using the facilities available at the Center.
The duration of the courses ranges from a few days (3 - 5 days) to two weeks, depending on the nature of the subject. Specifically designed courses for small groups can be offered on request. Initially, we suggest the following:

## Suggested Calendar [Short Term Activities]: Seminars and Courses to be offered

### A] For the Year 2001

**Introduction to PV.** This two days course offers a brief introduction to technology and possible applications for PV and different types and systems. Suggested date 4 - 6 April 1999, for about 40 people, budget: $10,000US. To complement ENPHO '01.

**Development of effective solar power generation.** Four Days International Seminar deals with:
Principles of Photovoltaic Energy Conversion, Introduction to PV Systems, Materials for PV, Organic PV (solar cells), Environmental impact of PV power generation, Industrial Presentations and Exhibition, Visit to Test Facility at Photoenergy Center. May 1999, around 40 participants, Budget:$35,000US

**PV Technicians Workshop.** This one-week course concentrates on the installation and maintenance of small PV lighting systems. Suggested date September 1999, for about 20 persons, budget $10,000US.

PV Applications Workshop and a one-week master's level course. 40 - 60 participants, Budget:
$35,000US, One-week training course, second half of November 2001.

B] For the Year 2002

**PV as an option for Rural Electrification.** This seminar and hands-on experimentation offers an insight into the scope and the advantages of PV technology for developers of rural electrification projects.
Suggested date January 2000 (in Sinai), budget: $35,000, for 25 persons.

**PV Water Pumping.** This is a three-day course with emphasis on design, installation, testing and maintenance of PV water pumping systems. Suggested date End of March 2000, for 20 persons, budget: $10,000US

**PV Engineers Workshop (Advanced level).** This international seminar and workshop will be designed for people with some experience with PV systems. It covers the designs and specification of various different applications for different PV, including larger systems and test case establishment. Suggested date November 2002, for about 40 persons, budget $35,000US.

## Detailed Examples of proposals [Tentative]:

General Title: PV Systems: Development and Utilization

Development of effective solar power generation
Four Days International Seminar, April - May 2001
20 - 40 participants
[Budget: $35,000US]
Principles of Photovoltaic Energy Conversion
Introduction to PV Systems
Materials for PV
Organic PV (solar cells)
Environmental impact of PV power generation
Industrial Presentations and Exhibition
Visit to Test Facility at Photoenergy Center

2. The principles, manufacture and application of photovoltaic systems

A one week masters level course
40 - 60 participants
[Budget: $35,000US]
One week training course, second half of November 2001
Photo energy Center
Ain shims university

Aims, Seminars and Course Structures

Develop Expertise
The use of photovoltaics (PV) is growing rapidly and expertise is needed for industry to take advantage of this expanding market both at home and abroad. Increased environmental concern has made the need for clean energy a central issue. In particular, against a background of falling PV prices, there is a huge potential for solar electricity generation.

World wide, PV sales have trebled in the past decade to 90 MWp in 1996, which represent a market of some 400 million USA $ for PV systems. The market is currently growing at about 15 percent per year and most analysts think that this rate of growth will be exceeded in the future years. This valuable and rapidly expanding market will lead to new opportunities across a broad range of manufacturing and service industries. Many areas of industry to develop expertise to help them exploit this expanding area to maintain market share or develop new products and skills.

WHO SHOULD ATTEND?

This course will give you an in depth understanding of the operation of PV cells and systems, and a comprehensive review of the latest developments in PV. you will get hands on experience of PV systems components and be taught by a wide range of experts from both industry and research. It will allow you to assess the potential for your own industry to take advantage of the expanding PV market.

The course will enable one to:

Understanding the global opportunities for PV from the scientific environmental and commercial basis.
Understand the principles of the design, performance and costing of both autonomous and grid-connected systems.
Assess the potential for your own industry to benefit from the manufacture and application of PV systems and components.

The course has a broad appeal to those wishing to understanding this exciting new technology, including:
Manufacturing companies interested in the potential for manufacture of systems components and export opportunities to both developing and industrialized countries.

Architectural and construction industries, especially those involved in building refurbishment.
Regional Companies interested in gaining operational experience of PV. Local and central government, both in the Egypt and from abroad.
Consulting companies involved with energy infrastructure.

Any Seminar or Course will contain all or some components of the following seven sections (including tuition, practical work & visits):

Concentrators.

## Section 5

## Grid-Connected PV Systems

**Building-integrated PV systems:** review of main types and opportunities, reasons for the recent expansion in various countries, case studies.

**Electrical aspects of PV:** wiring, choice of inverter and control system, regulation for grid connection, problems in grid operation, metering, a.c. vs. d.c. modules.

**Structural aspects of PV:** support systems, ventilation, maintenance, life time, safety.

Aesthetics of PV, costs of Aesthetics components of buildings.

Inter-industrial collaboration in the design and installation of PV.

Other integrated systems, e.g. Sound barriers.

Large PV grids.

## Section 6

## Economics, Funding Possibilities

Basic financial analysis of autonomous and grid connected PV systems, cost of electricity, potential for cost reduction.

Comparative costs and value of electricity in different locations.

Sources of finance in the national and international levels.

## Section 7

## Special topics/futures

Predictions of future trends (e.g. Hydrogen production), long-term strategy.

Space applications and the different requirements they impose.

Report of latest developments from the European and international PV conferences.

**The ICS Experts Group Meeting on**

**NETWORKING OF PHOTOVOLTAIC SYSTEMS AND APPLICATIONS**

**Cairo, 26-28 April, 2000**

# PV Solar Energy : Demand and Manufacturing Activities

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# PV Solar Energy : Demand and Manufacturing Activities

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## 1. Introduction

PV Solar energy is considered as one of basic milestones of Egypt national strategic plan for development of electronic industries .

Ministry of Military Production (MOMP) was requested (from Egyptian Government) to prepare a strategic plan for development of electronic industries in Egypt and this plan is covering the following activities :

- Silicon industry .
- Microelectronics chip and Systems industry : both design and fabrication .
- PV solar energy : cells and PV solar system components fabrication .
  Details of this plan were discussed in a workshop meeting held on 6-7/2/2000 and organized by MOMP.

## 2. PV Energy Demand For Underground Water Pumping :

MOMP is preparing a techno – economic study of a large – scale project in the Nile Valley (East Ouenat) in which up to 100.000 Acres of land would receive solar water pumping from underground water as a first phase of project (Total area 360.000 Acres) .

The project is environmentally benign because it reduces polluting air emissions from diesel generators which are used to pump water for the region and , economically , the project reduces the fuel, transportation and maintenance costs associated with diesel power .

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***NOMP ... National Organization for Military Production**
**MOMP ... Ministry of Military Production .**

It is estimated that the area of 1000 Acres will need about 0.5 MWp for underground water pumping . And, so the expected solar power to be installed is about 50 MWp for the area of 100.000 Acres .

It is a very ambitious plan and it encourages establishment of a PV cells and system manufacturing facility for this purpose in Egypt, in addition to taking into consideration solar requirements for rural areas .

## 3. Manufacturing Facilities :

It is expected that the local demand for PV energy will be about 2-5 MWp/year to support MOMP project . This demand guarantees the establishment of a feasible manufacturing facility .

**Benha Co. for Electronic Industries,** one of companies of NOMP, is a pioneer company in the field of electronic industries . The company, using its technical and human resources, can support the industrial part of the project as regarding : production of charge regulators, inverters and related aspects . And the company welcomes cooperation with other local and international interested parties .

## 4. Conclusion :

4.1- MOMP has an ambitious program – under study – for establishing a PV cells and system manufacturing facility to supply technical requirements for implementing PV solar energy in underground water pumping in Egypt.

4.2- MOMP welcomes cooperation both nationally and internationally in this program .

4.3- Periodic Expert Meetings is a successful idea necessary for :

- creation of awareness for importance of PV energy for both decision makers and users .
- exchange of expertise .

- determination of PV energy local demand in different countries .
- creating a network for coordination and cooperation .

4.4- More accurate data monitoring (case studies) of PV systems implementations need to be available , in addition to evaluation of PV system performance .

4.5- Feasibility studies of PV systems should take into consideration :

- pollution problem .
- governments subsidies of conventional energy sources .

Expert Group Meeting On
" Networking of PV Systems & Application "
26 - 28 April, 2000
Photo Energy Center, Cairo

Sponsored by: ICS - UNIDO

# THE ROLE OF SMALL AND LARGE SCALE PHOTOVOLTAIC SYSTEMS IN THE DEVELOPMENT OF RURAL AND ISOLATED AREAS IN EGYPT

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# THE ROLE OF SMALL AND LARGE SCALE PHOTOVOLTAIC SYSTEMS IN THE DEVELOPMENT OF RURAL AND ISOLATED AREAS IN EGYPT


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## ABSTRACT:


This paper presents the extensive experience of PV applications in Egypt which are carried out, in part, by the New and Renewable Energy Authority - NREA -. It also cover the future prospect of PV application and the constrains limiting the spread use of such technology in Egypt.


## 1- INTRODUCTION

Egypt has good prospects with regard to several renewable energy sources. The most promising of these are Solar, Wind and Biomass. For solar energy, Egypt lies in the solar belt ( 22° - 39° North ) with annual average daily insulation 6 kWh/m2. The direct component of the solar radiation reaches from 88% to 90% on clear day. Sunshine hours vary from 9 to 11 hours per day where there are only 30 cloudy days per year. In addition to that, Egypt has a high wind regime at the Red Sea (6.2 - 10.5) m/sec. Annual average, East Ewinat (Far South West of Egypt) 5 - 7 m/sec., North Coast 4 - 5 m/sec.

## 2- WHY RENEWABLE ENERGY

We are on time to look for renewable energy due to the following reasons:

- Decreasing conventional energy due to their limitation.
- Increase in the world energy consumption rate due to development and population growth.
- Renewable energy can not damage atmosphere and can not be exhausted.
- Availability of desert areas with high level insolation.

## 3- PREVIOUS EXPERIENCES IN THE FILD OF PHOTOVOLTAIC APPLICATION IN EGYPT

Photovoltaic power utilization has been addressed within the Egyptian Ministry of Electricity and Energy as early as 1979.
A number of photovoltaic (PV) systems totaling more than 2 $Mw_p$ have been installed in Egypt by public bodies (New & Renewable Energy Authority and other national and International Institutions) and private companies.

The main application field is water pumping, desalination, clinical refrigerators, rural village electrification and ice making. PV applications for telecommunication systems and high way advertising panels are already commercialized. Presently, there are two factories importing the PV cells and assembling PV modules, each with capacity of 300 - 500 $kW_p$ per year.

## 4- NREA ACCOMPLISHMENT IN THE FILD OF PHOTOVOLTAIC PROJECTS

NREA has accomplished considerable achievements in introducing PV to the Egyptian Context for various applications starting from pilot projects to field - testing and demonstration through commercialization. The most significant projects are follows :

### *Water Pumping*

- 14 $kW_p$ PV pumping system at Wadi El-Natroun with water production in the range of 80 - 100 m3lday.
- 2.2 $kW_p$ PV portable unit with water production in the range of 20 - 30 m3lday.
- 1.7 $kW_p$ PV pumping unit at Mansoreia Village.

### *Desalination*

- 7 $kW_p$ PV pumping and RO water desalination plant for producing 5 - 7 $m^{3}$lday of fresh water at High Voltage Research Center I EEA.
- 18.5 $kW_p$ PV desalination RO plant at El-Hamrawein on the Red Sea with a productivity of 60 m3lday.
- 8 $kW_p$ PV I Diesel - powered RO water desalination unit for producing 5 $m^3$lday of potable water at Abou-Ghosoon on the Red Sea Cost.

### *Village Electrification*

- 28 $kW_p$ PV pilot project for electrification of remote village has been implemented for :
- Household Lighting.
- Street Lights.
- Pumping Units.

### *Refrigeration*

- Installation of a 38 kW PV/Diesel/Battery hybrid power system powered Ice-Making Plant to produce 6 tons per day of flake ice for fish preservation at remote desert lake in Wadi El-Raiyan, El-Fayoum.
- 10 PV-Power Refrigerators for vaccine storage were installed in rural health care facilities.
- 1.2 $kW_p$ refrigerator for keeping medicine in health unit equipment at Mit Abou El-Kom Village.

### *Communication*

- 8 PV powered emergency communication systems.

### *Signaling & Warning*

- A naval warning system placed on Lake Nasser.

### *Others*

- A number of PV - Powered colour television sets.
- A loudspeaker system at Mit Abou El-Kom Mosque.

- Lighting some offices for the organization for Energy Conservation and Planning OECP.

### *Concultancy Services*

- Prepare tender document for PV powered obstruction lighting units with battery storage for High Voltage Transmission Lines (Towers) for Egyptian Electricity Authority EEA.
- Introducing the technical consultancy for acceptance and operation tests and preliminary hand over for Ein El-Skhona Tall Station and Suez Balance with 30 $kW_p$ PV power system for lighting.

## 5- CONSTRAINS LIMITING SPREAD PHOTOVOLTAIC APPLICATIONS

- High capital cost.
- System equipment's are totally imported.( mainly balance of system )
- Unavailability of spare parts.
- Unavailability of financial support or soft loans.
- Subsidies for other rural energy options.

## 6- LOCAL CAPABILITIES FOR PV SUPPLIERS

- **ASET:** (Arabian Solar Energy & Technology Co. ) acting as system house for Siemens Solar of Germany and selling complete systems.
-
- **ENGCOTEC:** acting as a branch of Engcotec of Germany.
-
- **EGYCEL:** a local financing company assembling PV modules ( 55 $W_p$ & 75 $W_p$ module ).
- **BIC**: a local financing company manufacture all range of PV modules (Gp 75, 40.20, 5 Watts) . The technical assistant and know how are obtained through a cooperation agreement with ASTRO power, USA.
- **EGAT:** Egyptian German air treatment Co.
- **SOLAREX:** acting as system house for Solarex USA.

No activities are known relevant to the balance of the system ( batteries, inverters, controller, etc ).

## 7- PV - PROSPECTS

### *1. Small Scale PV Application*

**<u>OFF-Grid Rural Village Electrification</u>**

There are 400 - 500 small isolated rural communities represent the most feasible option for PV electrification (South & North of Sinai, New Valley, Red Sea, Matrouh, ... etc) we estimated the market potential to be 4 Mw.

The main features of the remote villages are:

- Few houses (5-40).
- Dispersed nature of houses.

- Villages are far from the utility grid.
- Low energy demand.
- Constant load.

Priority is given to implement PV electrification project for 33 remote settlements in Sinai. Five remote settlements have been chosen in South of Sinai to be electrified by PV systems as a first stage. These five settlements will be assessed in terms of technical reliability and social impact and will feed back the next phases. The main features of the prefeasibilty study are:

- No. Of households to be electrifies = 141.
- No. of public building = 4.
- Estimated daily energy consumption / house = 800 wh/day.
- Estimated PV array size = 250 $W_p$ / house.

### Communication & Signal

PV is an ideal and reliable power source for remote telecommunication systems and repeater stations. Recently, there is a good market for these applications.

### 2. *Large / Very Large Scale PV Power Systems (PVPS)*

Today, the world is turning from the conventional limited-power PV systems to the very large-scale PV systems for power generation. Definitely, the VLS PV projects should be allocated in low price desert land, which is rich of solar irradiance. The VLS PV projects are considered a major support for the sustainable development programs and also help reserve the environment.

Currently the government of Egypt is placing high priority on developing New Desert areas in order to decrease the overpopulation arround the Nile Valley and Delta creating new societies, new job opportunities, new investment as well as raising the standard of living.

The Southern Part of Egypt is characterized by high level of solar radiation (where the annual global radiation reaches 7 kWh/m$^2$/day) and availability of ground water (average head 75 meter).

The ground water pumping through the use of large-scale PV power system is suitable application in their areas.

We forecast a market needs of several $MW_p$.

## 8- PV-Market Development

***<u>The Role of Government and Donor Agencies</u>***

To promote sustainable household PV electrification, government should assure the following :

- *<u>Rationalized import duties and taxes</u>*

Import taxes and duties on PV component and solar home systems should be avoided since they can increase the cost of solar home dramatically, limiting the potential market.

- *Equal fiscal treatment of rural electrification option*

PV systems should receive similar financial support as that provided under grid extension or isolated grids in rural areas.

- *Encourage the PV-Industry and the balance -of-system.*

- *Encourage the private sector.*

- *Encourage the Egyptian Social Fund.*

## ***The Role of the World Bank and Other Donor***

Potential support for household PV programs from multilateral development organization such as the World Banks, the United Nations, Regional Development Banks, the GEF Bilateral Aid and Development Agencies should be integrated.

The donor communities can facilitate PV electrification programs, provide technical assistance and help fund pilot and large-scale projects.

# Expert Group Meeting On
# " Networking of PV Systems & Application "
# 26 - 28 April, 2000
# Photo Energy Center, Cairo

## Sponsored by: ICS - UNIDO

## New & Renewable Energy Authority (NREA)
## R&D, Testing and Certification Activities
## For
## Photovoltaic Systems and Components

*Dr. Eng. Elham Mahmoud*
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# New & Renewable Energy Authority (NREA)
# R&D, Testing and Certification Activities
# For
# Photovoltaic Systems and Components

*Dr. Eng. Elham Mahmoud*
*Director of Photovoltaic Studies, R&D and Testing*
*New & Renewable Energy Authority, Egypt*

## Introduction

In the framework of the programs of the Ministry of Electricity and Energy for development and localization of renewable energy technologies, the Egyptian Renewable Energy for Development Organization (**EREDO**) has been established as a specialized center within the New and Renewable Energy Authority (**NREA**). The center was established with the financial support of the Government of Egypt, the European Community and Italy.

EREDO, through its advanced laboratories and technical capabilities is entrusted to carry the studies, research, testing and certification activities needed to develop Renewable Energy (**RE**) components and systems.

Tests on RE equipment performance, reliability, durability as well as environmental effects can be performed by EREDO.

EREDO has an integrated set of advanced research, testing and certification laboratories for the different technologies of renewable energy, energy conservation and environmental measurements. Besides, EREDO has a set of general purpose laboratories relevant to the general requirements and balance of system components of renewable energy systems.

It is managed and operated by a highly specialized crew trained in advanced European and international centers.

In the area of photovoltaic applications, there are two main laboratories;

- The outdoor laboratory
- The indoor laboratory

Also, the facilities of the following two general purpose labs, are used for the PV systems' research, development, testing and certification:

- The optical laboratory
- The aging laboratory

## 1- INDOOR LABORTORY

The Indoor laboratory consists mainly of two separate facilities; the PV cell test facilities, and the PV module test facilities.

The objective of the Indoor laboratory is to conduct R&D studies on PV cells, and perform testing and certification on PV modules.

### The following tests are available and can be performed in the PV labs:

- ***Tests on Photovoltaic cells***
    1- Measurement of the performance of solar cells in simulated sunlight by pulsed solar simulator.
    2- Measurement of the temperature coefficients for correction of Current-Voltage characteristics.
    3- Determination of the internal series resistance of solar cells.
    4- Determination of the spectral response of solar cells using the monochromator.
    5- Determination of the sheet resistance of wafers using the Four points probe system.

- ***Tests on photovoltaic modules:***
    1- Measurement of the mechanical resistance and the electrical continuity of modules due to twisting.
    2- Measurement of the electrical insulation of modules.
    3- with the aid of the aging test facilities and the PV outdoor test facilities, the following tests can be performed:
        3.1. Outdoor Exposure tests.
        3.2. UV Exposure tests.
        3.3. Thermal cycling test.
        3.4. Damp- heat test.

***Components:***
The photovoltaic Indoor laboratory is equipped with the following main equipment:

***a- Equipment to test the photovoltaic cells:***

- Pulsed solar simulator.
- Monochromator.
- Four points probe system.

***b- Equipment to test the photovoltaic modules:***

- Mounting Twist Tester.
- Insulation Tester.

## 2- OUT-DOOR PHOTOVOLTAIC LABORATORY

### The main activities of the lab are:

1. Testing & Certification of PV modules.
2. Testing PV arrays of installed PV systems.
3. Testing the performance of PV applications systems

The out-door photovoltaic laboratory consists mainly of two sections in addition to a meteorological station and data acquisition system.

*a - Testing Units:*

- Units to test the characteristics of photovoltaic modules.
- The Nominal Operating Cell Temperature (NOCT) calculation unit.
- Portable PV array tester unit.

***b - Units for photovoltaic applications equipped with measuring equipment and testing of their performance.***

- PV Powered AC household electrification system $300W_P$.
- PV Powered AC household electrification system $500W_P$.
- PV Pumping system 1500 $W_P$

***c - Data Acquisition System.***

***d - The meteorological station unit.***

## 3- OPTICAL LABORATORY

The Main Objective of the lab is to measure and evaluate the optical properties of the surfaces and materials used in solar energy equipment and energy conservation in the light frequency ranges:
- Infra red
- Near infra red
- Visible light
- Ultra violet

*Components:*

- *X - Y TRACKER:*

This device is designed to allow the measurements of the accuracy of focusing of mirrors.

*Applications:*
- Intended to be mirrors for parabolic focusing solar collectors.
- Suitable for any type of specular mirrors systems.

- *MICROSCOPE:*

This device is used to test visually the surface painting of new solar collector and the used solar collector after the aging test, to define the effect of weathering parameters on that painting. (It can be recorded by photograph)

- *ALBEDOMETER:*

This device is used to measure and record global solar radiation, reflected solar radiation, to display both radiations and calculate the albedo. (The albedo = Reflected radiation / Global radiation)

- *HIGH INTENSITY LAMP ARRAY:*

This device is designed to test and evaluate the performance of solar collectors (flat, cylindrical) in adjustable simulated solar radiation.

- *RADIOMETER:*

This device is designed to measure the emittance of infra red from sample of any solar collector via comparing it by another reference sample.

- *SPECTRO - PHOTO METER:*

This device is used to measure the following optical parameters in the light frequency ranges from NIR to UV:
- Reflectance
- Absorbance
- Emittance
- Transparency

## 4- AGING LABORATORY

This lab is prepared to perform aging tests on different components and equipment; such as RE components and systems, which are, exposed to specific climatic and environmental conditions.

***Components:***

- *CLIMATIC CHAMBER TEST FACILITY*

The objective of this accelerated test is to determine the resistance of solar thermal collectors, photovoltaic modules, general outdoor equipment and instrumentation to the effects of alternating ambient factors ranged from $-40^0$ C up to $100^0$ C in multiple cycles. So, it is very useful to quickly evaluate the limits and the expected lifetime of components.

***DESCRIPTION:***

The climatic chamber is capable to perform temperature / humidity tests using programmable logical controller PLC which achieves almost the test running conditions according to the international standards (IEC, ASTM, etc.). It has the advantage of recording and instantaneously demonstrating the cycles' profile using data acquisitions system.

***ENVIRONMENTAL MAIN FEATURES.***

TEMPERATURE RANGE: - $40^0$C/+100 $^0$C.

HUMIDITY RANGE: from 20% to 98% R.H. in the temp. Range +$10^0$C/+$90^0$C.

THERMAL LOAD DURING TEMPERATURE STABILIZATION:

3000 Watts maximum (at $-40^0$C), Max. R.H. with 3 kW dissipation 85%.

***CABINET DIMENSIONS:***

INTERNAL DIMENSIONS: Width, depth, and height: (2.96, 1.76, 2.4 m).

- *U.V. CLIMATIC CHAMBNER TEST FACILITY*

The objective of this accelerated test is to determine the effects of the solar radiation on components and materials, such as the deterioration of their physical and electrical characteristics caused by U.V. exposure.

*DESCRIPTION:*

The chamber volume has to be greater than the test component, and the U.V. radiation source area is approximately 10% of the internal horizontal area of the chamber. The solar radiation is simulated by means of an UV lamp placed inside the chamber.

*ENVIRONMENTAL MAIN FEATURES.*

TEMPERATURE RANGE: - 70 $^0$C / +180 $^0$C.

HUMIDITY RANGE: From 10% to 98%

DISSIPATION AT –50$^0$C: 600 Watt.

*CABINET DIMENSIONS:*

INTERNAL DIMENSIONS: 0.6 × 0.55 × 0.47 m (W × D × H).

- ***DURABILITY / RELIABILITY TEST FACILITY***

The objective of this test is to determine the resistance of the equipment to the effects of salt and/or $SO_2$ atmosphere. The concentration of moisture and salt is greater than what is found in service. The test is applicable to any equipment exposed to salt fog condition in service.

The test is also valuable for determining the durability of coatings and finishes exposed to a corrosive salt atmosphere.

*DESCRIPTION:*

The apparatus consists of an exposure chamber with racks for supporting test items, salt solution reservoir with means for maintaining an adequate level of solution, means for atomizing salt solution, including suitable nozzles and compressed air supply, means for humidifying the air at a temperature above the chamber temperature.

The chamber is able to meet the main international standards and rules such as ASTM. DIN, and UNICHIM 962 and 741.

*ENVIRONMENTAL MAIN FEATURES*

TEMPERATURE RANGE: from ambient temperature up to + 55 $^0$C.

HUMIDITY RANGE: From about 50% to 98% R.H.

Na CI TEST CONDITIONS: up to 5%

*CABINET DIMENSIONS* (INTERNAL DIMENSIONS):

Width: 3.5 m, Depth: 1.5m, Height: 1.1m (+3.2 at the cover top).

- ***DUST / SAND CHAMBER TEST FACILITY***

The objective of this test is to ascertain the ability of the equipment to resist the effects of a dry dust and / or sand laden atmosphere.

General effects resulting from the penetration of dust can cause a variety of damages such as fouling moving parts, making relays inoperative, forming electrically conductive bridges and acting as nucleus for the collection of water vapor, reducing optical properties of the transparent or reflecting covering. Hence it is a source of possible corrosion and malfunctioning of equipments such as solar collectors, PV modules, etc.

***DESCRIPTION:***

The test facility consists of a chamber and accessories for operating with different velocities and temperatures of the dust / sand laden air. It has the ability of maintaining and verifying the dust concentration in circulation to be capable to achieve the conditions and rules according to the international standards such as (DIN 40046, MIL-STD 331 and MIL-STD 810C.).

***MAIN FEATURES.***

TEMPERATURE RANGE: from +30 $^0$C to + 75 $^0$C.

AVERANGE AIR SPEED: from 1.5 to 10 m/sec.

TEPICAL TEST DUST TYPE CAN BE USED REFER TO:

DIN 40046: 50% limestone dust and 50% fly ash and quartz dust

MIL-STD 331 & MIL-STD 810C: 97 to 99% SiO2

DUST / SAND CONCENTRATION: from 5 to 11 g/m$^3$

***AIR VELOCITY SIMULATION SYSTEM:***

Horizontal air flows by means of high power ventilator to simulate a wind velocity up to 9 m/s. Air flow rate: about 200.000 m$^3$/h.

***ROTATING BENCH***

The chamber is equipped with a rotating bench by means an electrical motor with vertical axis passing through the center of the chamber in order to reach a 360$^0$ rotation (velocity: 2 r.p.m.)

***VACUUM SYSTEM:***

The vacuum condition inside the compartment (minimum absolute pressure: +10.000 Pa) will be reached by a flexible pipe connected to the component.

The vacuum system includes: Pressure gauges, dust filter, air flow meter, butterfly valve, vacuum pump.

*INSTRUMENTATION:*

***The chamber is equipped with the following instrumentation:***

- Air velocity meter and controller
- Air temperature meter and controller
- Dust/Sand concentration meter and controller

SAMPLES OF THE WORK DONE AT THE PV LABS:

- Evaluation of a PV pump performance for the AVECINNE project.
- Evaluation of a PV array performance after 13 years of operation at the Red Sea coast.
- Using natural outdoor conditions to realize STC for some tests.
- Evaluation of aging effect on the on shelf cells and modules.
- Evaluation of dust effect on the performance of the PV modules.
- Conducting the standard performance tests.
- Conducting training courses on PV technology and applications.
- Research work on PV concentrators.

*Arab Republic of Egypt*
*Ministry of Electricity & Energy*
*New and Renewable*
*Energy Authority* (NREA)

# The Egyptian Renewable Energy Development Organization "EREDO"

## A Center For Testing and Certification

In the framework of the programs of the Ministry of Electricity and Energy for development and localization of renewable energy technologies, the Egyptian Renewable Energy Development Organization **(EREDO)** has been established as a specialized center within the New and Renewable Energy Authority (**NREA)**. The center was established with the financial support of the Government of Egypt, the European Community and Italy.

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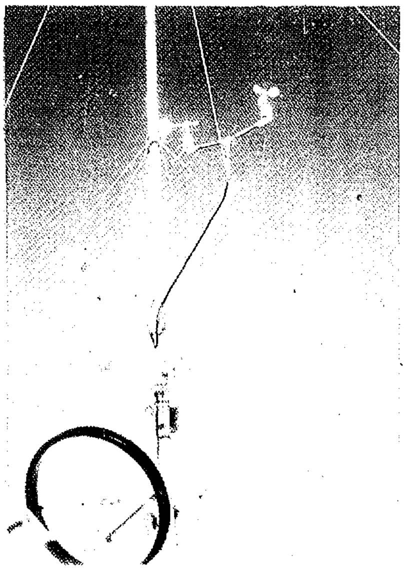
Tests on RE equipment performance, reliability,durability as well as environmental effects can be performed by **EREDO** .

*1998*

# THE EREDO TESTING AND CERTIFICATION CENTER

**EREDO** has an integrated set of advanced research, testing and certification laboratories for the different technologies of renewable energy, energy conservation and environmental measurements. Besides, **EREDO** has a set of general purpose laboratories relevant to the general requirements and balance of system components of renewable energy systems .

**EREDO** is managed and operated by a highly specialized crew trained in advanced European and International centers.



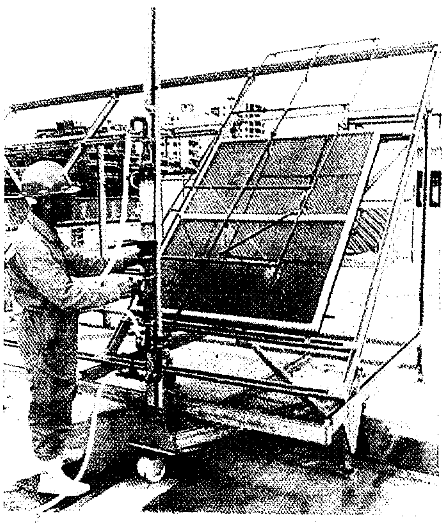
## RESOURCE ASSESSMENT

SIX resource assessment meteorological stations have been installed for the assessment of renewable energy resources and atmospherics in candidate project sites. It is used to satisfy the data needs for resource evaluation, sectorial studies, projects design and evaluation.
The following resource variables are measured by each station :
- Solar Radiation (Global, Direct and diffused).
- Wind speed (at 4m and 10 m) height .
- Atmospherics (Ambient temperatures, pressure and relative humidity)

## SOLAR THERMAL TECHNOLOGIES

***OUTDOOR SOLAR THERMAL " LOW AND MEDIUM TEMPERATURE LABORATORY (80 - 150°C)"***

The laboratory is dedicated for testing and certifying solar thermal low temperature water and air collectors, storage tanks and systems under natural solar field conditions.

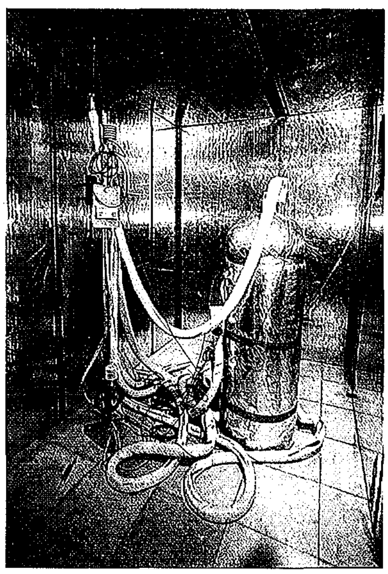


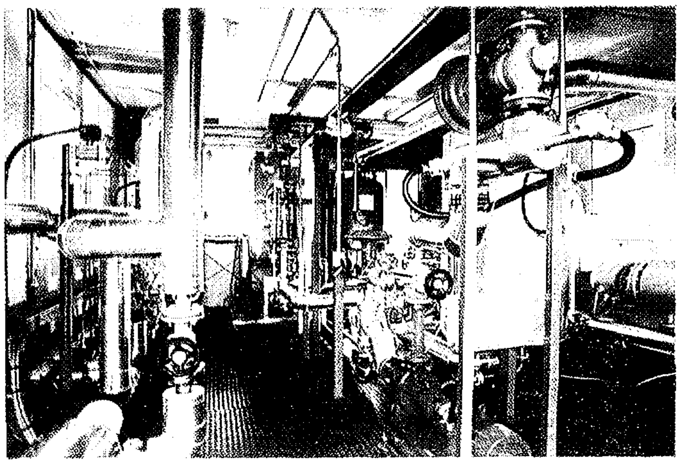
**The laboratory services are directed to the local manufacturers, researchers and the different application sectors. It includes ;**

* Standard testing and certification of Solar collectors, tanks and systems.

* Product Development and quality assurance.

* Evaluation of environmental impacts on equipment.





### *OUTDOOR HIGH TEMPERATURE SOLAR THERMAL TEST LABORATORY (UP TO 300 °C)*

The laboratory is directed for performing the efficiency, reliability and durability tests on concentrating solar collectors, hot oil storage and other components and systems used in the high temperature industrial applications as well as solar thermal electricity generation systems .

The facility includes both water and oil loops for testing systems operating in the temperature range of 100-300° C.

In addition, EREDO has:

* **A collector steering and driving unit** for tracking Solar concentrators.
* **A solar thermal supporting lab** with mobile instruments for field measurments.

## PHOTOVOLTAIC LABORATORIES

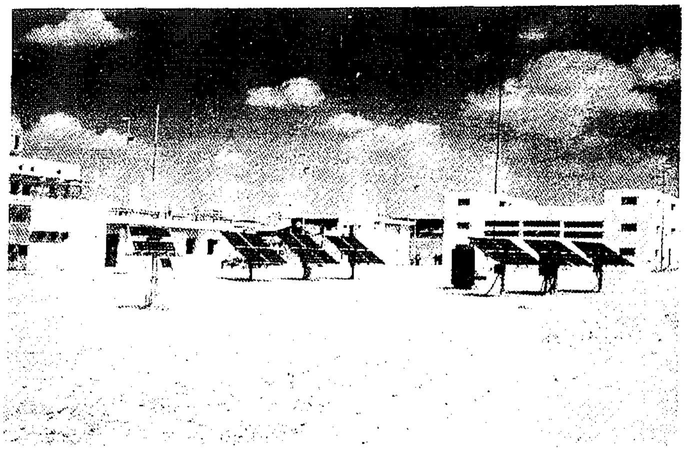
### *OUTDOOR PHOTOVOLTAIC LABORATORY*

The outdoor PV Lab. has two main sections :

1-Testing Units for measurement and evaluation of photovoltaic modules characteristics including:
- PV modules (NOCT).
-Testing arrays of PV installed systems.

2 - Demonstration Units for photovoltaic applications, household and pumping equipped with measuring instruments for testing their performance.

The laboratory is also equipped with a data acquisition system and a meteorological station unit.



### *INDOOR PHOTOVOLTAIC LABORATORY*

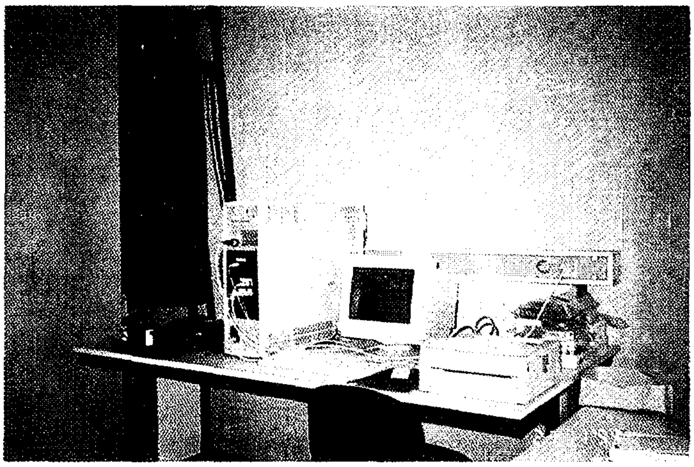
The Lab. can perform R&D studies on PV cells, as well as testing and certification of PV modules. It has two main separate facilities;

**- The PV Cell Testing Facilities** with pulsed solar simulator, monochromator and four points prob system.

**- Photovoltaic Modules Testing Facility,** with mounting twist tester and insulation tester.

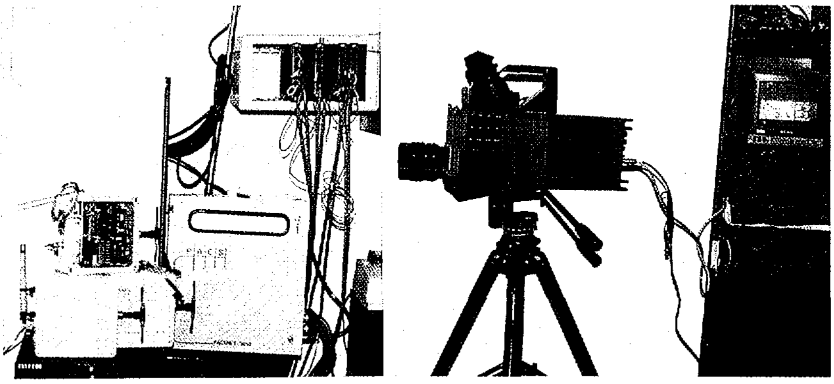
The following can be measured and evaluate:

* Performance, spectral response and temperature coefficient of solar cells .
* The sheet resistance of wafers.
* The mechanical resistance, electrical continuity and the electrical insulation of the modules.



# ENERGY CONSERVATION AND ENVIRONMENT LABORATORIES

The **EREDO** center has a number of advanced mobile and stationary laboratories that can serve field energy audits,testing and certification of equipment for both energy conservation and environment.

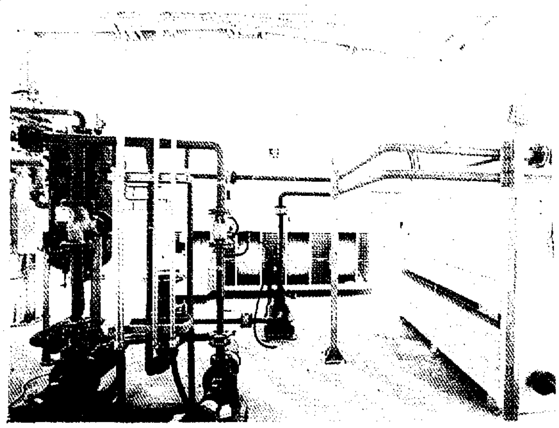


***THE MOBILE ENERGY CONSERVATION LABORATORY***

It includes advanced energy audit measuring facilities, mainly:
* Infrared thermovision camera.
*Building thermal behavior system.
* Electric measurement units.
* Thermal energy flow measurement.

***OUTDOOR ENERGY CONSERVATION LABORATORY.***

This Laboratory serves the different economic sectors, particularly the energy and industrial sectors by testing and evaluating the performance of the commonly used energy components according to the international standards. It also supports the quality control and the product development.
The lab. has two main test facilities;



* **The heat exchanger test facility** up to 580 KW
* **The Multiclimatic Test Facility,** for air conditioners and fan coils.

***INDOOR ENERGY CONSERVATION LABORATARY.***

The lab. facilities have been designed to help the different industrial and building sectors to improve the quality of their products by measuring, recording, analyzing and evaluation of the product performance which will lead to fulfill the energy conservation goals, it includes five facilities:

* **Sample conductivity test facility.**
* **Wall conductivity test facility.**
* **Special piping component test facility.**
* **Heat pump test facility.**
* **Photometric Test Facility.**

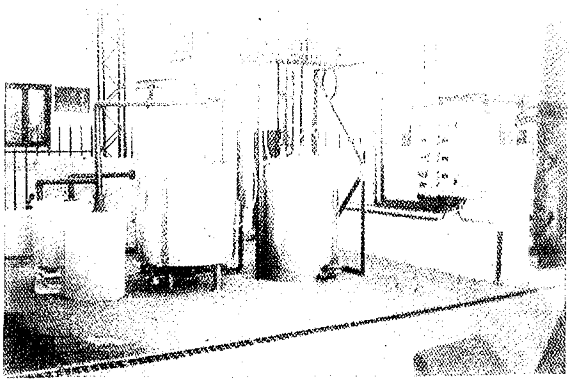
***THE ENVIRONMENTAL MEASUREMENTS LABORATORY***

The laboratory includes advanced measuring facilities for enviromental and climatic variables; using advanced equipment. It includes :
* Combustion engine performance analysis unit.
* Emission gas analyzer.
* Water quality control unit.

# BIOMASS LABORATORIES

### *OUTDOOR BIOMASS LABORATORY*

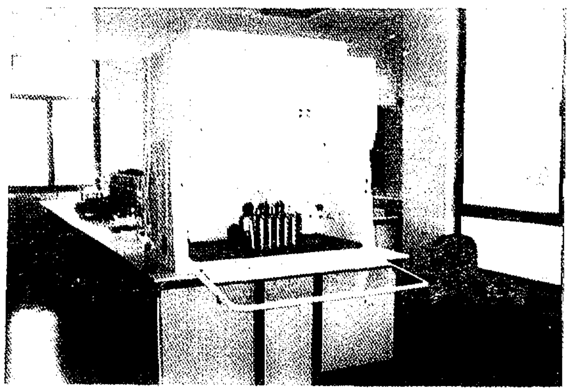
The laboratory includes a set of full scale equipment and systems for demonstration and testing of both biological and thermal biomass systems. It is equipped with instruments and control elements to simulate working conditions using different available kinds of organic wastes, as well as the necessary measuring instruments for performance evaluation. It includes mainly:

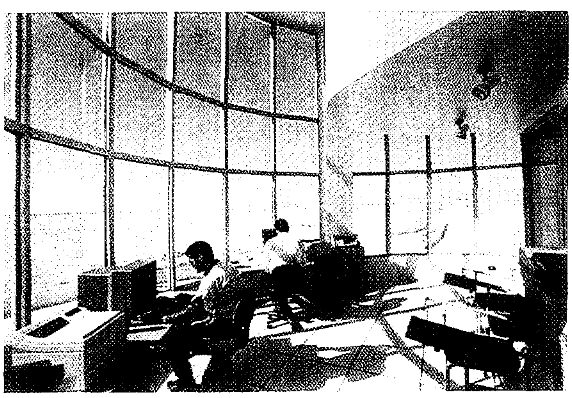


* **Gas Left Biogas Digeste**r (1 $m^3$ )
Connected to a biogas electric generator set ( 2.4 kw.) a biogas refrigerator (35L) and different biogas burners as demonstration appliances.
* **Pelletizing Unit** for agriculture wastes (200 - 400kg/hr)
* **Gasification Systems** for the pelletized agricultural waste connected to a gas/diesel electric generator set ( 25KVA ).

### *INDOOR BIOMASS LABORATORY*

The indoor biomass laboratory includes the equipment and instruments required for bio and organic chemistry measurements and analysis in the fields of biomass energy conversion and organic pollution.





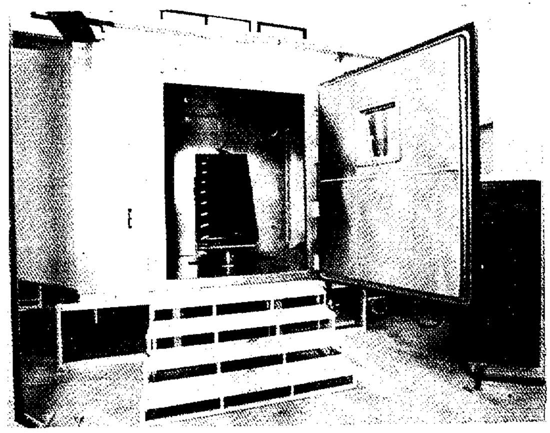
# EREDO WIND TESTING LABORATORY

### *EREDO Wind Testing Laboratory*

- Due to the poor wind resource at Cairo, the **EREDO** Wind Testing laboratory has been built in Hurghada (average wind speed 6.8 m/s), where various wind systems are operated in stand-alone conditions.
- Efficiency, functional and structural tests are performed at different wind speeds, the systems are;
* 10 KW wind system for electricity generation.
* 5 KW generator in connection with electric pumps.
* 4 KW multiblade wind machine for direct mechanical pumping.

## GENERAL PURPOSE LABORATORIES

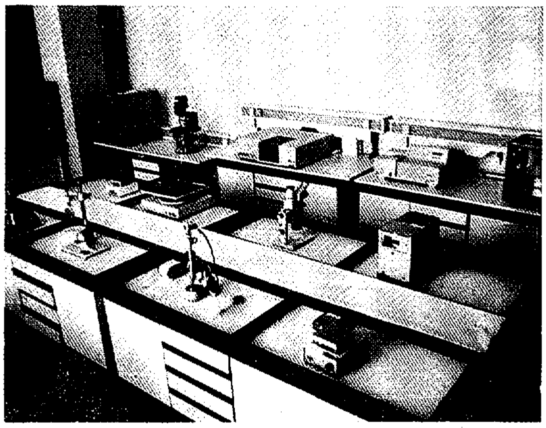
**EREDO** has a set of general laboratories equipped to satisfy most of the required laboratory works that can support renewable energy product development, projects services and maintenance support for **EREDO** specialized laboratories.



### *INDOOR AGING TEST FACILITIES*

This lab is prepared to perform aging tests on general purpose equipment, as well as renewable energy components, particularly solar thermal and PV collectors and materials which are exposed to specific climatic and environmental conditions. It has the following facilities.

*** Climatic chamber.(temp. & humidity)**
*** U.V. Climatic Chamber Test Facility**
*** Dust/Sand Chamber Test Facility.**
*** Durability/Reliability Test Facility.**

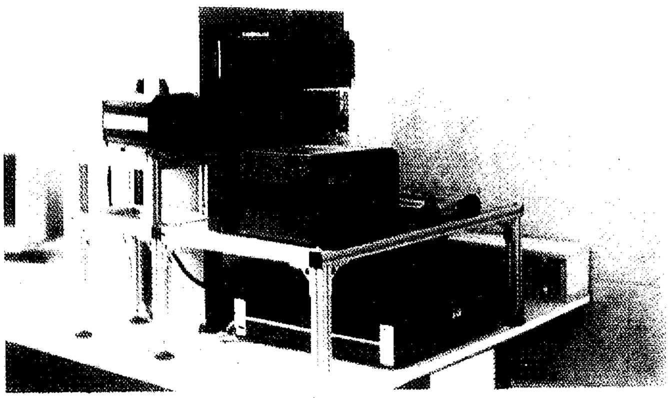


### *CHEMICAL / PHYSICAL LABORATORY*

It is directed for performing chemical/physical tests and measurements on materials used in renewable energy systems particularly for :
* Oils and water quality.
* Surface characteristics of materials.
* Mechanical stresses on components
* samples aging testes.

### *OPTICAL MEASUREMENT LABORATORY*

The laboratory is equipped with different measuring systems for measuring and evaluating the optical properties of materials used in renewable energy components and systems particularly solar energy and energy conservation. As well the laboratory includes a facility that can evaluate the focal properties of concentrated sun light and the accuracy of concentrating surfaces.

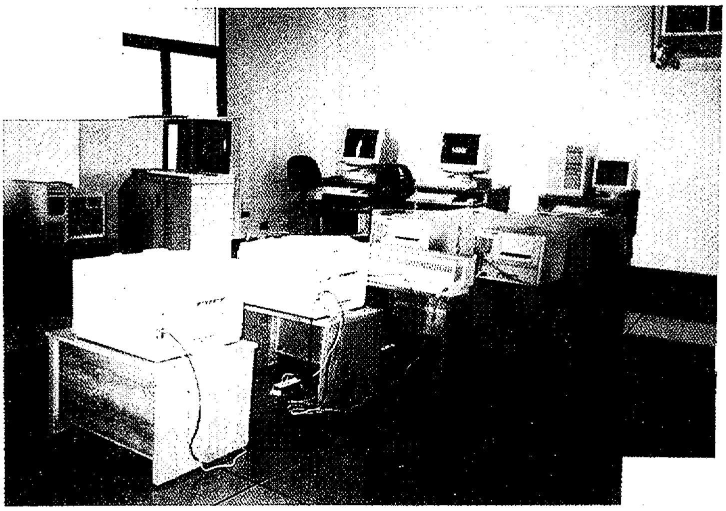


### *THE ELECTRONIC AND ELECTROTECHNICAL LABORATORY.*

The electronic & electrotechnical laboratory acts as a support for the activities of the other laboratories, field projects and general services Its activities also include : the design and construction of electric systems and boards dedicated to specific tasks, and advanced capabilities for measuring electric / electronic quantities.

**EREDO also has facilities for hydro measurements and general purpose thermal measurements.**

## RENEWABLE ENERGY INFORMATION CENTER



**EREDO** laboratories are supported by an advanced renewable energy information center. It includes an integrated Local Area Network of computers (LAN) distributed between the main information center and the different indoor and outdoor laboratories.

The LAN consists of one physical network where two Network Systems are running simultaneously: The Mini-computer which acts as a server for one system: runs UNIX Operating System while another powerful PC acts a Novel File Server for the other system.

Those two Network Systems connect 45 PC's and work stations and run different applications such as GIS, Oracle Database, AutoCAD, Archiving SW in addition to other DOS/Windows applications. Advanced Network laser Printers, Colour Local Printers and a Plotter are prepared to respond to any printing commands from any node on the Network.

## TRAINING AND INFORMATION DISSEMINATION ACTIVITIES

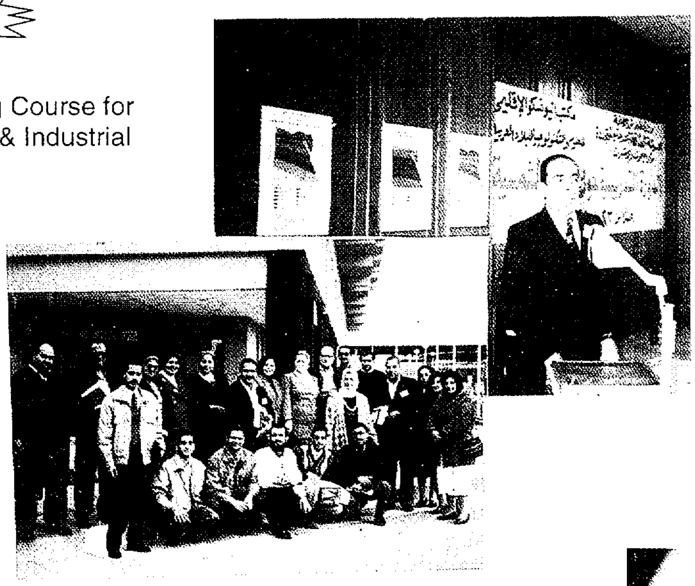
Training, information dissemination and enhancement of public awareness are in the core of EREDO objectives. The training activities are directed both for upgrading the expertise within NREA/EREDO staff and to disseminate the experience they have to other concerned groups national and/or regional. It can involve engineers, technicians, specialists as well as the public.

NREA/UNSECO Training Courses

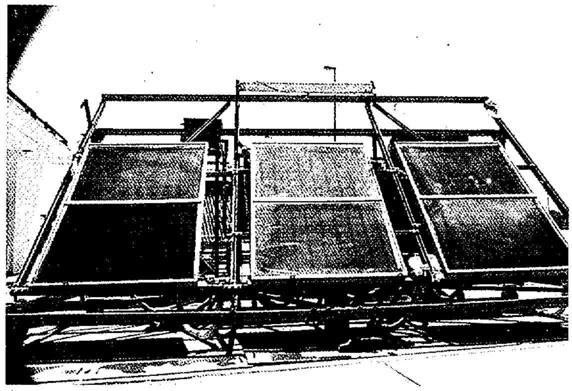
**EREDO / NREA** training and dissemination activities are directed to enhance the effectiveness of the center facilities, capabilities and increase the public awareness about renewable energy potential and applications.

Currently intensive training programs are being organized with the EU in support to **EREDO** as well as other national, regional and international institutions.

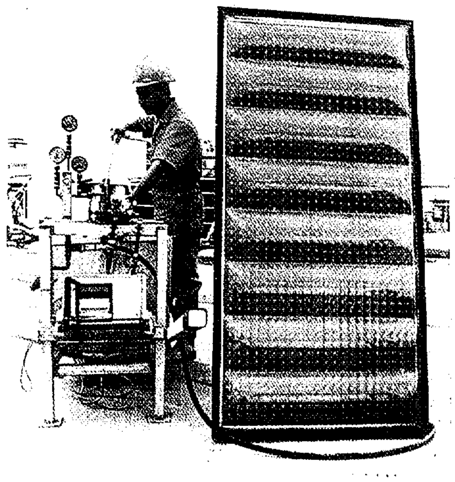
Training Course for Energy & Industrial Sectors



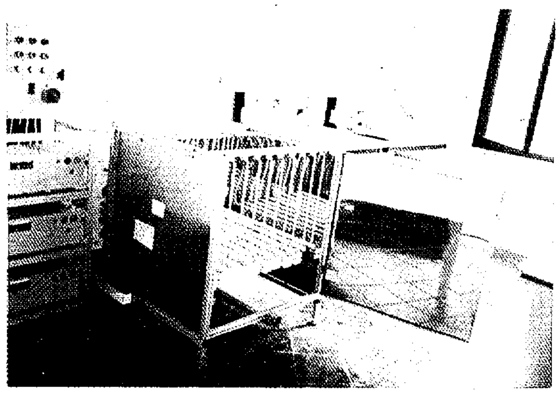
Specialized training programs are organized by EREDO for participants from different economic sectors, particularly the Energy and industrial sectors.
As well the center welcome research students and scientists using EREDO Facilities and supports their research and development activities.



# *E R E D O*



# N R E A



## *For More Information*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New And Renewable Energy Authority (**NREA**)

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*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *Italy*
# *Eurosolare*

# *PHOTOVOLTAIC STANDARD SYSTEMS*

# 1. GENERAL

## 1.1 Justifications

Decentralized village-planning of remote areas not reached by the traditional electric power grid is becoming so widespread that specialists are urged to look for new technical solutions at low investments/operating costs.
All this is particularly felt in African and Asiatic Countries where energy networks are not fully developed.

Anyhow, these countries remote areas enjoy a high degree of solar radiation which suggest the tapping of such resource by using photovoltaic (PV) technology, in order to improve the qualitative lifestyle of dwellers.

## 1.2 The Photovoltaic Effect

The photovoltaic effect is a physical phenomenon deriving from the exposition of a semiconducting material to sun light. However, the photons in sunlight are not all identical in terms of cell operation. In order o be absorbed and participate in the conversion process, the energy of a photon must be greater than a certain minimum value depending on the material used in the cell. If the device is connect to an external circuit, current will circulate.

The rated peak power (Pm) of a PV generator is the power delivered by the generator in standard operating conditions (1000 W/sqm irradiation and module temperature of 25°C). Since the quantity of energy produced by he PV generator is proportional to the incident radiation on the surface of its modules, they are positioned to ensure optimum surface irradiation on order to maximize the energy produced by the generator during use.

The PV system offers the following advantages:

- a cost competitive source, due to its long life cycle, in remote areas not grid connected;
- a silent, not polluting, inexhaustible and ecological source of energy;
- the possibility of encouraging local industrial agricultural, social relation and support health services;
- minimum maintenance even in harsh operating;
- expansion ease to satisfy growing requirements;
- reduction of rural-urban migration pattern.

A PV system of the right size and used in the right area can offer the ideal solution to numerous energy requirements.

## 1.3 Service

As described in the following examples of the main PV systems, the size of each system can change in function of the required load and the site of installation.
The EUROSOLARE engineering division is able to solve any kind of question concerning the design, the installation and the after sale service, the training and transfer of know-how.

# GENERAL DESCRIPTION

# FOR

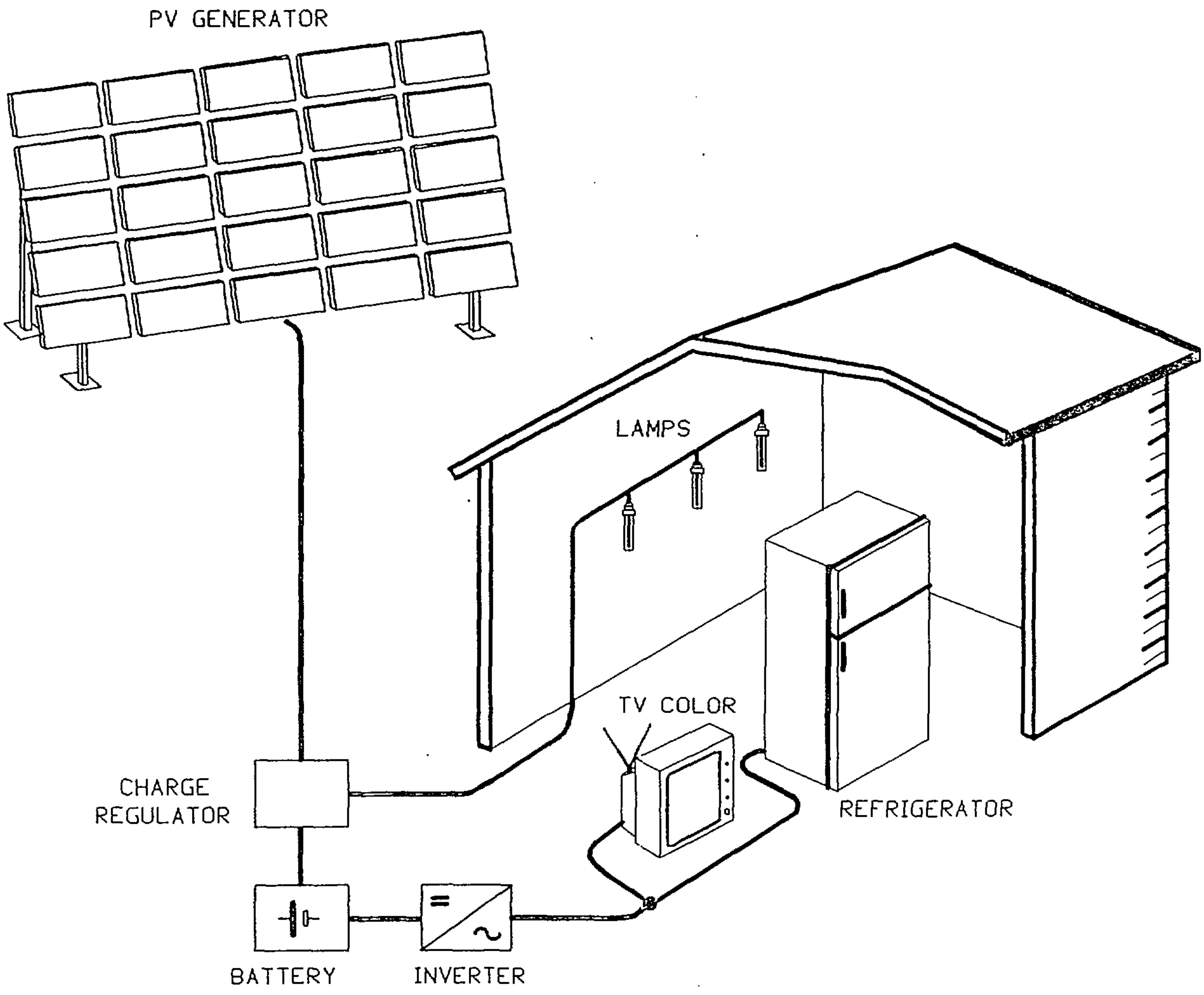
# TYPICAL PV SYSTEMS

- *RURAL HOUSE ELECTRIFICATION*
- *HEALTH CENTRE SYSTEM*
- *VACCINE REFRIGERATOR*
- *MINIKIT FOR LIGHTING SYSTEM*
- *WATER PUMPING SYSTEM*
- *STREET LIGHTING POLE*
- *GAZEBO*

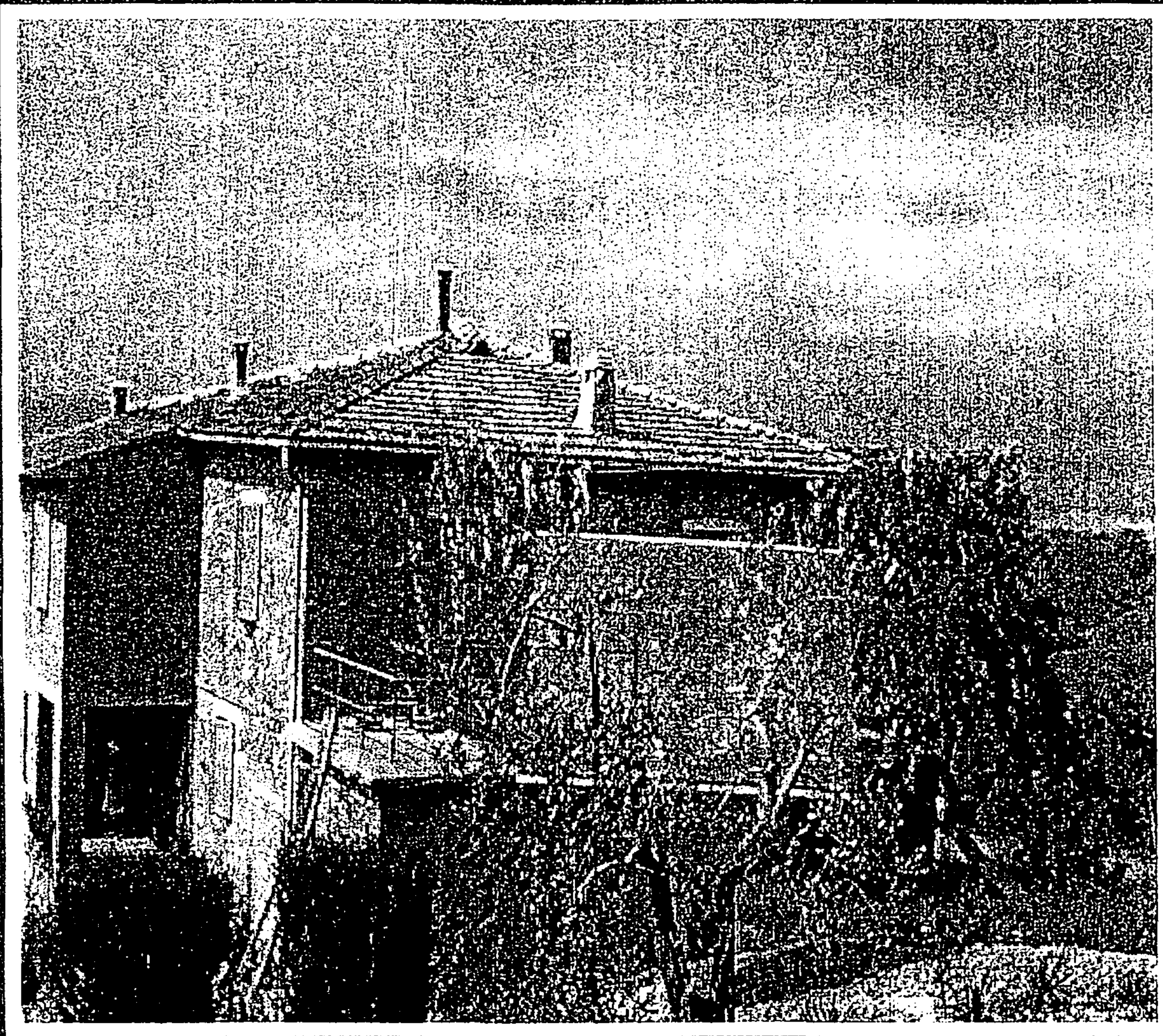
## RURAL HOUSE ELECTRIFICATION

This system is composed of following components:

- PV generator from 100 to 600 Wp
- Charge regulator 12/24V 30A
- Battery 12/24V, 100 - 500 Ah
- Fluorescent lamps
- Inverter 12V(24V)/ 220VAC - 1kW
- Refrigerator 110 liters
- TV color 14"
- Accessories (miscellaneous)



# Stand - Alone plants



Rural House electrification, ( IT ) - ( 0.6 KWp )

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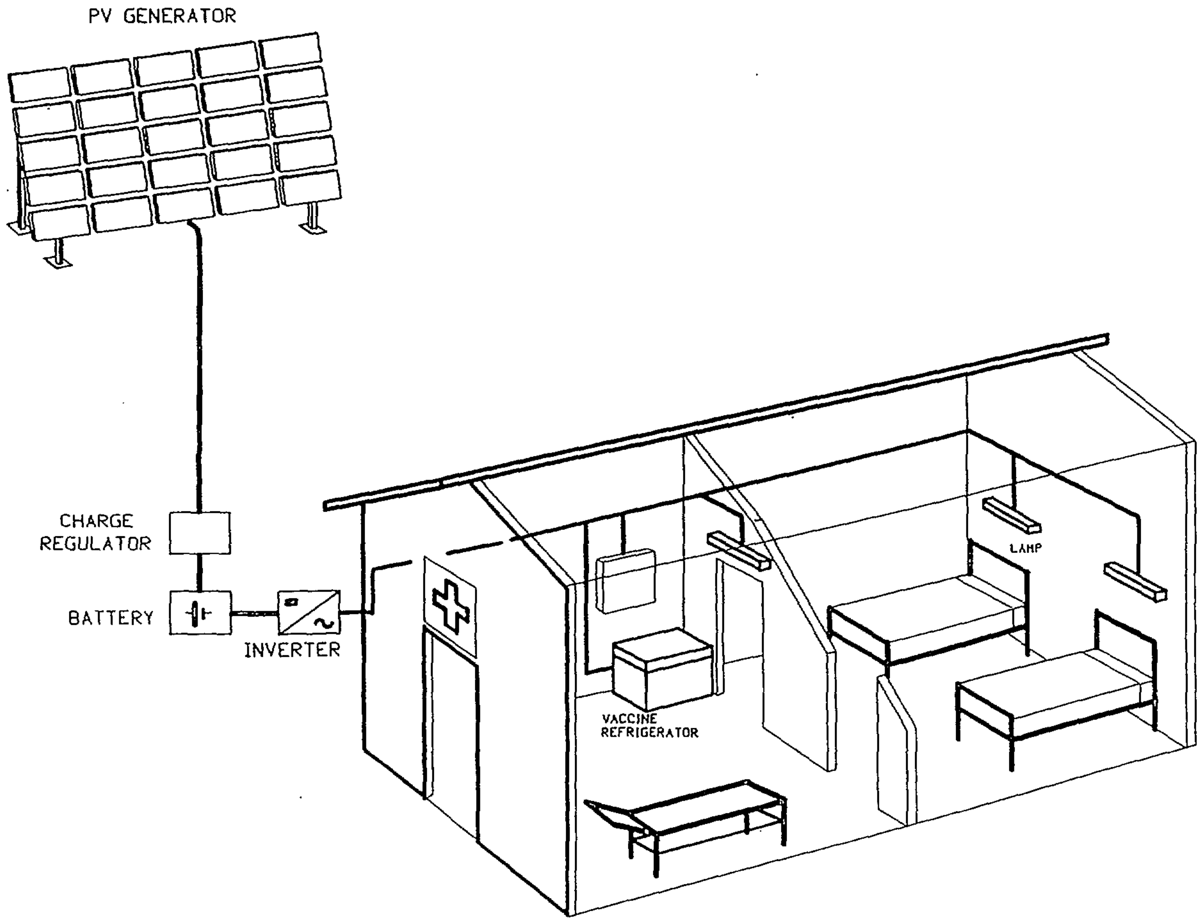
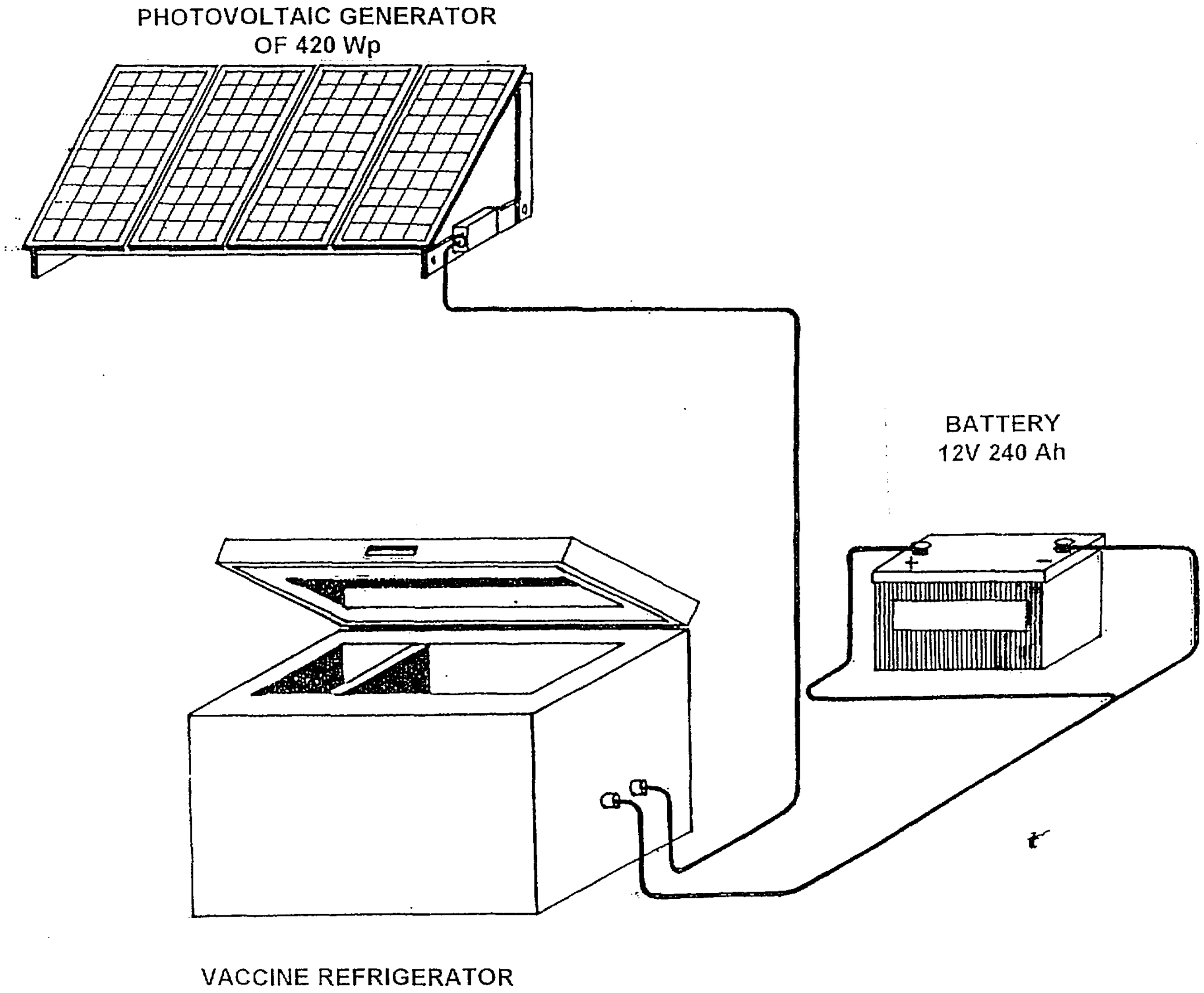
## HEALTH CENTRE SYSTEM

This system is composed of following components:

- PV generator from 100 to 600 Wp
- Charge regulator 12/24V 30A
- Battery 12/24V, 100 - 500 Ah
- Fluorescent lamps
- Inverter 12V(24V)/ 220VAC - 1kW
- Vaccine refrigerator
- Accessories (miscellaneous)



# SOLAR POWERED REFRIGERATION SYSTEMS



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**Caratteristiche frigo:**
*Refrigerator characteristics:*

| | | |
|---|---|---|
| — Volume netto zona di refrigerazione:<br>*Net volume of refrigeration space:* | l/Lt 40 | |
| — Volume netto zona di congelazione:<br>*Net volume of freezing space:* | l/Lt 4,3 | |
| — Dimensioni esterne:<br>*Outside measurements:* | cm 99 x 72 x h 68 | |
| — Prestazioni a:<br>*Performance at:* | 32°C | 43°C |
| — Produzione ghiaccio/N° ore<br>*Production of ice/# hours* | 5,7 kg/24 | 6,05 kg/24 |
| — Temp. interna minima<br>*Minimum internal temperature* | +1°C | +2°C |
| — Temp. interna massima<br>*Maximum internal temperature* | +3,6°C | +5,2°C |
| — Holdover time senza alim.<br>*Holdover time without supply* | 6,75 ore/h | 4 ore/h |
| — Consumo energia in 24 ore con prod. ghiaccio<br>*Energy consumption in 24 h, with ice:* | 0,565 kWh | 0,877 kWh |
| — Consumo energia in 24 ore senza prod. ghiaccio<br>*Energy consumption in 24 h, without ice:* | 0,291 kWh | 0,517 kWh |

| | | | | |
|---|---|---|---|---|
| Insolazione (Wh/m² giorno) a 32°C<br>*Insolation (Wh/m² day) at 32°C* | 3,5 | 4,7 | 5,8 | 7,0 |
| Con produzione di ghiaccio - Moduli<br>*With ice - Modules* | 6 | 4 | 4 | 3 |
| Senza produzione di ghiaccio - Moduli<br>*Without ice - Modules* | 3 | 3 | 2 | 2 |

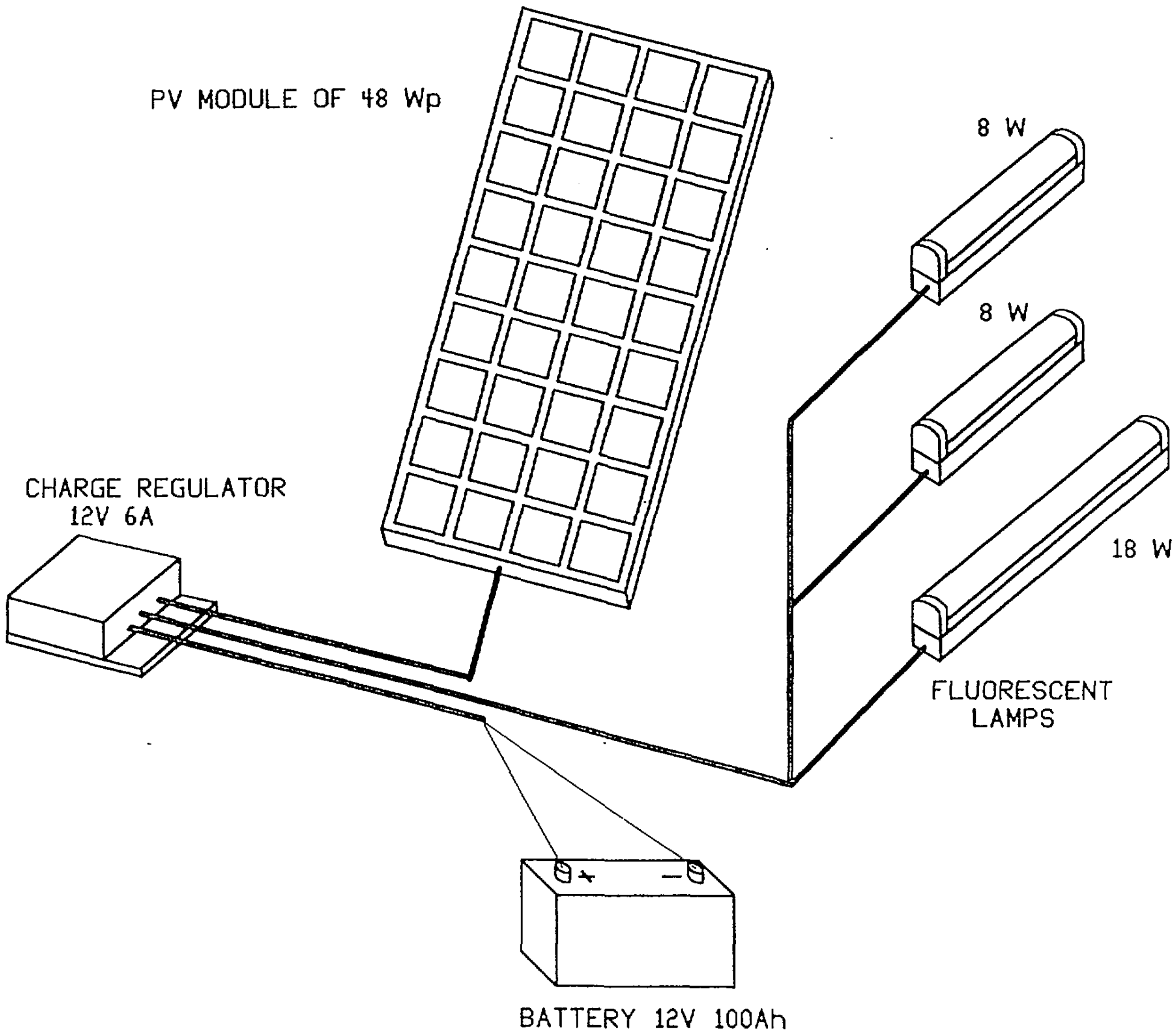
**Batteria di accumulatori:** del tipo stazionario al piombo-acido, particolarmente adatta ai sistemi fotovoltaici (a richiesta, la batteria può essere del tipo ermetico) e relativo contenitore in PVC lucchettabile con fasce di alluminio.

***Batteries:*** *stationary lead acid type particularly suitable for photovoltaic systems (hermetic battery available on request), and lockable PVC container with outside aluminium lamination.*

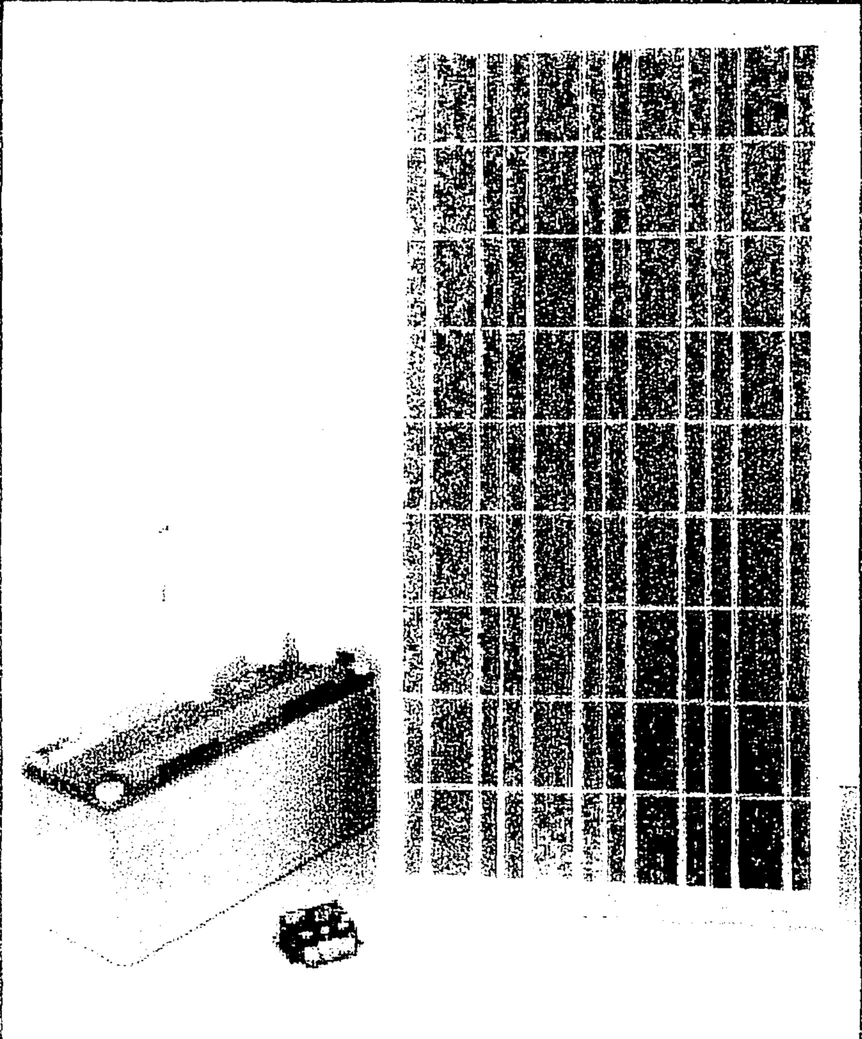
## MINIKIT FOR LIGHTING SYSTEM

This is a small PV system that can be utilized for lighting, telecommunication , rice mill, etc.
The minikit for PV lighting system is composed as follows:

- PV generator of 48 Wp
- Charge regulator 12V, 6A
- Battery 12V, 100 Ah
- Fluorescent lamps (no. 2 of 8 W, no. 1 of 18 W)
- Accessories (miscellaneous)



# Stand - Alone plants



## Minikit for lighting system ( up to 70 Wp )

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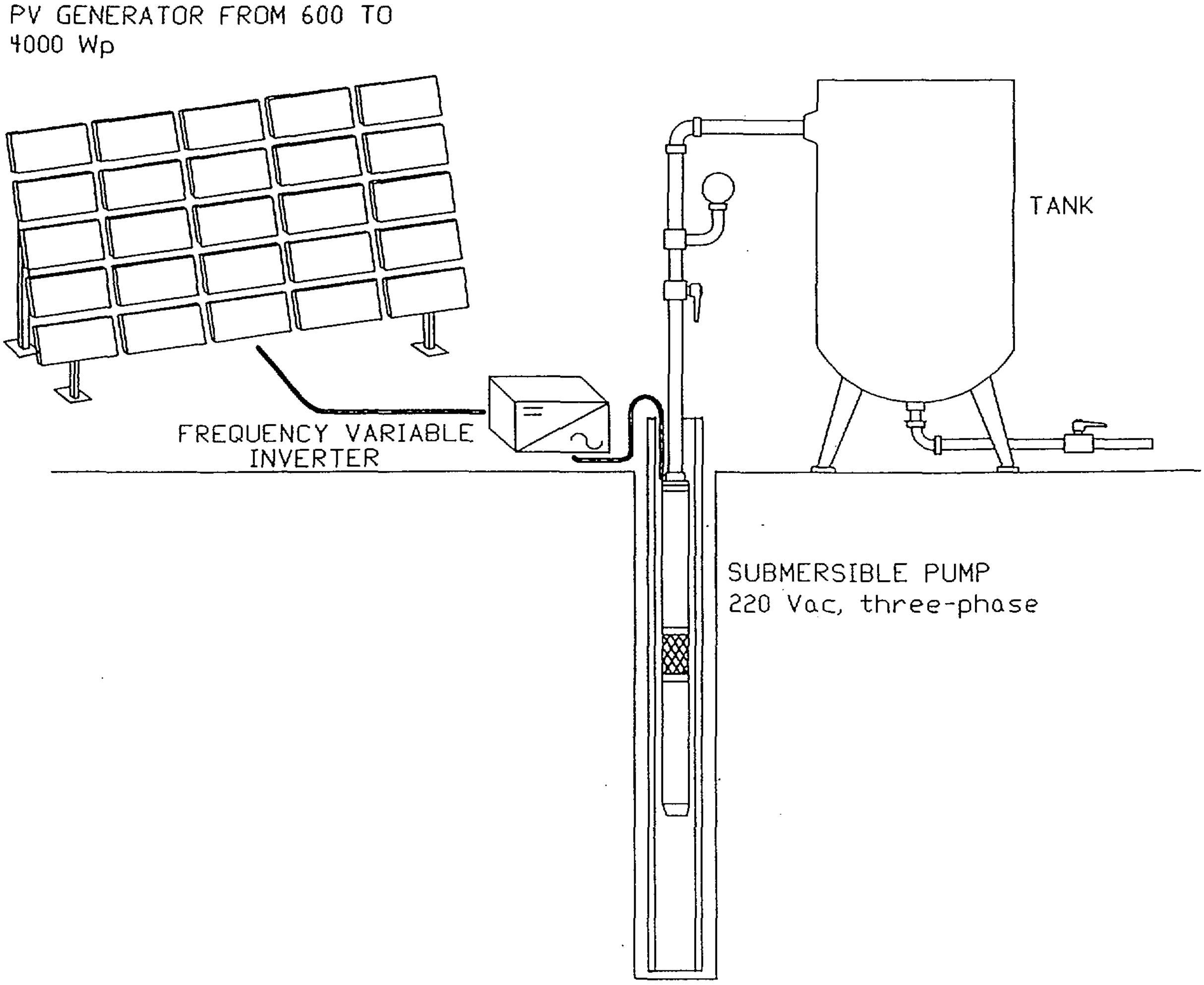
## WATER PUMPING SYSTEM

This system allows to pump water without the battery bank; a special type of inverter is used to supply directly an AC standard water pump.
The typical system is composed as follows:

- PV generator fro 600 to 4000 Wp
- Frequency variable inverter
- Standard water pump, 220 Vac three-phase, 50 Hz
- Electrics and hydraulic accessories



# Stand - Alone plants

Water pumping system - Mali ( 3 KWp )

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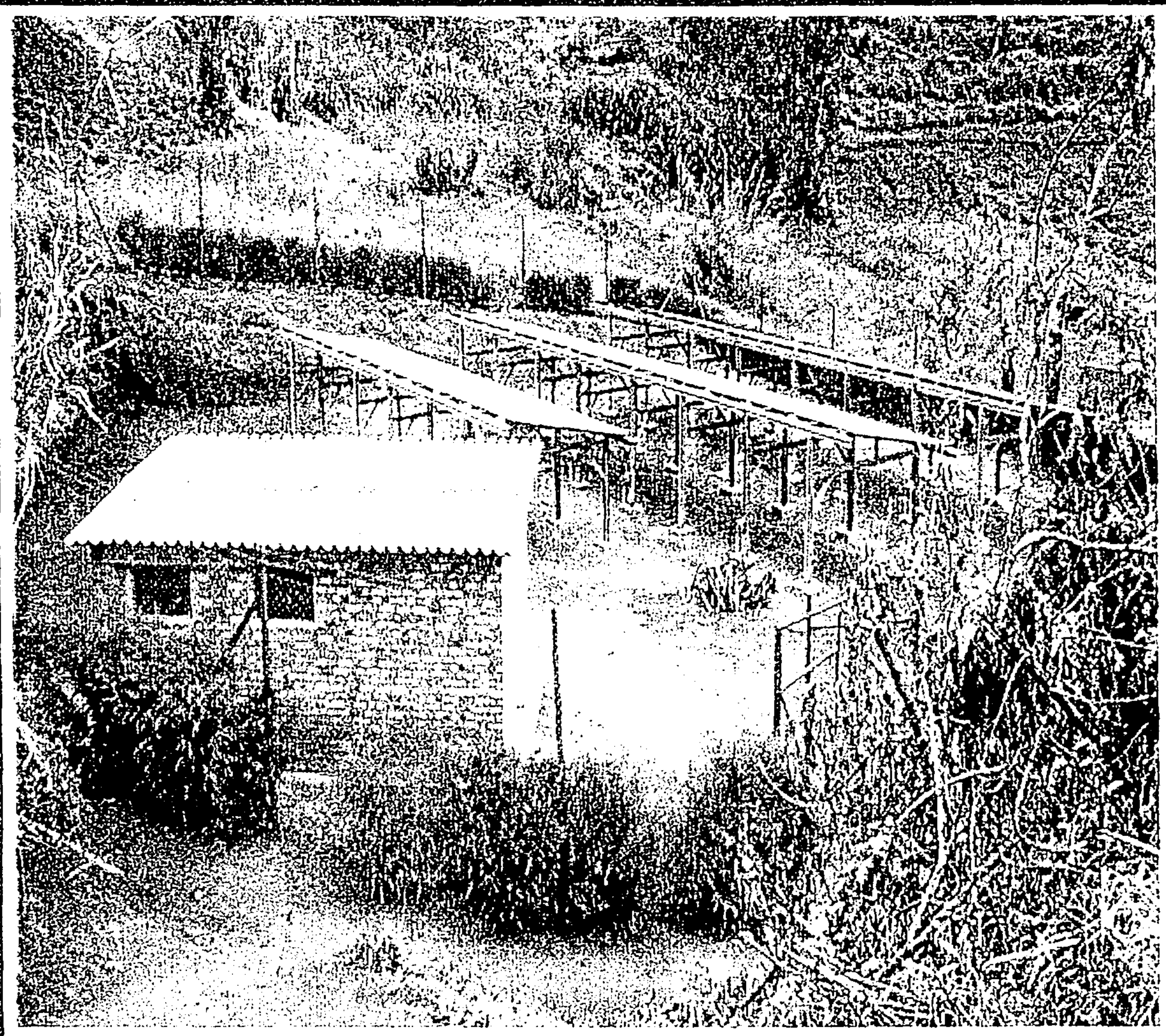
# Stand - Alone plants



Water pumping system - Ruanda ( 5 KWp )

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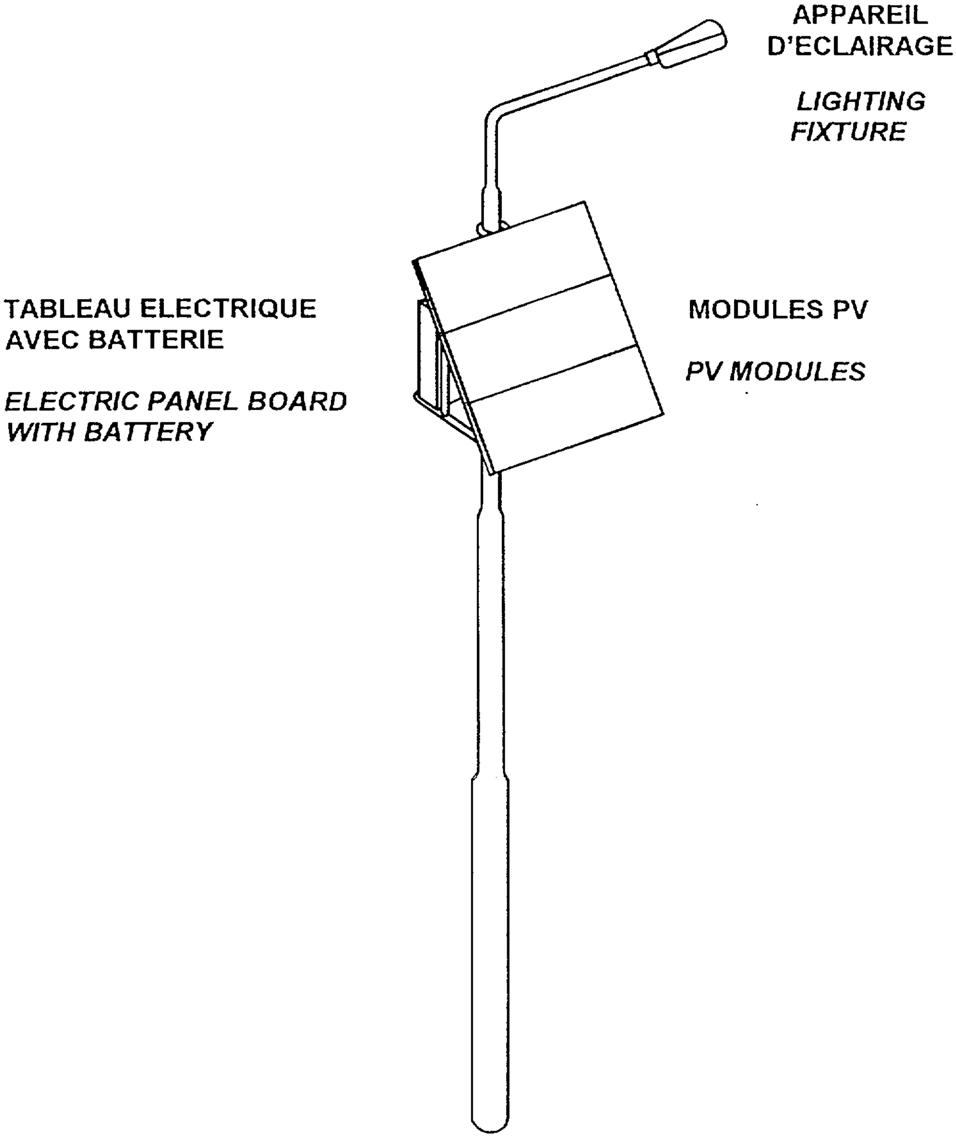
Doc. N. 00-SG-I-061

# CANDELABRE A ENERGIE SOLAIRE
# SERIE SLP-1

## *SOLAR LIGHTING POLE*
## *SLP-1 SERIES*



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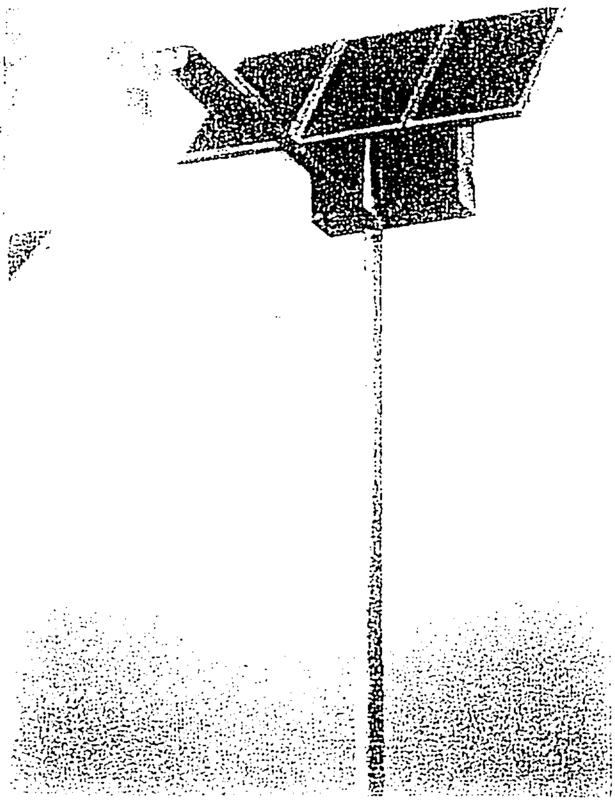
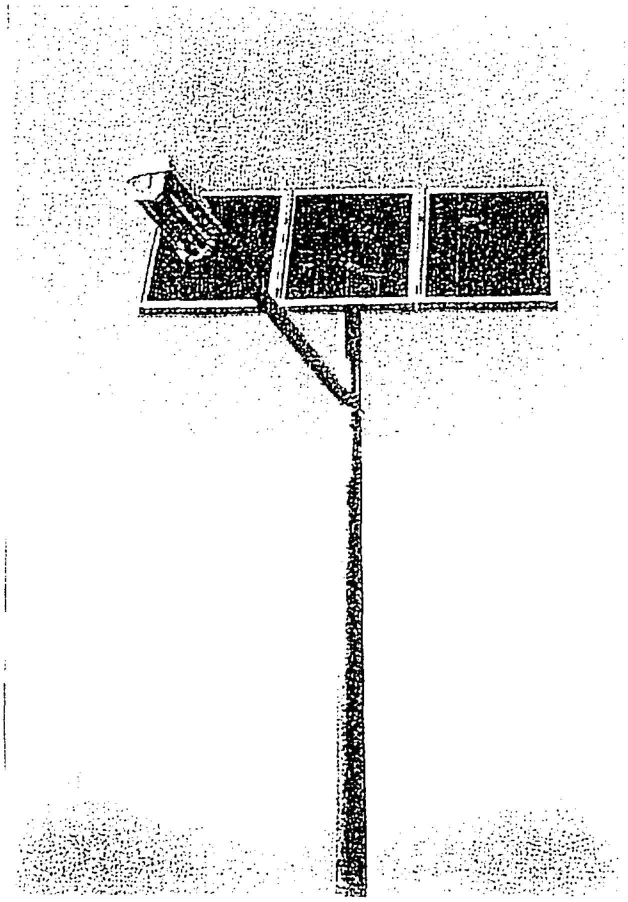
# LAMPIONE STRADALE AD ENERGIA FOTOVOLTAICA
# *CANDELABRE A ENERGIE SOLAIRE*
# PV STREET LIGHTING POLE

Eni GROUP



- Batteria in sommità del palo
- *Batterie dans la sommet du poteau*
- Battery at the top of the pole



- Batteria contenuta nel basamento del palo
- *Batterie dans la base du poteau*
- Battery at the bottom of the pole

| DESCRIZIONE<br>*DESCRIPTION*<br>DESCRIPTION | CARATTERISTICHE TECNICHE<br>*CARACTERISTIQUES TECNHNIQUES*<br>TECHNICAL CHARACTERISTICS | | | | |
|---|---|---|---|---|---|
| Identificazione - *Identification* - Identification | **LP1** | **LP2** | **LP3** | **LP4** | **LP5** |
| **MODULI FV (quantità - potenza di picco)**<br>*MODULES PV* (quantity - peak power)<br>PV MODULES (quantité - puissance de crête) | 1 x 72Wp | 2 x 55Wp | 2 x 72Wp | 3 x 55Wp | 3 x 72Wp |
| **BATTERIA (tensione - capacità a C100)**<br>*BATTERIE* (tension - capacité à C100)<br>BATTERY (voltage - capacity at C100) | 12 V - 75 Ah | 12 V - 100 Ah | 12 V - 150 Ah | 12 V - 200 Ah | 12 V - 250 Ah |
| **POTENZA DELLA LAMPADA AL SODIO**<br>*PUISSANCE DE LA LAMPE AU SODIUM*<br>SODIUM LAMP POWER | 18 W | 18 W | 27 W | 27 W | 27 W |
| **FLUSSO LUMINOSO (lumen)**<br>*FLUX LUMINEUX (lumen)*<br>LUMINOUS FLUX (lumen) | 1800 | 1800 | 3700 | 3700 | 3700 |
| **ORE DI FUNZIONAMENTO ( h )**<br>*HEURES DE FONCTIONNEMENT ( h )*<br>OPERATING TIME ( h ) | 4 - 10 | 7 - 14 | 6 - 12 | 8 - 14 | 10 - 16 |
| **GIORNI DI AUTONOMIA**<br>*JOURS D'AUTONOMIE*<br>DAYS OF AUTONOMOUS OPERATION | 10 - 4 | 4 - 8 | 4 - 10 | 5 - 9 | 5 - 9 |

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Tel. +39 - 6 - 98560.1 - Fax +39 - 6 - 9850267 - 98560234 / e-mail: eurosolare@eurosolare.agip.it

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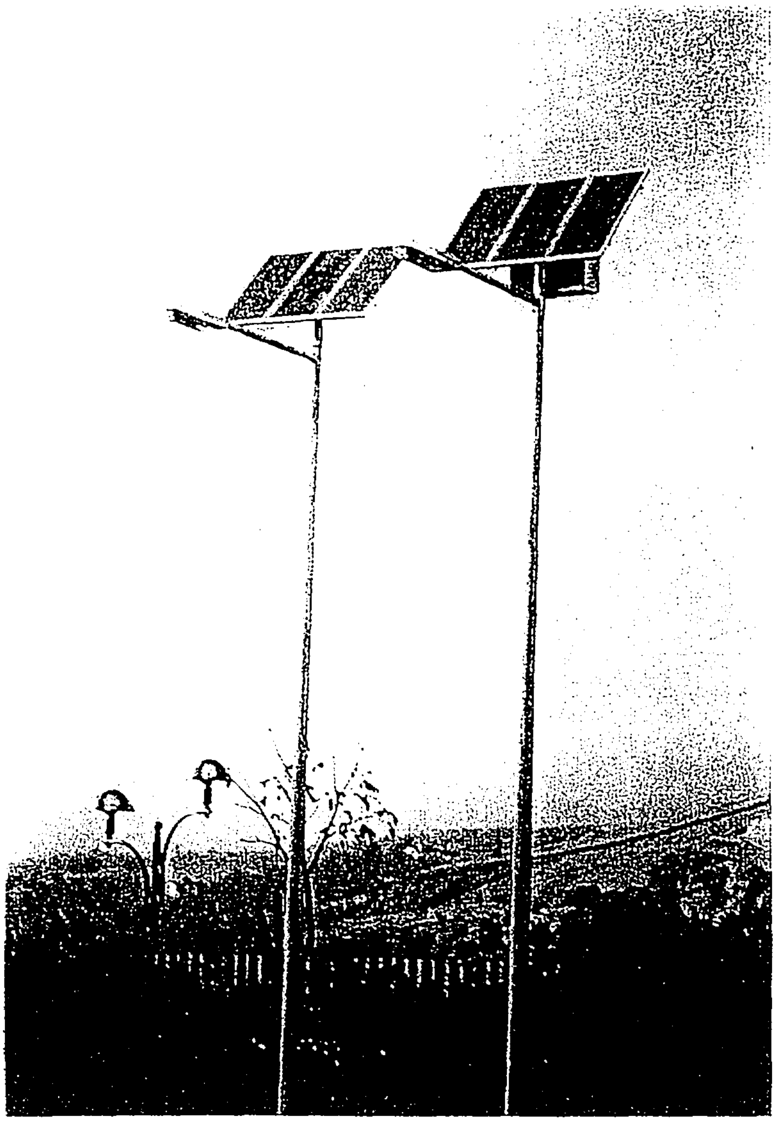
# LAMPIONE STRADALE AD ENERGIA FOTOVOLTAICA
## *CANDELABRE A ENERGIE SOLAIRE*
## PV STREET LIGHTING POLE



Questo tipo di sistema costituisce una scelta economica ed efficiente per l'illuminazione stradale.
L'elevato illuminamento prodotto dalla lampada utilizzata (vapori di sodio a bassa pressione), la semplicità di installazione e la ridotta manutenzione, sono alcuni dei principali vantaggi offerti.
E' disponibile in più versioni:

- lampada da 18 W o da 26 W
- batteria in sommità del palo
- batteria contenuta nel basamento
- autonomia in assenza di sole: da 3 a 15 giorni

*Ce système represente un choix économique et efficace pour l'éclairage routier.*
*Les avantages principaux sont: haut degré d'éclairement produit par la lamp utilisée (vapeur de sodium à basse pression), simple installation et reduite entretien.*
*Il est produit dans les suivantes versions:*

- *lampe de 18 W ou 26 W*
- *batterie dans la sommet du poteau*
- *batterie dans la base du poteau*
- *autonomie de fonctionnement pour no-sun: de 3 à 15 jours*

This system is an efficient and economical solution for street lighting.
Some of advantages are high brightness of the lamp used (low pressure and sodium vapors) and easy installation and maintenance.
It is available in different versions:

- 18 W or 26 W lamp
- Battery at the top of the pole
- Battery at the bottom of the pole
- Autonomy operation in no-sun conditions: from 3 to 15 days

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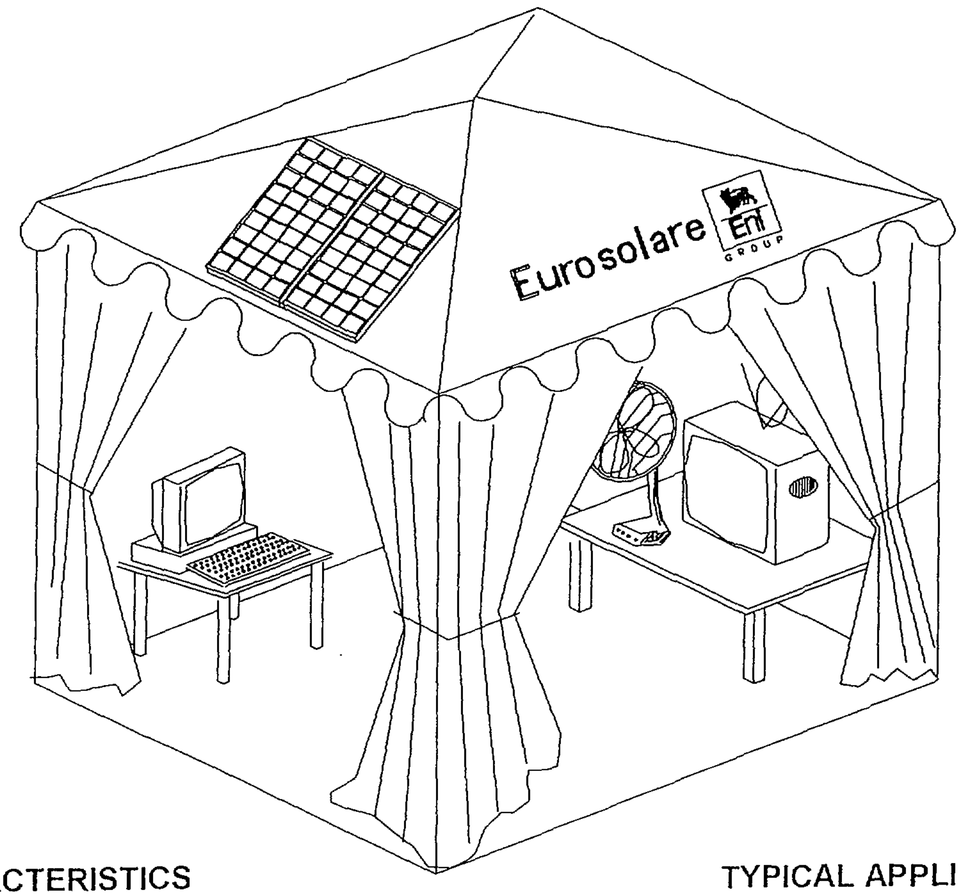
# GAZEBO




## L CARACTERISTICS

generator of 130 Wp
ɘled aluminium supporting structure (dimensions : 3 x 3 x 2,5 m)
ȷer control unit
ıance battery, 12 V 240 Ah, with enclosure

## TYPICAL APPLICATIONS

- Portable computer
- Fan
- Fluorescent lamp
- Small refrigerator
- TV color, radio and tape recorder

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# ***Japan***

*Networking of PV systems and applications*

NEDO

# Present Status of PV Development in Japan

April 2000

Hideji OSAWA
Solar Energy Department
NEDO,Japan
New Energy and Industrial Technology Development Organization

NEDO

## Outline

1. National policy
2. NEDO's Role
3. Photovoltaic R&D
4. International Cooperation Projects
5. Budgetary Measures

# Total Primary Energy Supply Outlook in Japan

as of June 1998

| Item | FY | 1990 | | 1996 | | 2010 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Case1 | | Case2 | |
| Item | Unit | Qty | % | Qty | % | Qty | % | Qty | % |
| Oil | mill.kl | 307 | 58.4% | 329 | 55.2% | 358 | 51.6% | 291 | 47.2% |
| Oil(Except LPG | mill.kl | 288 | 54.8% | 310 | 51.9% | 337 | 48.6% | 271 | 44.0% |
| LPG | mill.t | 14.3 | 2.7% | 15.2 | 3.3% | 16.1 | 3.0% | 15.1 | 3.2% |
| Coal | mill.t | 115.3 | 17.0% | 131.6 | 16.4% | 145 | 15.4% | 124 | 14.9% |
| Natural Gas | mill.t | 37.9 | 10.0% | 48.2 | 11.4% | 60.9 | 12.3% | 57 | 13.0% |
| Nuclear | bill.kWh | 202 | 9.4% | 302 | 12.3% | 480 | 15.4% | 480 | 17.4% |
| | mill.kWh | 31.5 | | 42.5 | | 66-70 | | 66-70 | |
| Hydro | bill.kWh | 91 | 4.2% | 82 | 3.4% | 105 | 3.4% | 105 | 3.8% |
| Geothermal | mill.kl | 0.5 | 0.1% | 1.2 | 0.2% | 3.8 | 0.5% | 3.8 | 0.6% |
| New Energy | mill.kl | 6.7 | 1.3% | 6.8 | 1.1% | 9.4 | 1.3% | 19.1 | 3.1% |
| Total Supply | mill.kl | 526 | 100% | | 100% | 693 | 100% | 616 | 100% |

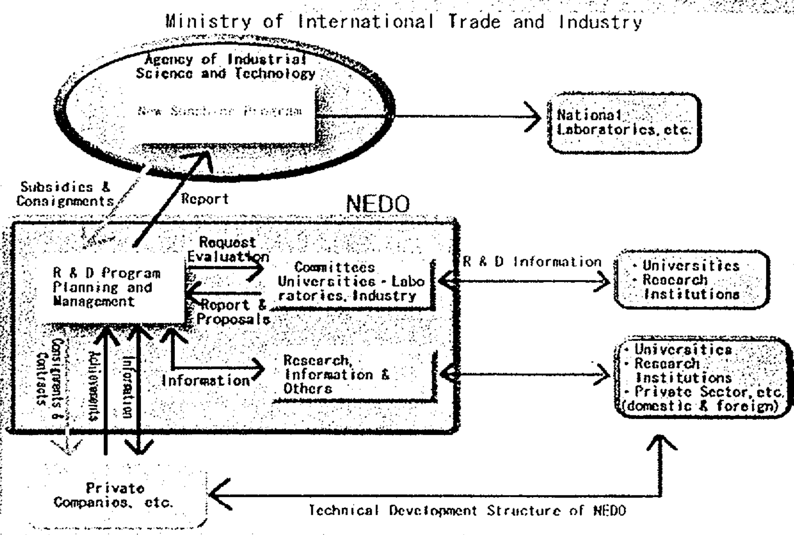
NOTES: 1. Converted to crude oil equivalent at a rate of 9,250kcal/L.
2. New Energy Sources include solar energy, black liquids (pulp liquids), firewood and other renewable resources
3. LNG is converted to tons at a rate of 0.712 ton/kl.
4. The sum total of the figures does not necessarily amount to 100 due to rounding.
5. Given that economic/energy situations are likely to continue to be dynamic, the figures shown here approximat

# Total New Energy Supply Outlook in Japan

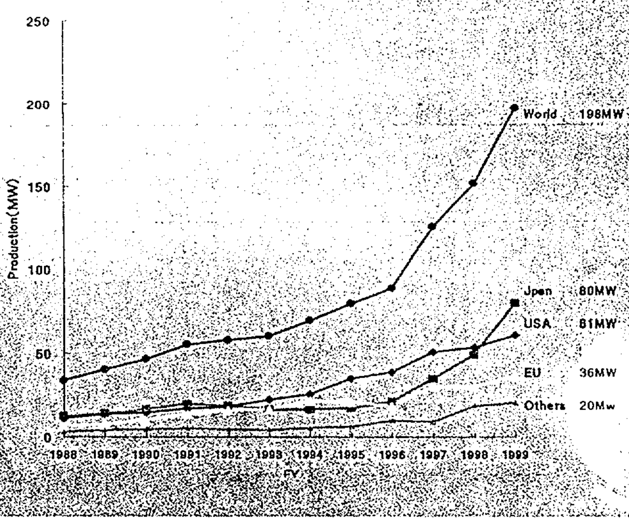
as of June 1998

| Item | FY | 1990 | 1996 | 2010 | |
|---|---|---|---|---|---|
| | | | | Case1 | Case2 |
| Item | Unit | Qty | Qty | Qty | Qty |
| Photovoltaic | MW | 9 | 57 | 230 | 5000 |
| | mill.kl | (0.002) | (0.014) | (0.060) | (1.220) |
| Solar Thermal Energy | mill.kl | 1.26 | 1.04 | 1.09 | 4.5 |
| Wind Power | MW | 3 | 14 | 40 | 300 |
| | mill.kl | (0.001) | (0.006) | (0.020) | (0.125) |
| Waste combination | MW | 480 | 890 | 2130 | 5000 |
| | mill.kl | (0.440) | (0.820) | (2.820) | (6.600) |
| Heat from solid waste | mill.kl | 0.037 | 0.044 | 0.12 | 0.14 |
| Temperature difference Energy | mill.kl | 0.018 | 0.033 | 0.09 | 0.58 |
| Heat from liquid waste | mill.kl | 5.03 | 4.9 | 5.17 | 5.92 |
| Total Supply | mill.kl | 6.79 | 6.85 | 9.4 | 19.1 |
| (Primary Power supply) | | | 1.1% | 1.3% | 3.1% |

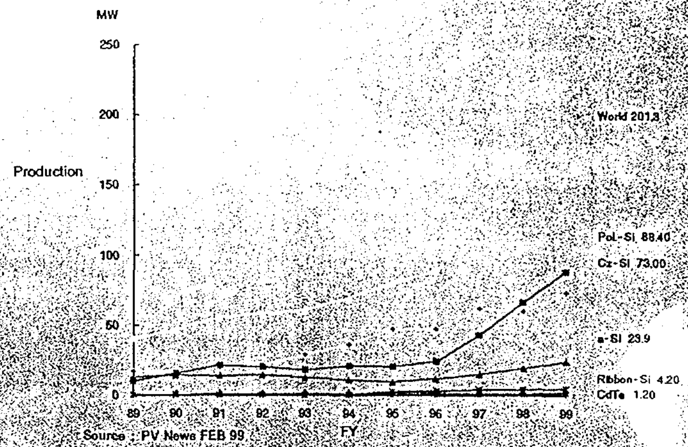
## R&D System in NEDO




## World PV Module/Cell Production



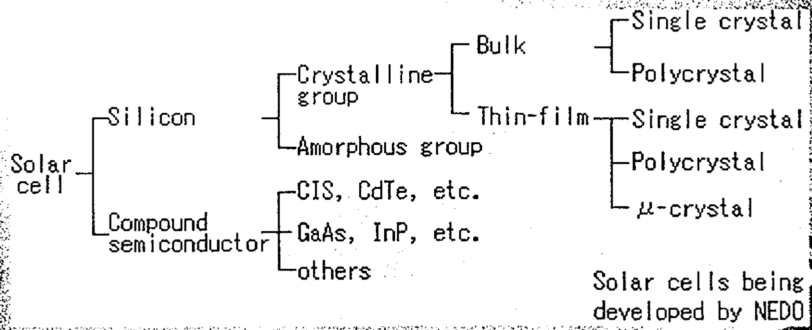
## World PV Module/Cell Productin




## PV Target

- USA: President Clinton's
  "Million Solar Roofs" Program
  Solar hot water & PV by 2010
- EU : 1997 White paper
  500,000PV Systems by 2010
  for EU & Developing country
- Japan : 5GW by FY2010

## Categories of Solar Cell

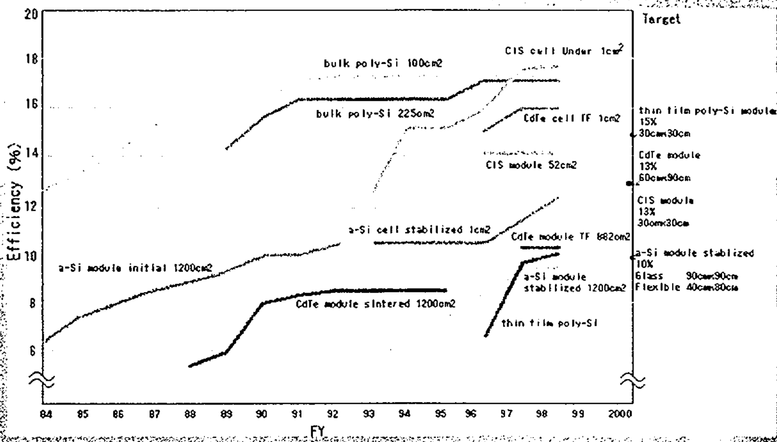



## Long-term R&D Plan for PV in New Sunshine Program

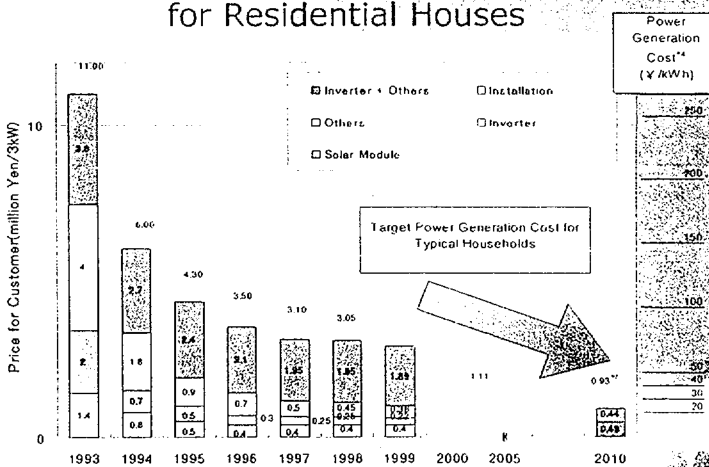
◆Duration:1993-2010
1st phase:1993-2000
2nd phase:2001-2010

◆Milestone:Establishing Economic Competitiveness in the Residential Sector

# Conversion Efficiency improvement in NSS Program




# Average Price of 3kW PV System for Residential Houses




Notes:

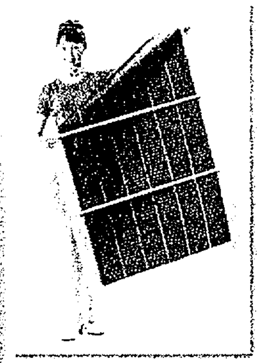
1. The above figures were calculated by averaging the costs of several different companies.
2. Cost target of the New Sunshine Program [In the case of production amount of 100MW, incl. management cost]
3. It usually takes a few years to start production operations after completing R&D projects.
4. Calculations

Irradiation (annual) 1,400kWh/m², Interest 3.0%, Durability 20 years,
Maintenance cost (annual) 1.0%, System efficiency 75%

## R&D Program

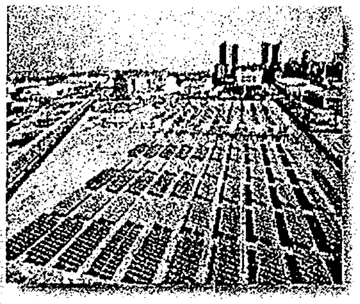
- Cell / Module
- System Technology
- Solar - grade Si Manufacturing

## Solar Cells

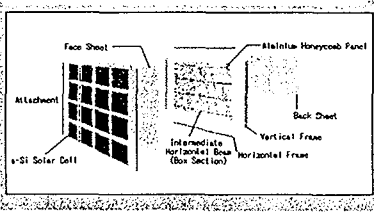


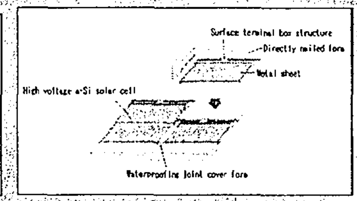
1. a-Si glass substrate
2. a-Si flexible
3. CdTe
4. CIS
5. a-Si/Thin film poly-Si hybrid solar cell
6. Super high-efficiency solar cell

## Photovoltaic Power Generation System Technology

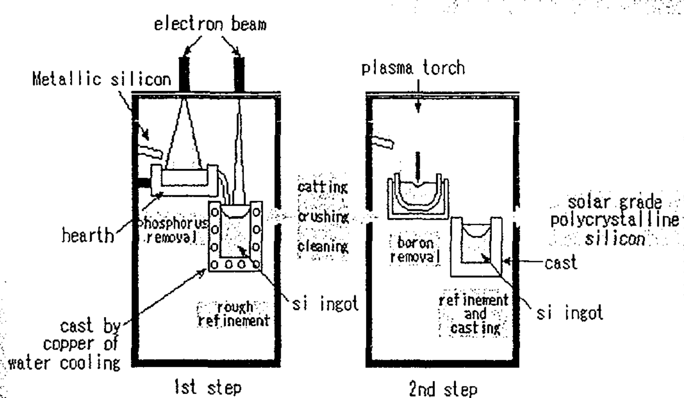


- System Evaluation
- Application & BOS
- Demonstrative Reserch on PV Systems




## Development of Solar Grade Silicon Production Process



International Cooperation Project
for PV R&D in NEDO

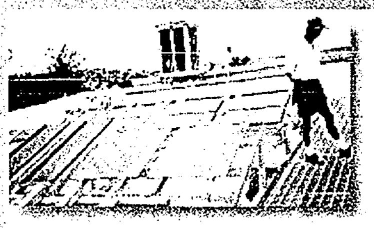
1. International cooperation project

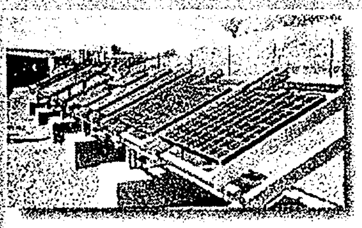
2. International cooperration Demonstration project for PV generation system

3. International Reserch Cooperation Projects

**Solar Cell Exposure Test Site in Oman & Alice Springs**

Alice Springs



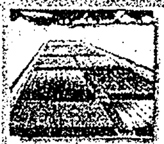


Oman

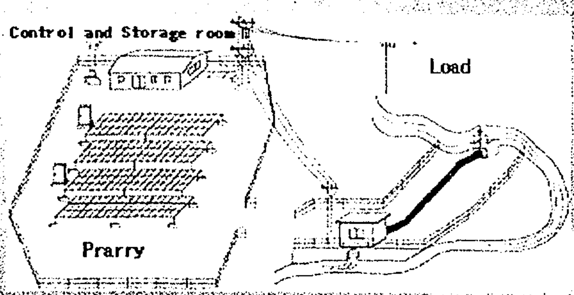
# International Enegy Agency(IEA) / PVPS

IEA/Photovoltaic Power Systems

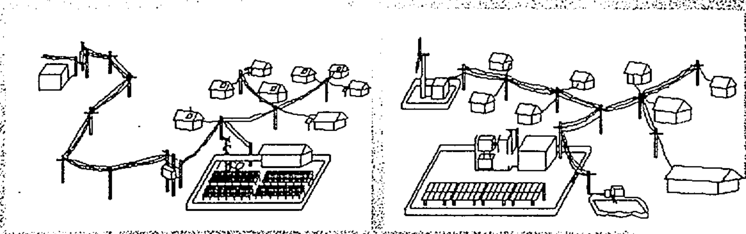
| | | |
|---|---|---|
| Task I | Exchange and dissemination of information on PV power system | 1998- |
| Task II | Operational performance and design of photovoltaic systems and subsystems | 98-2002 |
| Task III | Use of photovoltaic power systems in stand-alone and island applications | 99-2003 |
| Task IV | Modelling of distributed photovoltaic power generation in support of the electric grid | No activity |
| Task V | Grid interconnection of building intergrated and other dispersed photovoltaic power systems | 1998-2001 |
| Task VI | Design and operation of modular photovoltaic plants for large-scale power generation | completed in 1997 |
| Task VII | Photovoltaic power systems in the built environment | 1997-2001 |
| Task VIII | Very large scale photovoltaic power generation systems in remote area | taskVI-5 in 1998 taskVIII for 1999-2001 |
| Task IX | Deployment of photovoltaic technologies in cooperation with developing countries | 1999-2004 |

# Demonstrative Research on a Hybrid System of Photovoltaic Power Generation and Micro-hydropower Generation
# (Electricity of Vietnam, Socialist Republic of Vietnam

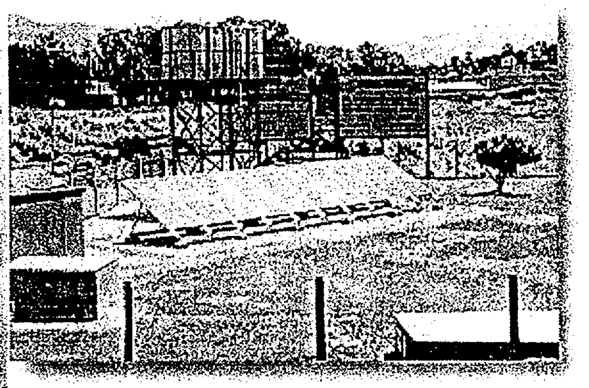


## Demonstrative Research on a Grid-connected Photovoltaic Power Generation System (Thailand/Myanmar)

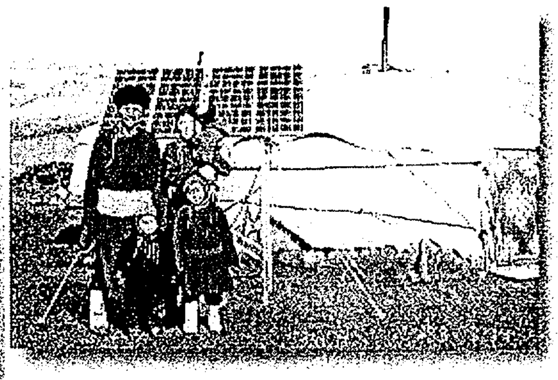


## Accelerated Demonstrative Research Utilizing Highland Weather Conditions

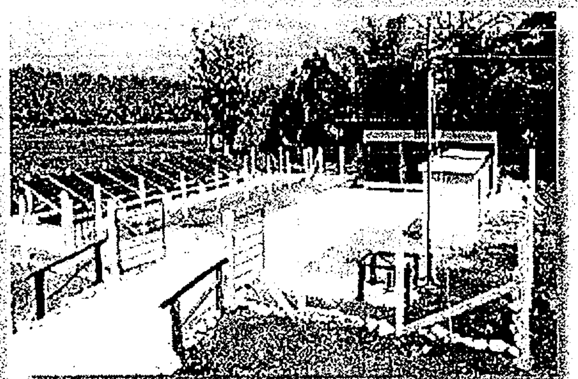
(Royal Nepal Academy of Science & Technology, Nepal)

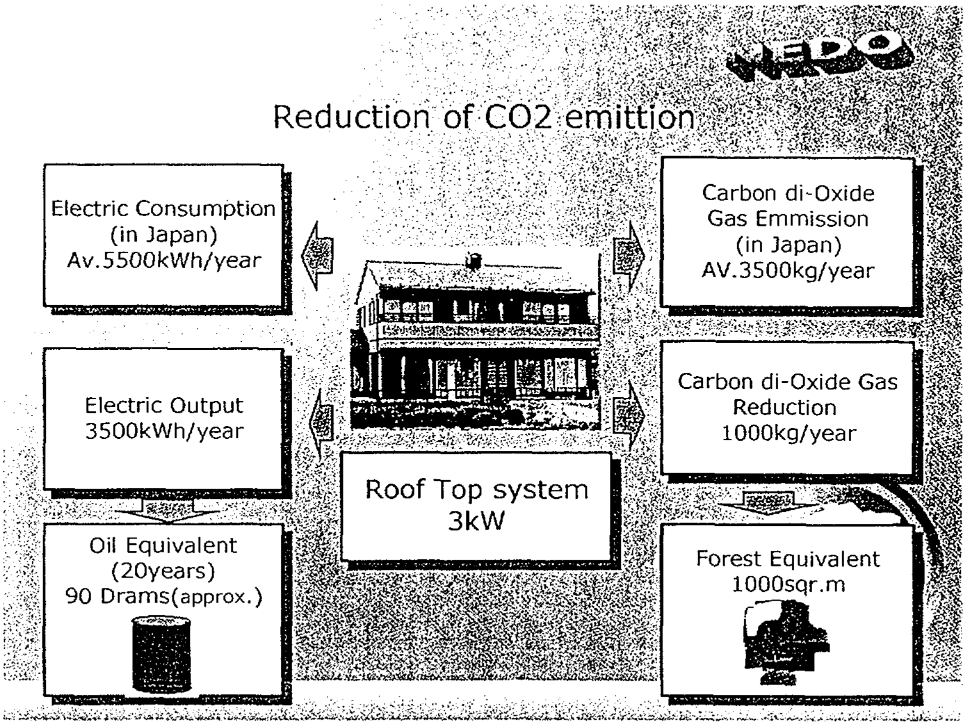


Demonstrative Research on Portable Photovoltaic Power Generation Systems
(Ministry of Fuel and Energy, Mongolia)



Demonstrative Research on a Photovoltaic Power Generation System for Battery Charging Stations
(Department of Energy Development and Promotion, Thailand)





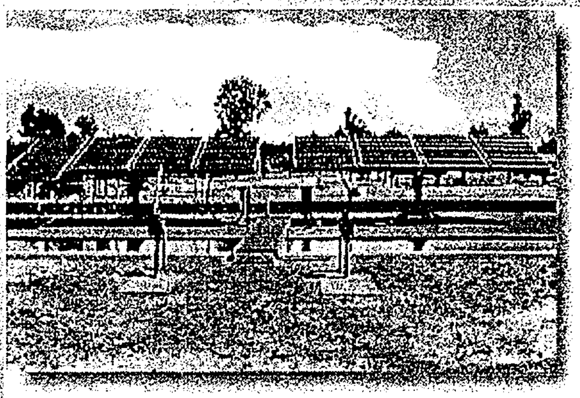

## Budgetary Measures

2000FY

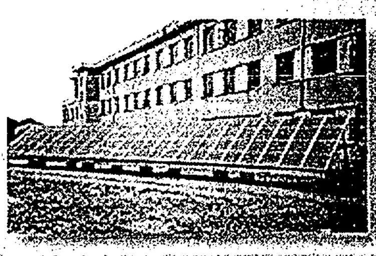
| | |
|---|---|
| R&D | 7.41 billion yen |
| SOG | 0.53 billion yen |
| PV promotion type R&D | 1.27 billion yen |
| total | 9.21 billion yen |

## Accelerated Demonstrative Research under Tropical Conditions

(Ministry of Energy, Telecommunications and Posts, Malaysia)

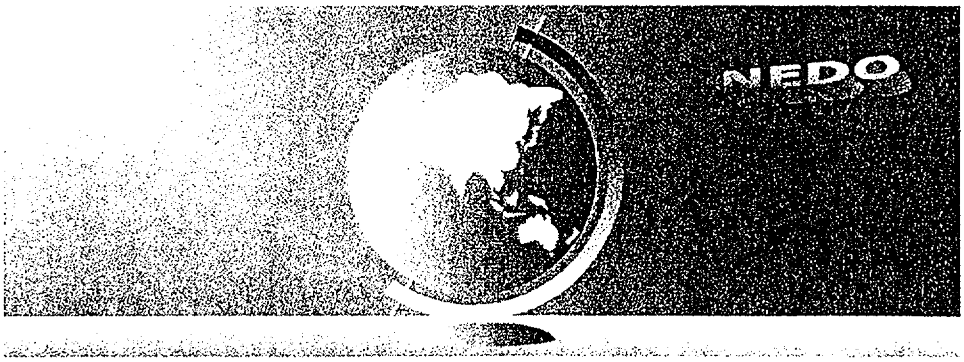


## R&D Cooperation in Practical Application of Locally-oriented Photovoltaic Power Generation Systems



Jiangde County, Ningxia Hui Autonomous Region, Shatang Secondary School

Lamu Township, Lasa City Tibet Autonomous Region Lamu Township Wangua Primary School




More information:

http://www.nedo.go.jp/
taiyo/eng/intro/index.htm

E-mail : osawahdj@nedo.go.jp
qtai@nedo.go.jp

# 太陽・風力エネルギー利用技術
# Solar and Wind Energy Utilization Technology

新エネルギー・産業技術総合開発機構
New Energy and Industrial Technology Development Organization (NEDO)
太陽技術開発室
Solar Energy Department

# はじめに

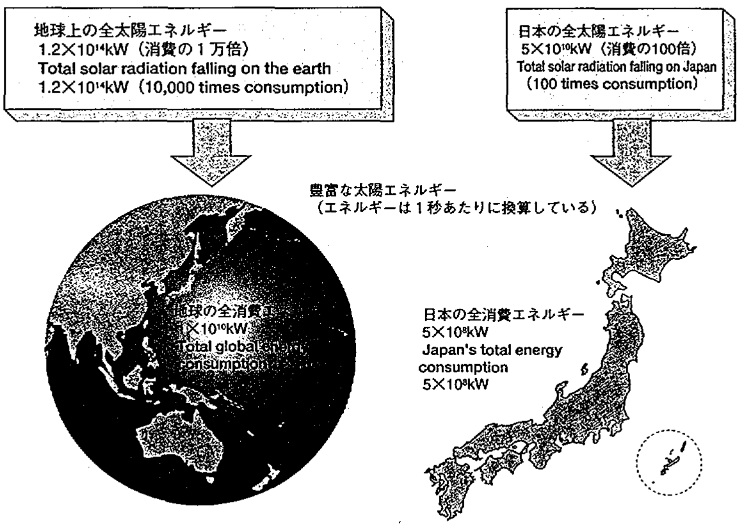
この広大な地球に降り注ぐ太陽の光は、太陽が放つエネルギーの二十二億分の一といわれていますが、そのエネルギーは1時間分だけでも世界中で一年間に使用するエネルギーに匹敵します。

私達は、この光を様々な形で利用しようとしています。太陽エネルギーを光または熱として比較的大規模に直接利用するものには、太陽光発電、太陽熱発電が例としてあげられます。また、風力発電や水力発電、波力発電などは、自然エネルギーを間接利用した例といえます。

# Preface

Scientists estimate that the radiation falling on the earth is only 1/2.2 billionth of the energy that the sun emits. Yet just one hour of the energy that the earth receives is equal to the total amount of energy consumed by humans in one year.

Solar radiation can be utilized in various forms. Examples of direct utilization on a comparatively large scale include photovoltaic and solar heat power generation. Wind, hydroelectric and wave power generation can be considered examples of energy.




**■太陽エネルギーの利用**
**Utilization of Solar Energy**

直接利用 Direct Utilization

- 太陽光 Light
  - 太陽光発電 Photovoltaic Generation
  - 光化学反応（水素） Photochemical Hydrogen
- 太陽熱 Heat
  - 温水器（給湯）
  - ソーラー（熱供給冷暖房） Solar Thermal Application
  - 熱蒸留（淡水化） Heat Distillation
  - その他 others

間接利用 Indirect Utilization

- 風力 Wind
  - 風力発電 Wind Power Generation
  - 波力発電 Wave Power
- 水 Water
  - 波力発電 Wave Power
  - 水力 Hydroelectric Power
- 光合成 Photosynthesis
  - バイオマス Biomass
  - 人工光合成 Artificial Photosynthesis

# 太陽エネルギーの特徴

### ・クリーンであること

化石燃料の燃焼には、炭酸ガスや二酸化窒素などのガスの発生が伴います。これらのガスが地球環境に少なからず影響を及ぼします。太陽エネルギーは、このガスの発生がなく、極めて清浄です。

### ・無限であること

地球上の資源は、利用できる量に限りがあります。例えば、石油の可採年数は43年、石炭174年、天然ガス56年、ウラン66年といわれています。

しかし、太陽エネルギーは永久的に存在します。

一方、太陽エネルギーを実際に利用する場合は、次の点が特徴としてあげられます。これは、同時に技術開発の課題となっています。

### ・変動が激しいこと

日射量は、気候や毎日の天候によっても大きく変動します。

### ・密度が低いこと

地球に降り注ぐエネルギー量は、膨大であっても、1㎡あたり1kWと密度は低いのです。

# Characteristics of Solar Energy

### ・Clean

The combustion of fossil fuels results in the production of gases such as carbon dioxide and nitrogen dioxide. These gases have a significant influence on the earth's environment. Solar energy utilization, however, produces very little exhaust gas and is very clean.

### ・Infinite

Many resources on earth exist in limited amounts. For example, it is estimated that petroleum will be exploitable for another 43 years, coal for 174 years, natural gas for 56 years, and uranium for 66 years. Solar energy, however, will exist virtually forever.

To achieve the practical utilization of solar energy, the following characteristics must be considered. They present a significant challenge to technological development.

### ・Wide fluctuation

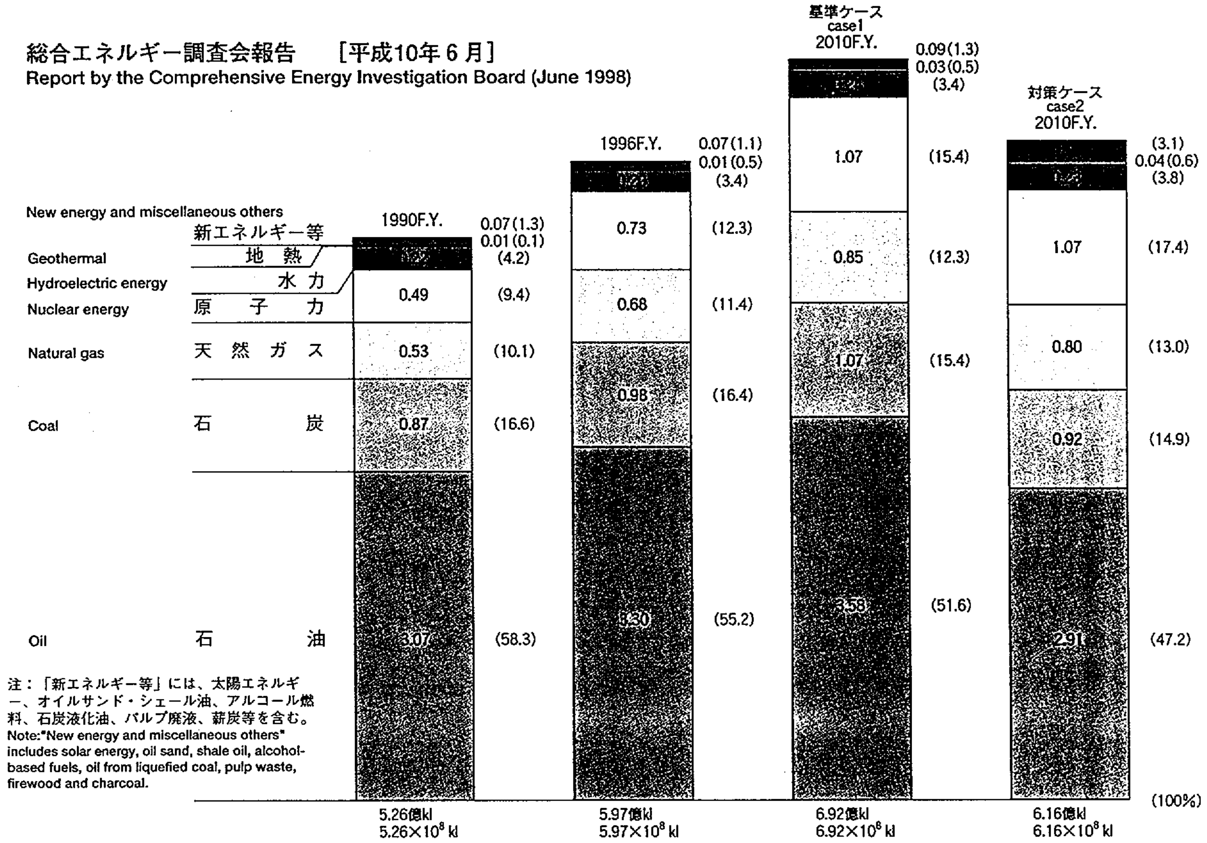
Insolation varies greatly according to climate and day-to-day weather.

### ・Low density

Although the amount of energy falling to earth is vast, its density is 1 kW/m², lower than would be expected.

## ■長期エネルギー需給見通し

### 総合エネルギー調査会報告　[平成10年6月]
Report by the Comprehensive Energy Investigation Board (June 1998)




注：「新エネルギー等」には、太陽エネルギー、オイルサンド・シェール油、アルコール燃料、石炭液化油、パルプ廃液、薪炭等を含む。
Note:"New energy and miscellaneous others" includes solar energy, oil sand, shale oil, alcohol-based fuels, oil from liquefied coal, pulp waste, firewood and charcoal.

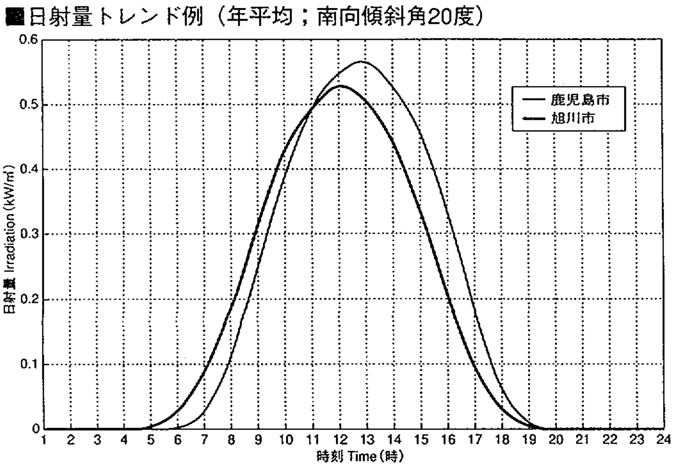
（単位）（Unit）
新エネルギー等　New energy and miscellaneous others ……100万kl 1 million kl
石炭　Coal ……100万t 1 million t
地熱　Geothermal ……100万kl, 1 million kl
水力　Hydroelectric energy ……1億kWh 1×10⁸kWh
天然ガス　Natural gas ……100万t, 1 million t
原子力　Nuclear energy ……1億kWh 1×10⁸kWh
石油　Oil ……100万kl, 1 million kl
原油換算は、9,250kcal/lによる
Rate of conversion into crude oil is 9,250kcal/l

## ■新エネルギー等の供給の見通し

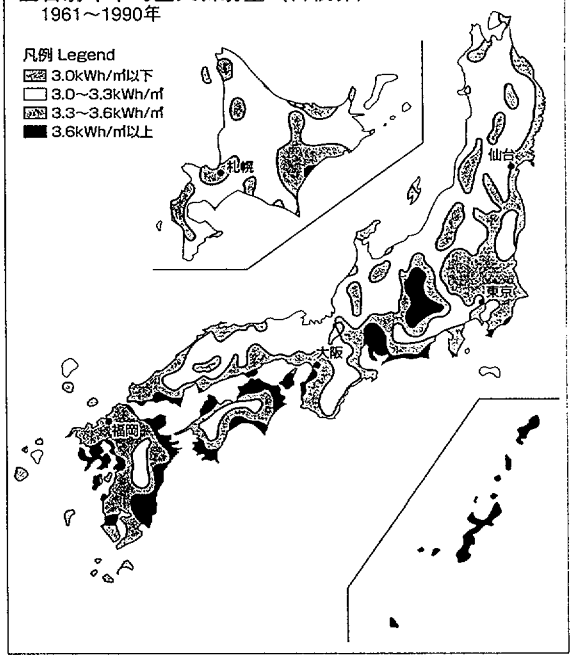
1998年6月

| 年度(FY) 項目(Item) | | 単位 unit | 1990 | 1996 | 2010 基準ケース CASE1 | 2010 対策ケース CASE2 |
|---|---|---|---|---|---|---|
| 太陽光発電 | Photovoltaic | MW | 9 | 57 | 230 | 5000 |
| | | mill.kl | (0.002) | (0.014) | (0.060) | (1.220) |
| 太陽熱利用 | Solar thermal energy | mill.kl | 1.260 | 1.040 | 1.090 | 4.500 |
| 風力発電 | Wind power | MW | 3 | 14 | 40 | 300 |
| | | mill.kl | (0.001) | (0.006) | (0.020) | (0.125) |
| 廃棄物発電 | Waste combustion | MW | 480 | 890 | 2130 | 5000 |
| | | mill.kl | (0.440) | (0.820) | (2.820) | (6.620) |
| 廃棄物熱利用 | Heart from solid waste | mill.kl | 0.037 | 0.044 | 0.120 | 0.140 |
| 温度差エネルギー等 | Temperature difference energy | mill.kl | 0.018 | 0.033 | 0.090 | 0.058 |
| 黒液、廃材等 | Hert from liquid waste | mill.kl | 5.030 | 4.900 | 5.170 | 5.920 |
| 合計 | Total | mill.kl | 6.79 | 6.85 | 9.40 | 19.10 |
| (一次エネルギー総供給に占める割合) | | | | | | |
| Primary power supply | | | | (1.1%) | (1.3%) | (3.1%) |

## ■日射量トレンド例（年平均；南向傾斜角20度）




## ■日射年平均全天日射量（日積算）
1961～1990年



# NEDO

NEDO（新エネルギー・産業技術総合開発機構）は、日本経済の石油に対する依存度の軽減を図ることを目的に、昭和55年10月に設立されました。
以来、我が国石油代替エネルギー技術開発の中核的推進母体として、各界、各方面の支援を受けながら、その責務を果すべく努力しています。
具体的には、太陽エネルギーを始めとして、地熱エネルギー、燃料・貯蔵、アルコールバイオマスエネルギー等に関する技術開発を推進しています。

# ニューサンシャイン計画

NEDOの太陽技術開発室では、太陽エネルギーに関する技術開発である「ニューサンシャイン計画」という国の基本方針の管理下で技術開発を推進しています。

## ニューサンシャイン計画とは

これまで通産省では、オイルショックを契機に我が国のエネルギー問題の解決を図るための長期的・総合的な新エネルギー技術開発計画として、昭和49年に「サンシャイン計画」をスタートさせました。また、省エネルギー技術については、昭和53年に「ムーンライト計画」を、平成元年度からは地球環境技術に係る研究開発制度を発足させました。

これらの新エネルギー、省エネルギー、地球環境問題を三位一体として連携を図り効率的に解決するため、平成5年度に「ニューサンシャイン計画」を発足させ、持続的成長とエネルギー・環境問題の同時解決を目指した革新的技術開発を開始しました。

# Introduction

The New Energy and Industrial Technology Development Organization (NEDO) was established in October 1980 with the aim of reducing the dependence of the Japanese economy on oil. Since its establishment, NEDO has endeavored to promote the development of oil-alternative energy such as solar, geothermal and biomass energy.

# New Sunshine Program

Technological development in Japan related to solar energy is being implemented under the direction of a national plan called the "New Sunshine Program".

## The New Sunshine Program is:

The Ministry of International Trade and Industry (MITI) launched the "Sunshine Project," a long-term comprehensive plan for the research and development of new energy technologies, in 1974. The goal of the Sunshine Project was to resolve Japan's energy difficulties which emerged after the oil crisis. The "Moonlight Project" was subsequently established in 1978 for energy conservation, and a research and development system focusing on global environment technologies was initiated in 1989.

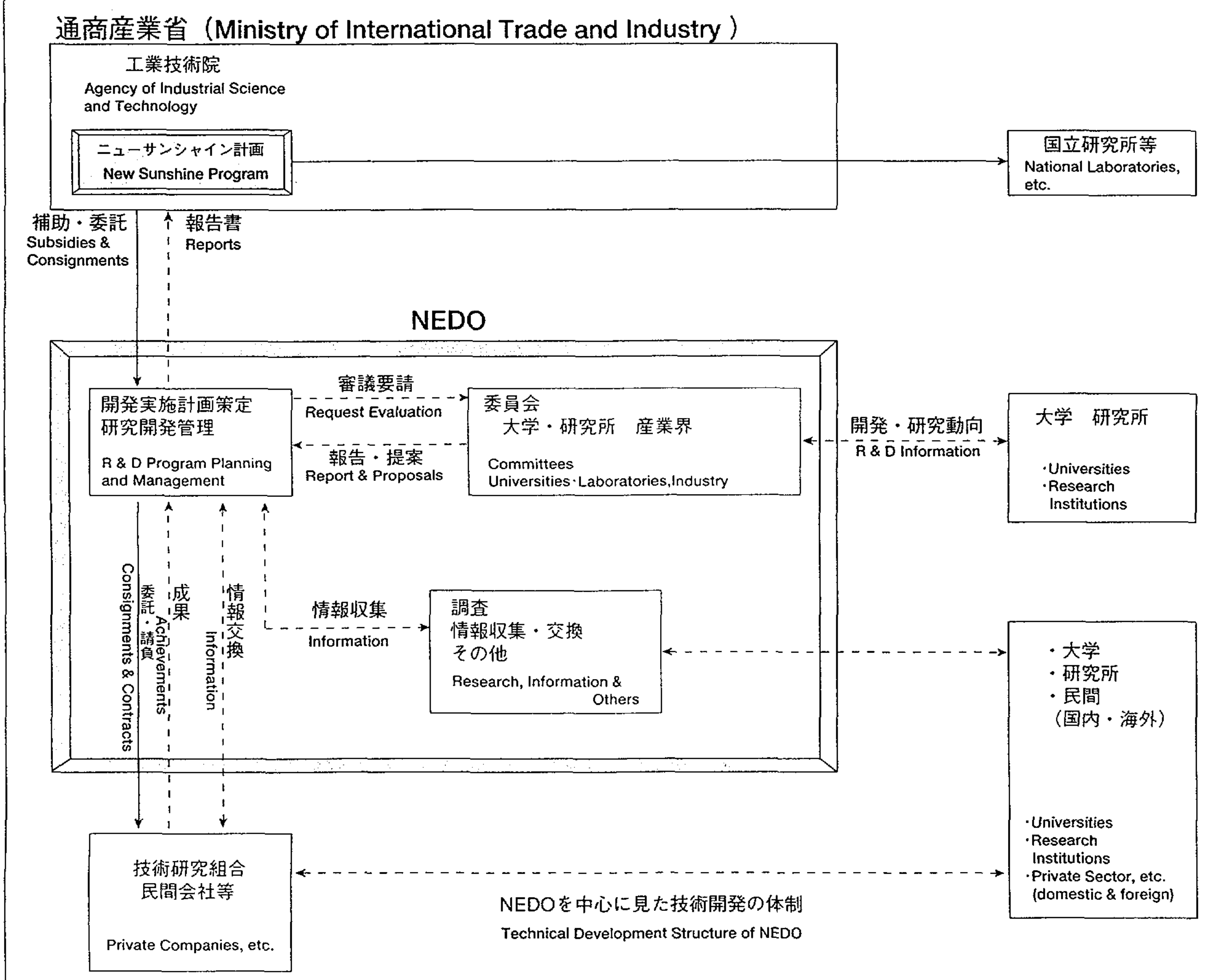
In 1993, as a way to efficiently overcome barriers related to new energy, energy conservation and global environment protection, a new innovative technological development project called the "New Sunshine Program" was started in order to address all related issues in a coordinated manner. This new program aims at sustainable growth and the resolution of energy and environmental problems.

# ニューサンシャイン計画における太陽エネルギー技術開発の概要

1. 太陽光発電システム実用化技術開発
   a．太陽電池製造技術
   b．太陽光発電システム技術
2. 産業用等ソーラーシステム実用化技術開発
3. 離島用風力発電システム等技術開発
4. 海外事業

# Solar Energy Technology for the New Sunshine Program

1. Development of technology for the practical application of photovoltaic power generation systems
   a. Manufacturing technology for solar cells
   b. Photovoltaic power generation system technology
2. Development of solar energy system technology for industrial use, etc.
3. Development of Advanced wind Turbine Systems for Isolated islands
4. Intenational cooperation, projects and program.




NEDOを中心に見た技術開発の体制
Technical Development Structure of NEDO

# 太陽電池の原理とは？

## 電子の動きがつくる新エネルギー

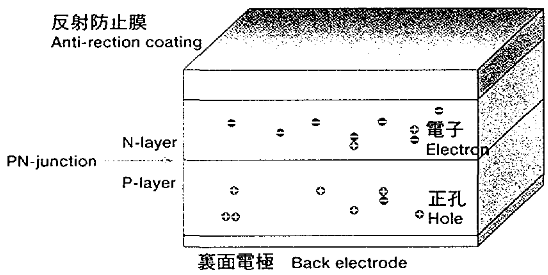
太陽の光がどうして電気に変わるかですが、太陽光には"光子"というエネルギーの粒子が含まれています。この光子は太陽電池内の半導体の電子に自分のエネルギーを与えて活性状態をつくります。光子の刺激で力がついた電子は、自分をつなぎとめていた原子の力を振り切って、自由に動きまわれる場所に飛び出します。こうして電子が動き始めると電流が流れ、結果として電気が生まれたことになるわけです。電子が集まって飛び出していく電極がマイナス、反対側がプラス極となり、電線をつなぐと、電球がつくのです。

# What is the Theory of Solar Cells?

## New Energy Created by the Motion of Electrons

Why can sunlight be converted to electricity? Solar radiation contains elementary particles of energy called "photons." Photons cause the excitation state in the semiconductor of solar cells by giving energy to electrons. The excited electron powered by a photon severs its bond with an atom and jumps to a place where it can move freely. Thus electrons start travelling and an electric current flows, and as a result, electricity is generated. The electrode to which electons gather and run out from is negative polarity, and the opposite electrode is positive polarity. If both electrodes are connected with wire, a light bulb can be illuminated.

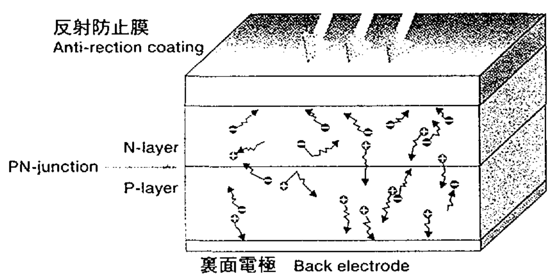
(1)




代表的な結晶シリコン太陽電池はシリコンにボロン（ホウ素）をほんの少し添加したｐ型シリコン半導体をベースに、この表面にリンを拡散してｎ型シリコン半導体の層（ｎ層）を作ってあり、ｐ型とｎ型の境目近傍をｐｎ接合と呼んでいます。このｐｎ接合部には電界（電位勾配）ができます。

Based on a P-type silicon semiconductor laced with boron, the layer of a N-type silicon semiconductor or N-layer is made by diffusing phosphorus on its surface. This is called a PN junction semiconductor.

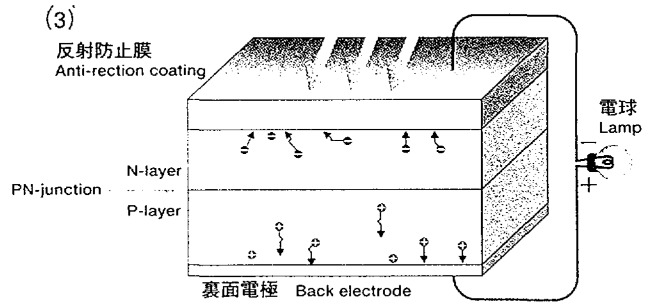
(2)




この太陽電池に太陽光があたると、電子が励起されて半導体内を自由に動きまわれる状態になります。この自由に動きまわれる状態の電子のうち、ｐｎ接合部の電界（電位勾配）に進入した電子は負の電荷を持っているために、電界との相互作用により正に帯電しているｎ型側に流れ込みます。同様に電子が励起されることによってできた正の電荷を持つ正孔は負に帯電しているｐ型側に流れ込みます。

When the cell is exposed to light, the free electrons and holes within the semicoductor become active. Continued stimulation causes the free electrons and holes to reach a state where they can move freely. The free electrons move to the N-layer, and the holes in the P-layer attempt to enter the N-layer across the PN junction.

(3)




ｐ型とｎ型の表面に電極を取り付けて、流れ込んできた電子および正孔を外部回路に流すことにより、太陽電池が発電した電流が流れることになります。こうして太陽光があたり続ける限り、太陽光のエネルギーは電気エネルギーに変換され続けるのです。
これが、太陽電池による発電の原理です。

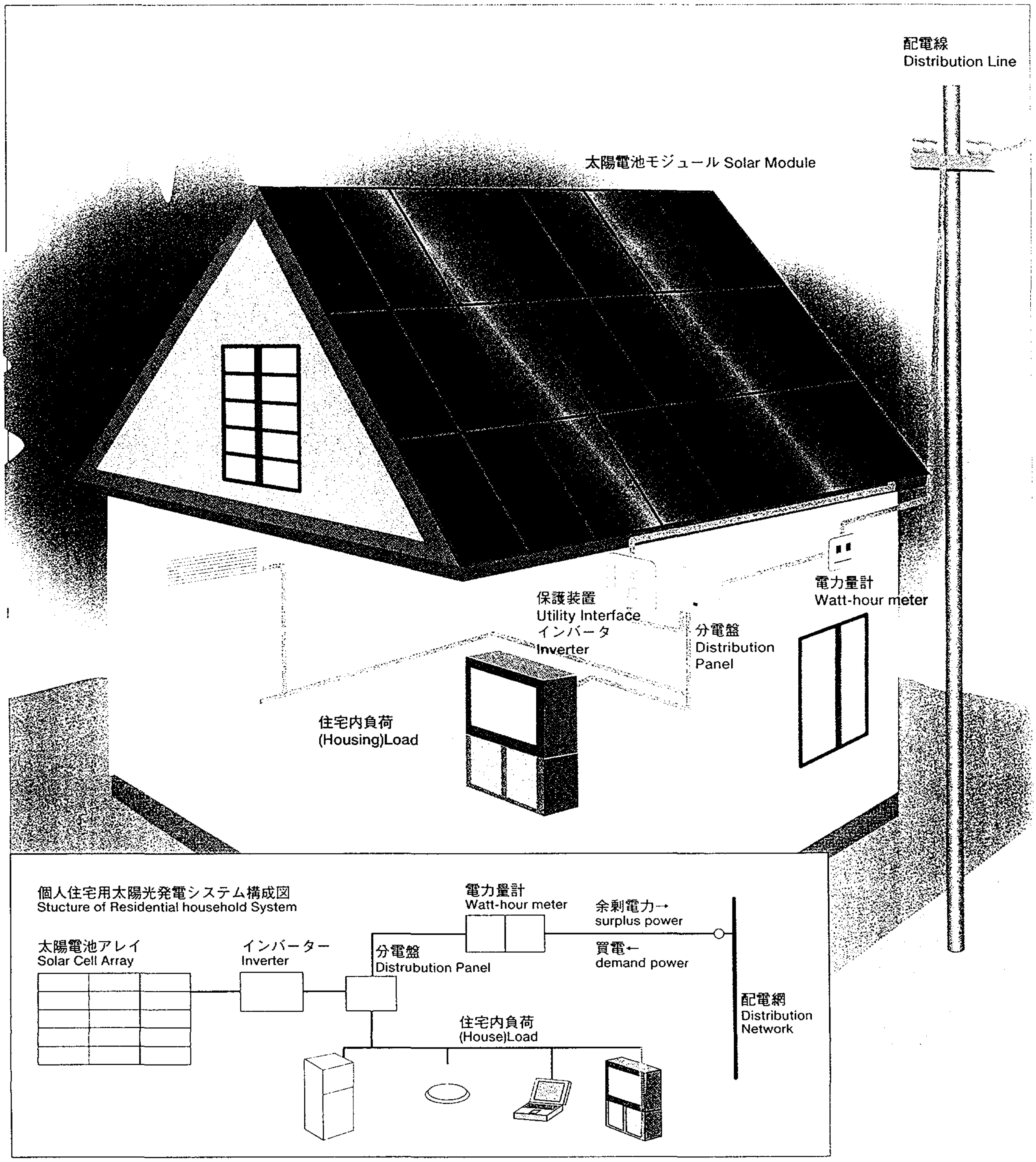
If this state continues, a light-induced free electron reaches the N-layer electrode and similarly a free hole reaches the P-layer electrode. Thus electric current flows through the circuit. As long as sunlight is provided, the light energy continues to be converted to electric energy. This is the basic principle of solar photovoltaic power generation using a solar cell.

# 太陽光発電システムとは？

太陽光発電は、光を受けると直流電力を発生する太陽電池を利用した新しい発電方式で、一般的には、下図の様なシステムを構成しています。
このような太陽光発電システムの実用化開発を促進するため、いっそうの高効率・低コスト化を目指した太陽電池製造技術開発および総合的なシステム技術の開発に取り組んでいます。

# What is a Photovoltaic Power Generation System?

Photovoltaic power generation utilizes solar cells and sunlight to produce direct current electricity. A typical configuration of a photovoltaic system is shown in the picture below. In order to promote the practical application of such systems, the development of solar cell manufacturing techniques and comprehensive system techniques are being implemented, aiming at higher efficiency and lower cost.



# 太陽電池製造技術
# Solar Cell Production Technology

ニューサンシャインプログラムでは、太陽電池のモジュールコストを2000年初頭に100～200円／Wpまで下げる目標を設定しています。

太陽電池は、現在でも電卓や通信用電源さらには照明標識にと数多くの分野で小規模電源として使われています。これは、高効率・低コスト化が進む一方、太陽電池の利便性が広く認識されているからです。それは、次に示すような生産量の推移にはっきりと現われています。

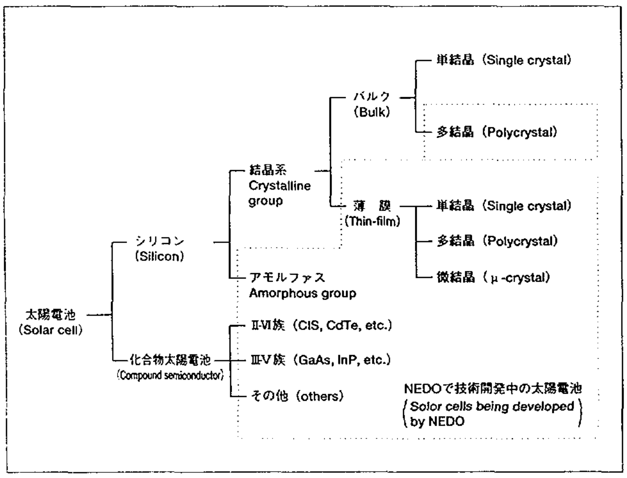
また、日本の電池の生産量は世界全体でも大きなシェアを占めています。

The New Sunshine Program has the objective of reducing the cost of solar cell modules to ¥100-200/Wp by 2000.

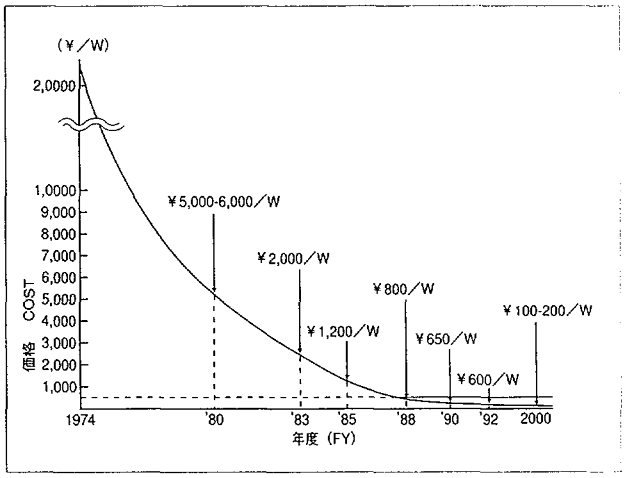
Solar cells are now used as a small electric power source in many applications such as pocket calculators, telecommunications and light beacons. This is because they have become known for their convenience of use, as well as their high efficiency and low cost. This is shown clearly by the growth in production illustrated below.

Japan accounts for a large portion of world solar cell production.

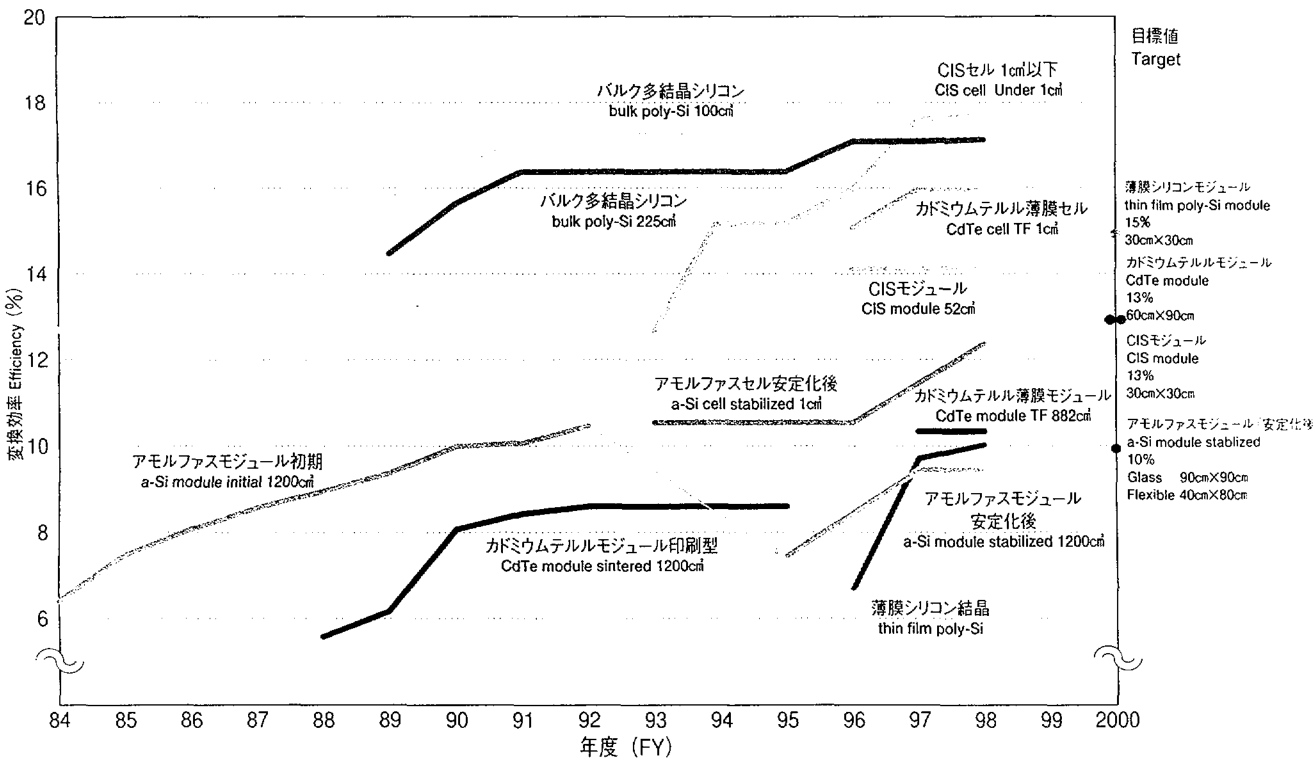
## ■太陽電池の種類
Categories of Solar Cells




## ■太陽電池の製造コストの推移及び今後の目標
Trend and Next Target for Solar Cell Module Cost

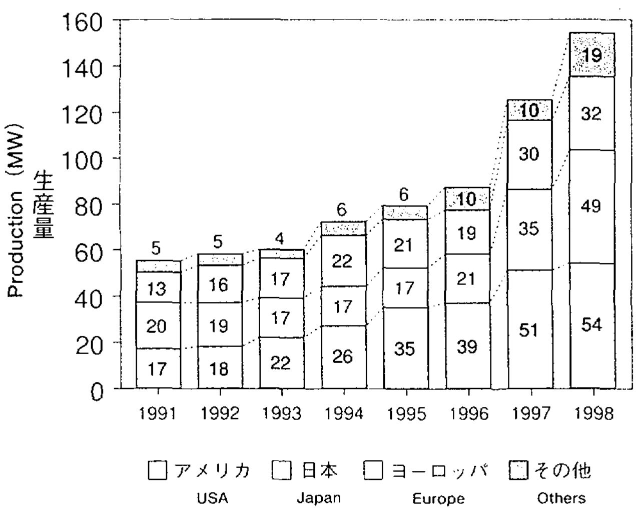



## ■変換効率の推移
Trend of Conversion Efficiency



■ 世界の太陽電池生産量

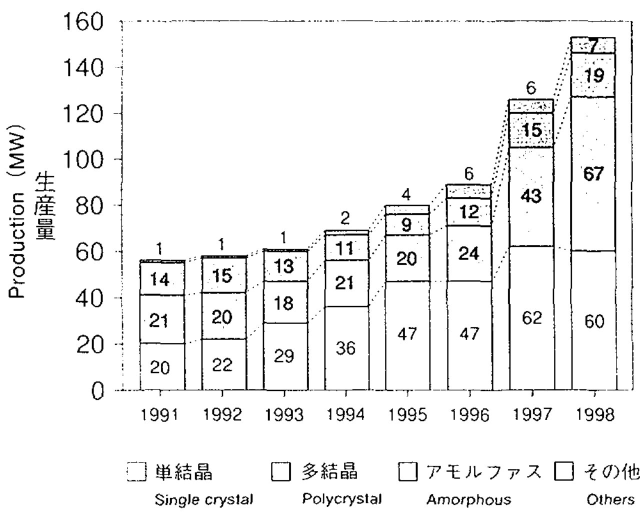
World Solar Cell Production by Region




出典 Source：PV news

■ 世界の種類別太陽電池生産量

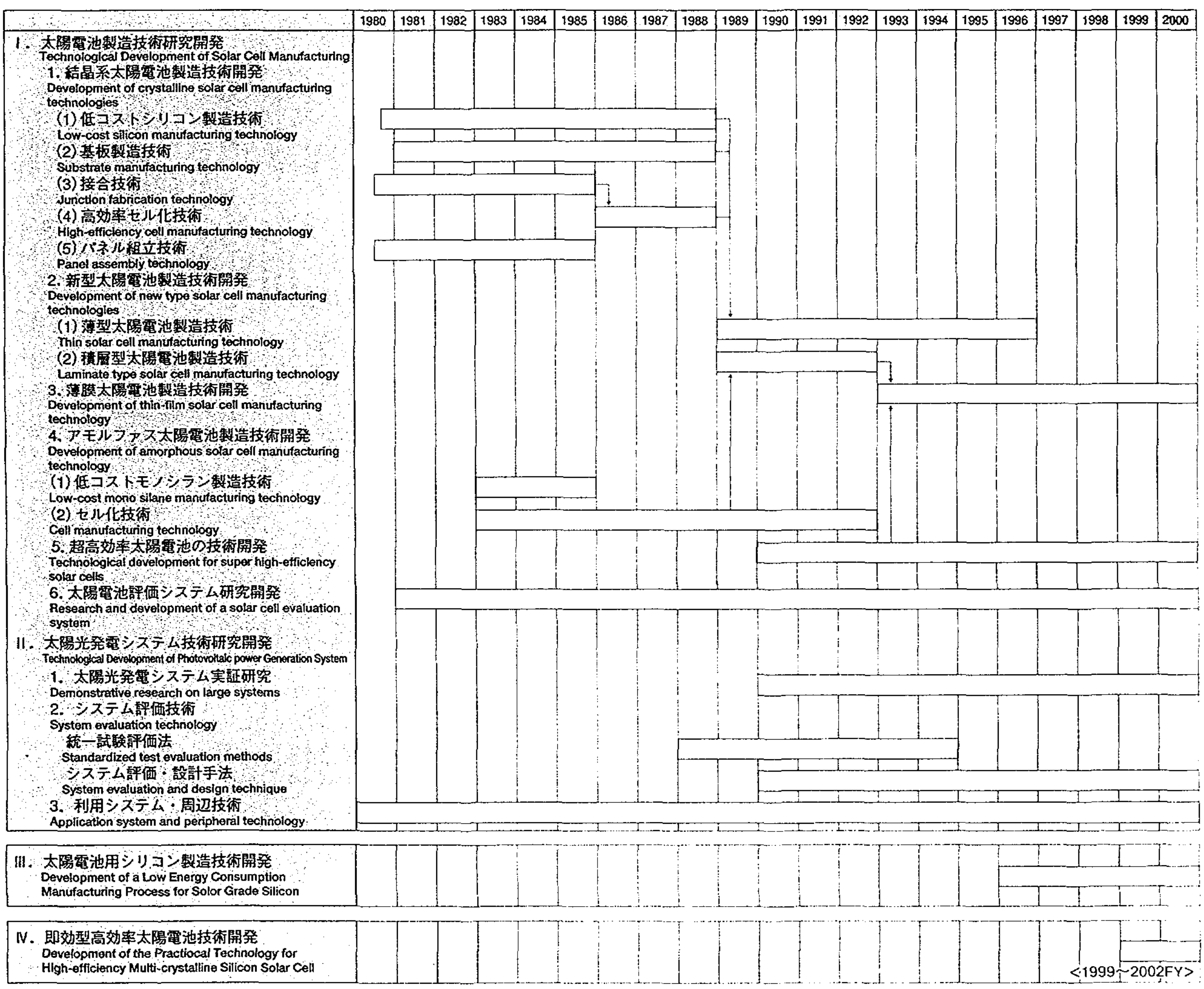
World Solar Cell Production by Type




出典 Source：PV news

■ 日本の太陽光発電技術開発スケジュール

Schedule for Technological Development of Photovoltaic Generation in Japan



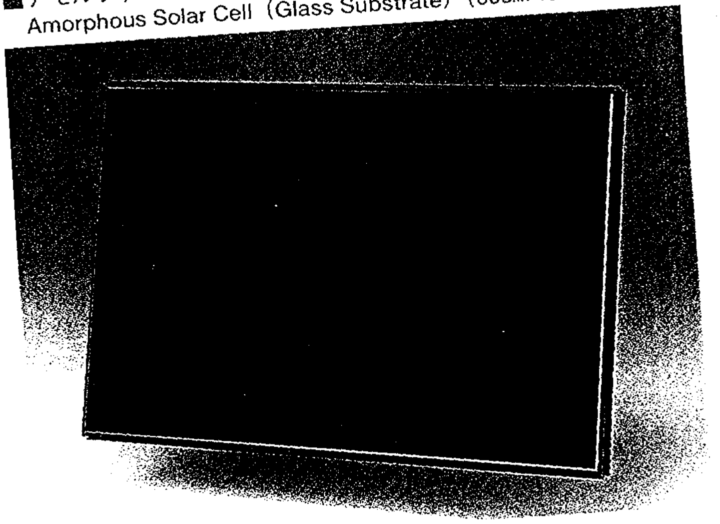
## ■ 薄膜太陽電池の技術開発目標
Objectives for the Technological Development of Thin-film Solar Cells

| 開発項目 Item | 2000年度開発目標 Objectives for 2000 |
|---|---|
| (1) 低コスト・大面積モジュールの製造技術開発<br>Technological development for the low-cost production of large-size modules | |
| ①新型アモルファス太陽電池モジュール製造技術開発<br>Development of manufacturing technologies for new amorphous solar cell modules | ・モジュールコスト Module cost：¥140/W（年産100MW）<br>(based on annual production at 100MW)<br>・安定化後変換効率：10%以上<br>Conversion efficiency after stabilization: 10%<br>・サイズ Size：<br>90cm×90cm（ガラス基板 Glass substrate）<br>40cm×80cm（フレキシブルタイプ Flexible type） |
| ②高信頼性CdTe太陽電池モジュールの製造技術開発<br>Development of manufacturing technology for highly reliable CdTe solar cell modules | ・モジュールコスト Module cost：¥140/W（年産100MW）<br>(based on annual production at 100MW)<br>・変換効率 Conversion efficiency：13%<br>・サイズ Size：60cm×90cm |
| ③次世代薄膜太陽電池モジュールの製造技術開発<br>Development of manufacturing technologies for next-generation thin-film solar cell modules | |
| (a) CIS太陽電池モジュールの製造技術開発<br>CIS solar cell module | ・モジュールコスト Module cost：¥140/W（年産100MW）<br>(based on annual production at 100MW)<br>・変換効率 Conversion efficiency：13%<br>・サイズ Size：30cm×30cm |
| (b) 薄膜多結晶シリコン太陽電池モジュールの製造技術開発<br>Thin-film polycrystalline solar cell modules | ・モジュールコスト Module cost：¥140/W（年産100MW）<br>(based on annual production at 100MW)<br>・変換効率 Conversion efficiency：15%<br>・サイズ Size：30cm×30cm |
| (c) 応用型太陽電池の製造技術開発<br>New structure application type thin-film solar cells | |
| (イ) アモルファス／薄膜多結晶シリコンハイブリッド製造太陽電池<br>Amorphous/thin-film polycrystalline silicon hybrid solar cell | ・変換効率 Conversion efficiency：14%<br>・サイズ Size：5cm×5cm |
| (ロ) 薄膜シリコン系ハイブリッド構造太陽電池<br>Thin-film silicon hybrid solar cell | ・変換効率 Conversion efficiency：16%<br>・サイズ Size：10cm×10cm |
| (ハ) マイクロ集光太陽電池<br>Concentrated type micro solar cell | ・変換効率 Conversion efficiency：15%<br>・サイズ：外接円直径2mm程度の微小セル<br>Size : Approx. 2mm in circumscribed circle diameter |
| (ニ) 新型単結晶シリコン太陽電池<br>New type single crystalline silicon solar cell | ・変換効率 Conversion efficiency：16%<br>・サイズ Size：10cm×10cm |
| (2) 材料・基板製造技術開発<br>Technological development for new materials and substrates | |
| ①アモルファス系高品質材料・基板の製造技術開発<br>Development of high-quality amorphous substrate manufacturing technologies | ・膜成長速度 Film growth rate：20Å/sec<br>・安定化後の欠陥密度：200万Siに1個程<br>Density of defects after stabilization: Approx. 1 in 2,000,000Si |
| ②シリコン結晶系高品質材料・基板の製造技術開発<br>Development of high-quality silicon substrate manufacturing technologies | ・膜成長速度 Film growth rate：10Å/sec<br>・欠陥密度：500万Siに1個程度<br>Defect density: Approx. 1 in 5,000,000 Si. |

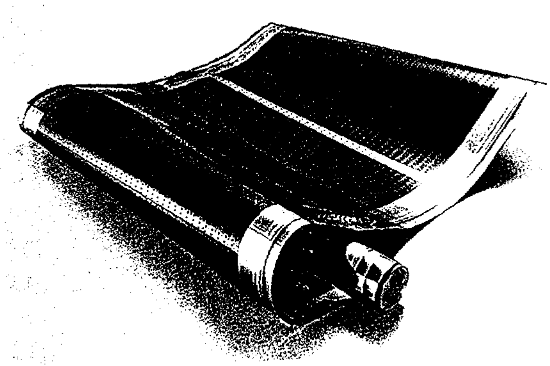
## ■ 超高効率太陽電池の技術開発目標
Objectives for the Technological Development of Super High-efficiency Solar Cells

| 開発項目 Item | 2000年度開発目標 Objectives for 2000 |
|---|---|
| 超高効率結晶化合物太陽電池の製造技術開発<br>Technological development of super high-efficiency crystalline compound solar cells | |
| ①大面積セルの製造技術開発<br>Development of manufacturing technologies for large-size solar cells | ・変換効率 Converson efficiency：30%（Ge基板 Ge substrate）<br>25%（Si基板 Si substrate）<br>・サイズ Size：5cm×5cm<br>・上記目標はメカニカルスタックを用いない構造の場合、メカニカルスタック構造の場合においては、上記目標を上回るセル効率。<br>The conversion efficiencies given above are for the non-mechanical stack structure type. A higher efficiency is targeted for the mechanical stack structure type. |

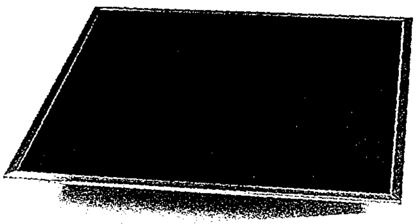
■アモルファスシリコン太陽電池（ガラス基板）
Amorphous Solar Cell（Glass Substrate）（60cm×90cm）



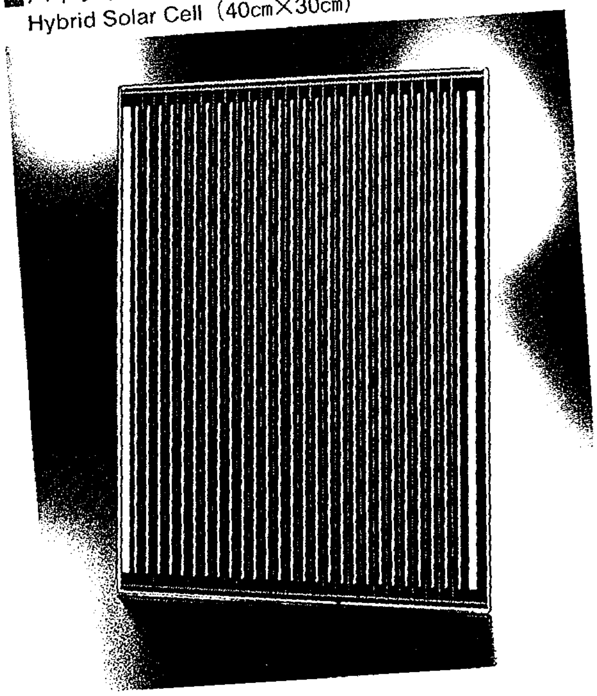
■アモルファスシリコン太陽電池（フレキシブル）
Amorphous Solar Cell（Flexible）（巾80cm）



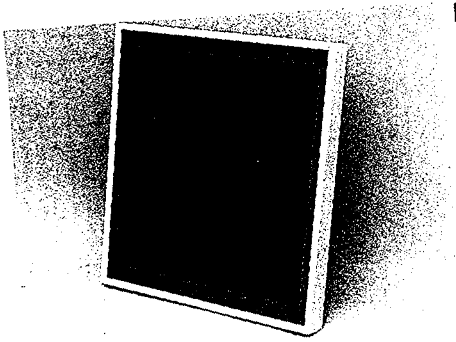
■CdTe太陽電池
CdTe Solar Cell
（80cm×70cm）



■ハイブリッド太陽電池
Hybrid Solar Cell（40cm×30cm）



■CIS太陽電池
CIS Solar Cell
（30cm×30cm）



## 1．薄膜太陽電池

平成9年度から薄膜太陽電池（アモルファスシリコン、CdTe、薄膜多結晶シリコン、CIS）の製造技術の開発を進めています。
アモルファスシリコン太陽電池ではガラス基板やフイルム基板の太陽電池について製造コストの低減、性能・信頼性の向上を目指し、一貫した製造プロセス（パターニング、製膜、モジュール化）に亘る連続的かつ高速に製造するための要素技術を開発しています。
また、製造コストの低減に大きく係る製膜速度の向上をはかるため、材料や基板技術からアプローチする基礎研究が同時に進められています。
結晶化合物太陽電池の一つであるCdTeやCISなどについても、太陽電池膜の光吸収性能が良いことから、薄膜で高性能な太陽電池が期待できるため、研究開発を進めてきました。

## 1. Thin-film Solar Cells

The technological development of thin-film solar cells. which include amorphous silicon, CdTe thin-film polycrystal silicon and CIS, has been underway since 1997.

Concerning amorphous solar cells, development of the element technologies necessary to achieve an integrated manufacturing process (patterning, film deposition and module fabrication) for the continuous and rapid production of glass substrate and film substrate versions is being conducted. The goal is to lower production cost and improve performance and reliability.

At the same time, basic studies aimed at further reducing costs by speeding up film deposition are being carried out chiefly on materials and substrate technology.

CdTe and CIS solar cells have a crystalline structure featuring a high light-absorption rate. By utilizing the merits of this feature, research and development on thin-film and high-performance solar cells can be accelerated effectively.

With the target of lowering CdTe cell production costs, CdTe太陽電池は、これまで得られた成果を活かし、低コスト化を図るため、変換効率の向上と、大面積形成技術の開発を進めており、具体的には太陽電池膜の厚みを数μm以下にして高性能化する技術の確立と、その太陽電池膜を60cm×90cmの面積に均一に形成する技術の開発を進めています。

CIS太陽電池については、引き続き高品質化、高効率化のための要素技術開発と、大面積形成技術の開発を進め、太陽電池生産技術としての確立を図っていきます。

薄膜多結晶太陽電池は、材料にシリコンウエハーを用いずに気相または液相でシリコン結晶を基板上に成長させてシリコン薄膜多結晶を形成し、シリコンの使用量が少なく、かつ、性能の安定したシリコン多結晶太陽電池の製作を目指しています。気相成長法は、これまでの成果を活かし、量産技術の確立のための研究をすすめており、新たな方式である、液相成長法では、その基礎技術の研究開発を進めています。

これらの太陽電池の応用型として、アモルファスシリコン太陽電池と薄膜多結晶太陽電池を組み合わせた太陽電池について、気相成長法による製造技術ならびに高効率化のための要素技術開発も進めています。

NEDO has been developing large-area film fabrication technology for enhancing the conversion efficiency rate. Specifically, technology for high-performance CdTe solar cells of only a couple μm thickness and equalizing the film deposition rate over a 60cm x 90cm area is being developed.

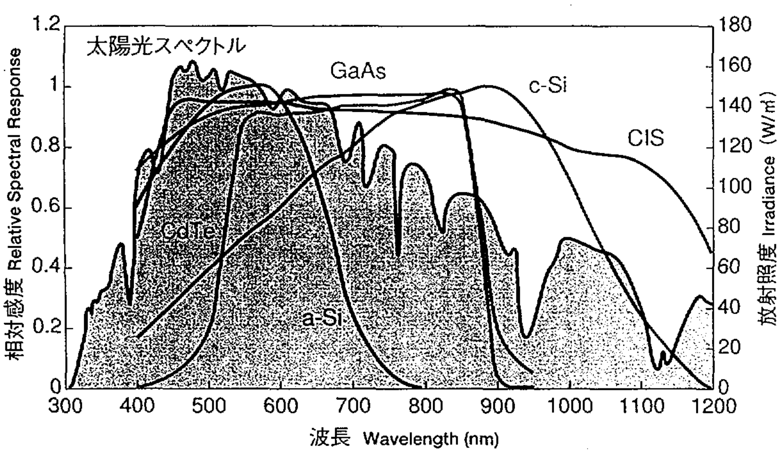
Regarding CIS solar cells, research and development has been carried out to establish basic technologies for improving quality and efficiency as well as large-area film fabrication technologies.

Regarding thin-film polycrystal solar cells, NEDO is focusing its efforts on optimizing the process for producing silicon thin-film polycrystal on substrate using silicon-deposition techniques such as vapor phase or liquidity phase. These techniques will realize a more stabilized condition. Also, these methods can be carried out using less silicon as compared with the silicon wafers application.

Based on previous results, research on mass production technology using the vapor phase silicon deposition method is under way. Basic studies on liquid phase silicon film deposition, a relatively new concept, are also being conducted.

Like the applied model, a solar cell combining amorphous silicon and thin-film poly-crystalline has been developed. Moreover, solar cell manufacturing technology with the Chemical Vapor Deposition Method, as well as factor technology to realize the high efficiency, has been continued.

**■図A：太陽電池の分光感度**
**Spectral Response Characteristics of Solar Cell**



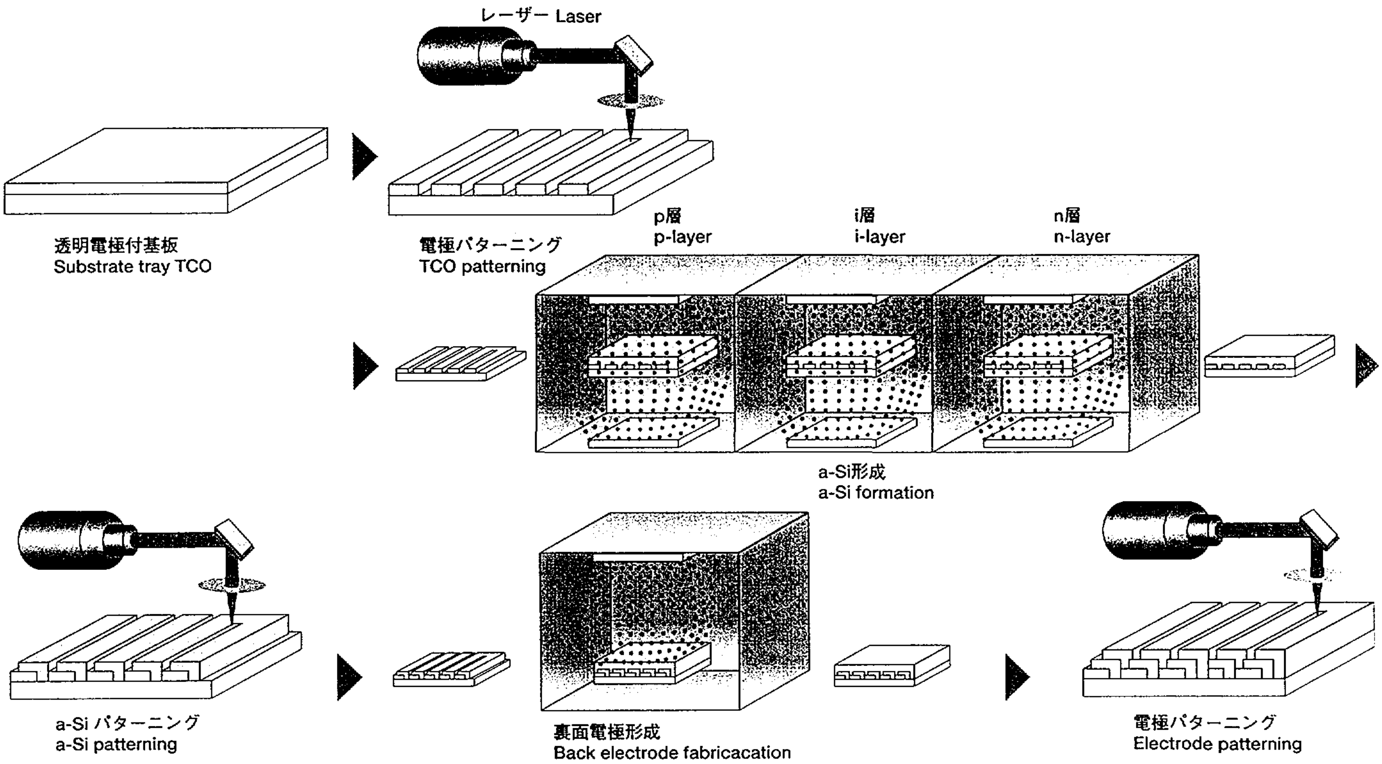

図Aは各種太陽電池の分光感度特性を示します。太陽電池は材料により吸収できる光の波長が異なります。このため、どの波長の光をどれだけ吸収できるかを分光感度特性として評価しています。GaAs、CdTe、CIS等の化合物半導体を用いた太陽電池は500nmから900nmの波長の光を充分に吸収できることから、高効率太陽電池として期待されています。また、a-Si太陽電池とc-Si太陽電池は、それぞれ短波長、長波長光の吸収に優れており、a-Siとc-Si太陽電池を組み合わせることで、より高効率の太陽電池が期待できます。

Diagram A shows the Spectral Response Characteristic of solar cells.

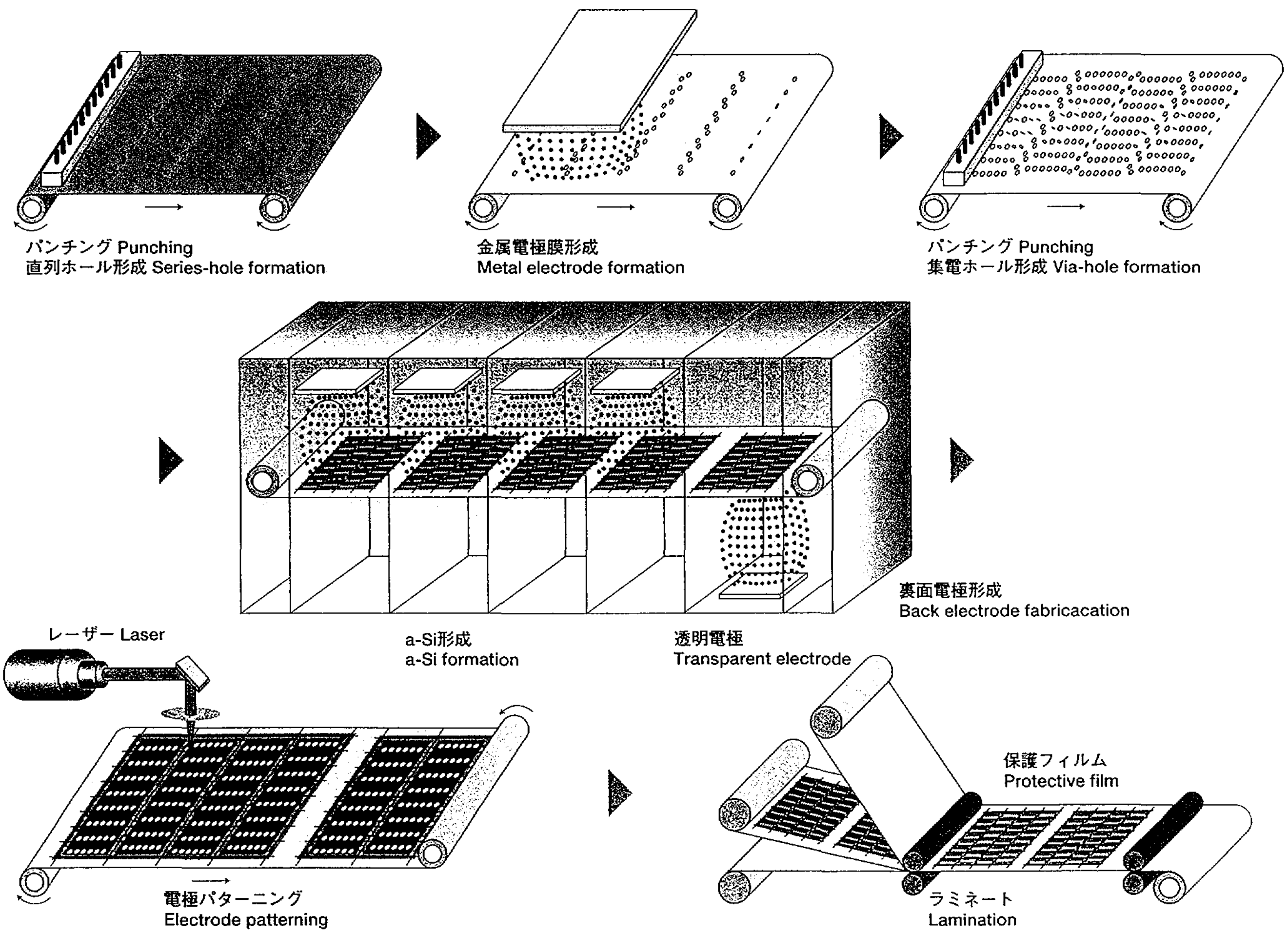
Solar cells absorb different wavelengths according to their composition. The Spectral Response Characteristic indicates the range of the solar spectrum a cell can absorb, thereby identifying its virtues. Cells which consist of a compound semiconductor, namely GaAs, CdTe and CIS, absorb wavelengths in the range of 500 ~ 900nm and are recognized as high-efficiencycy solar cells.

Correspondingly, a-Si and c-Si solar cells show excellent absorption at short wavelengths and long wavelengths, respectively. Solar cells composed of a combination of these are capable of achieving higher efficiency.

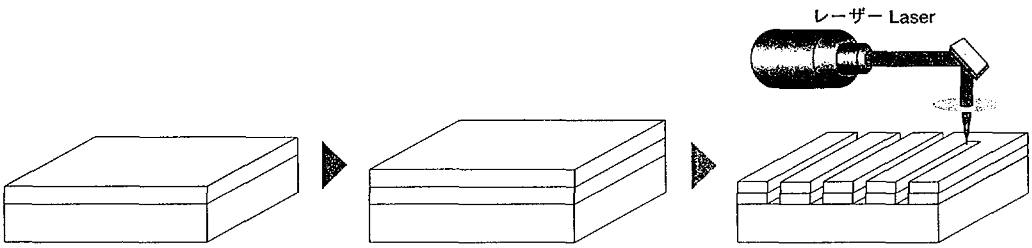
## アモルファス太陽電池の製造工程（ガラス基板）Process of Manufacturing Amorphous Solar Cell (Glass Substrate)




## アモルファス太陽電池の製造工程（フィルム基板）Process of Manufacturing Amorphous Solar Cell (Film Substrate)



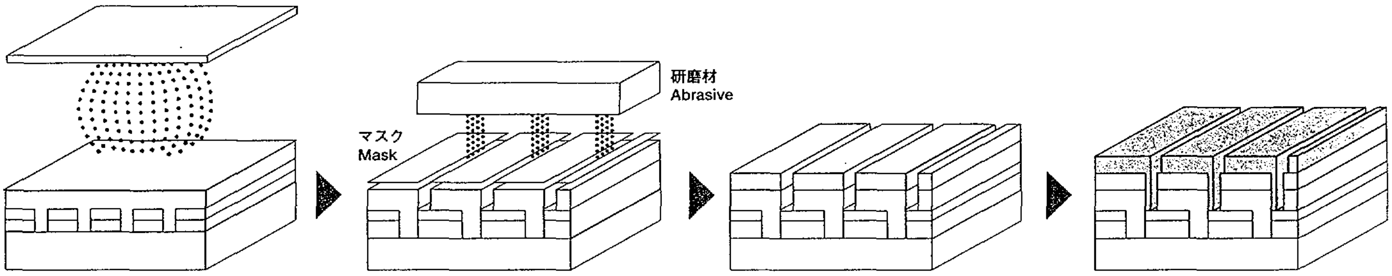
## 薄膜CdTe太陽電池の製造工程 Process of Manufacturing CdTe Solar Cell




TCO膜形成
TCO(Transparent Conducting Oxide) formation
<MOCVD法>
<MOCVD :Metal-Organic Chemical Vapor Formation>

CdS膜形成
Window layer(CdS) formation
<常圧MOCVD法 >
<Atmospheric pressure MOCVD>

TCO/CdS膜パターンニング
TCO patterning
<レーザスクライブ法>
<Laser scribing>



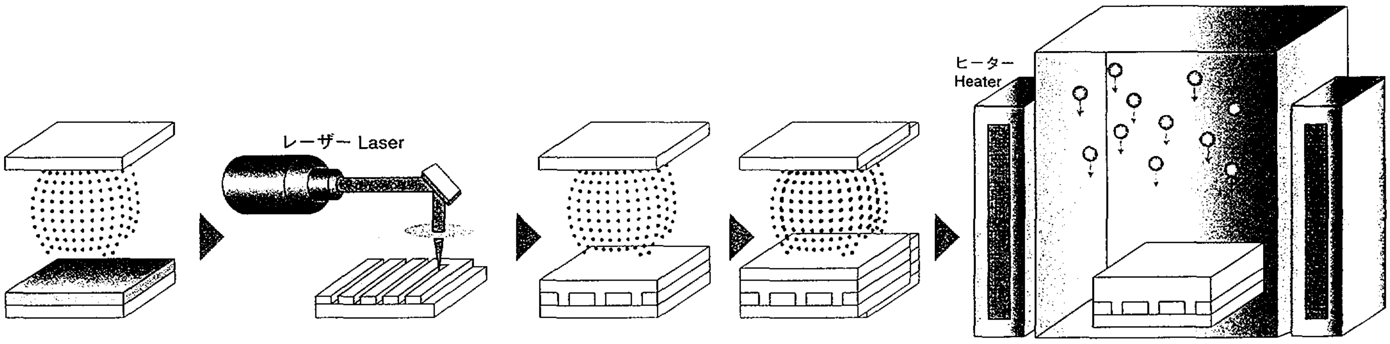

CdTe膜形成
*Absorber(CdTe) formation*
<常圧近接昇華法>
<AP-CSS: Atmospheric Pressure Close Spaced Sublimation>

CdTe膜パターンニング
*Absorber patterning*
<サンドブラスト法>
<Mechanical scribing >

カーボン電極形成
*Back contact layer formation*
<スクリーン印刷・焼成>
<Screen printing and sintering>

銀電極形成
*Back contact layer formation*
<スクリーン印刷・焼成>
<Screen printing and sintering>

## CIS太陽電池の製造工程 Process of Manufacturing CIS Solar Cell

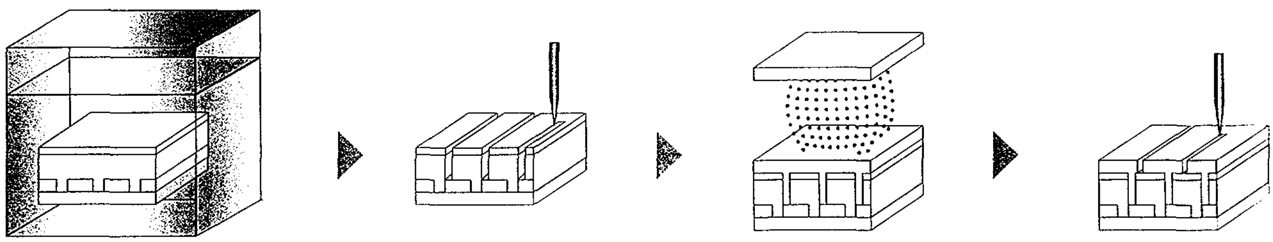



金属裏面電極製膜
Back contact layer formation
<DCマグネトロンスパッタ法>
<Sputtering>

パターンニング
Back contact layer patterning
<レーザスクライブ>
< Laser scribing>

プリカーサー製膜
Precursors formation
<DC マグネトロンスパッタ法>
< Sputtering>

光吸収層作製
(CIGS:CuInGaSe2) Absorber formation
<セレン化法>
<Selenization>



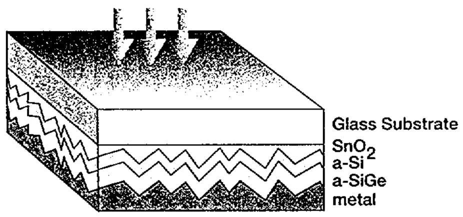
バッファ層製膜
Buffer layer formation
<溶液成長法>
<CBD:Chemical Bath Formation>

パターンニング
Absorber patterning
<メカニカルスクライブ>
<Mechanical scribing >

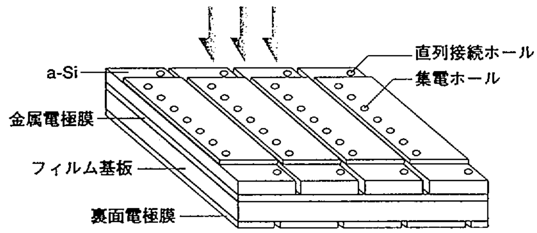
透明導電膜製膜
TCO(Transparent Conducting Oxide) formation
<DC マグネトロンスパッタ法 またはMOCVD法 >
< DC magnetron sputtering or MOCVD :Metal-Organic Chemical Vapor Formation>

パターンニング
TCO patterning
<メカニカルスクライブ>
<Mechanical scribing>

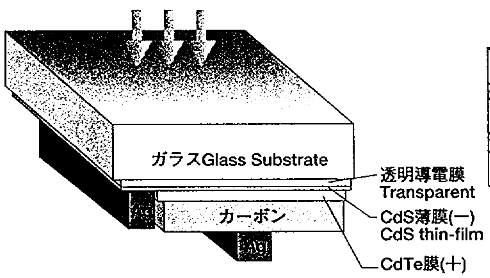
■アモルファス太陽電池（ガラス基板）
Amorphous Solar Cell (Glass Substrate)
〈a-Si/a-SiGe multi-layered structure〉



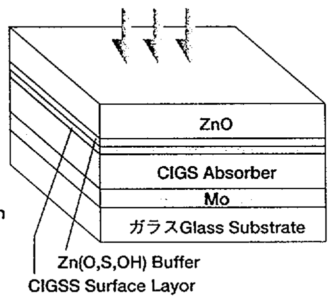

■アモルファス太陽電池（フレキシブル）
Amorphous Solar Cell (Flexible)



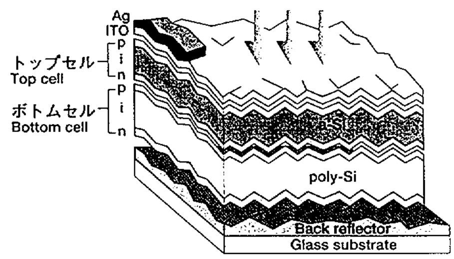

■CdS/CdTe太陽電池
CdS/CdTe solar cell




■CIS太陽電池
CIS solar cell




■アモルファスSi/薄膜多結晶Siハイブリッド型太陽電池
Hybrid solor cell (amorphous Si & thin-film polycrystal Si)



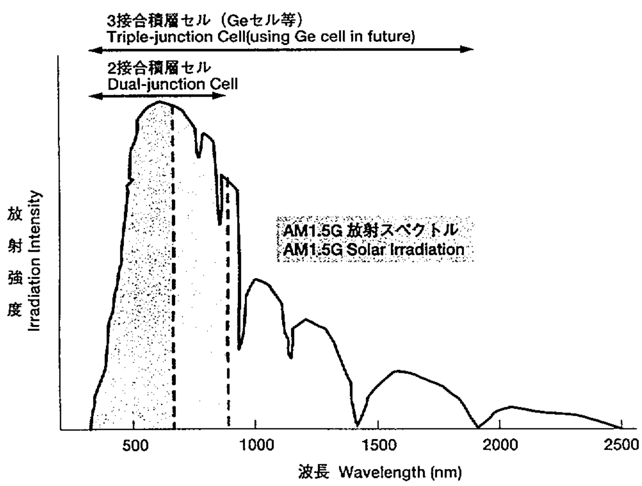

## 2. 超高効率太陽電池

平成２年度より超高効率太陽電池の開発に取り組んでおり、平成８年度までの成果ではInGaP/GaAsタンデムセルとInGaAsセルとのメカニカルスタック構造により変換効率33.3%（１cm×１cm）が得られています。現在はセルの更なる大面積化ならびにSi等の安価な基板への結晶成長技術などの開発を進めており、Ge基板上に作成した2接合セルでは、30%を超える変換効率を達成しています。

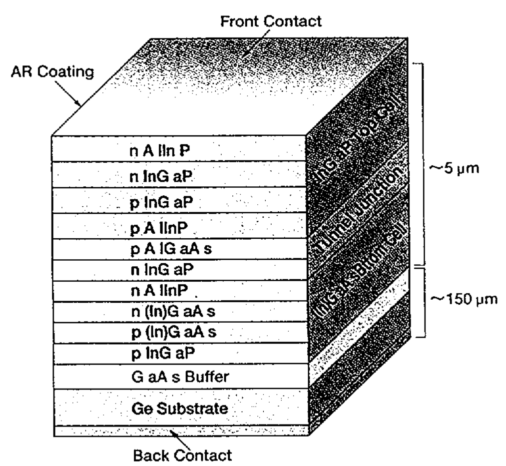
## 2. Super High-efficiency Solar Cells

Technology development for super high-efficiency solar cells has been under way since 1990. By 1996, conversion efficiencies of 33.3% was achieved with InGaP/GaAs tandem cell (2cm by 2cm) and with a mechanical stack structure combining InGaP/GaAs tandem cell and InGaAs cell (1cm by 1cm), respectively. Currently, technology development is in progress for larger area cells and for the process of crystal growth on low-cost substrate, Si and Ge.

多接合積層セルを用いた太陽エネルギーの有効利用
Utilizing Solar Energy by the Multi-junction Cells




Ge基板上の2接合積層セル
Dual-junction Cell on Ge



Solar Energy Utilization Technology

# 太陽光発電システム技術

# Photovoltaic Power Generation System Technology

太陽光発電システムを本格的に普及させていくためには、太陽電池の技術開発とともに、システム全体とシステムの構成要素である周辺装置について性能向上と低コスト化を図ることが必要です。

このため、次のようなシステムに関する技術開発を行っています。

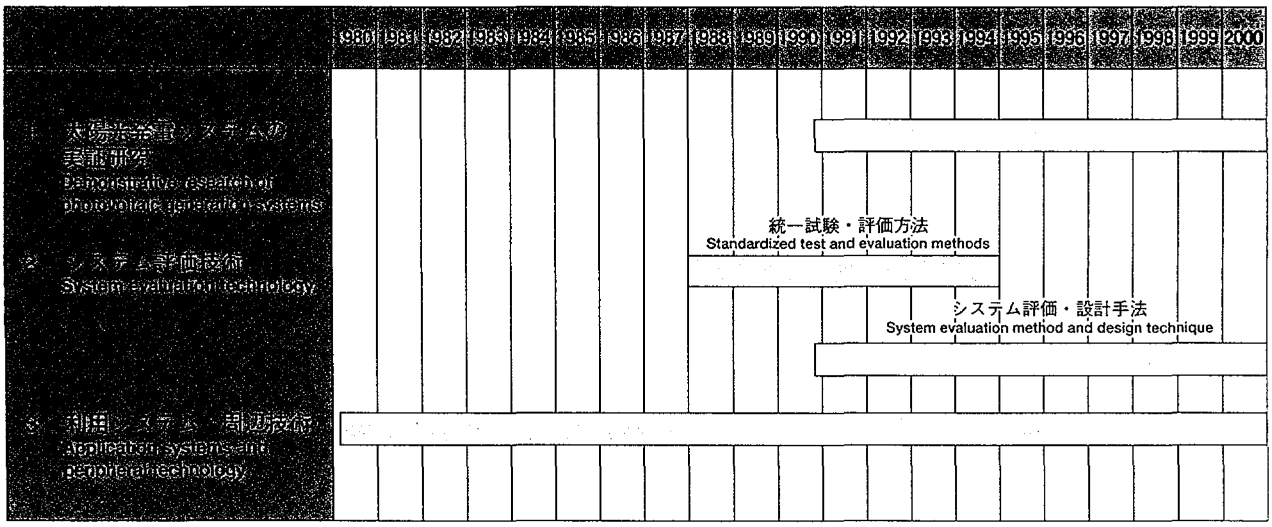
1. 太陽光発電システムの実証研究
   離島用電源として、太陽光発電システムと風力発電システム及び既存電源を連系したマルチハイブリッドシステムの適用可能性の研究。
   配電系統へ高密度に太陽光発電システムが系統連系した場合の課題の研究。
2. システム評価技術
   インバータ、蓄電池等の周辺装置の性能を正しく把握するため統一的な試験・評価法を確立。
   太陽光発電システムの総合効率の向上を図るためシステム評価法と設計手法を確立。
3. 利用システム・周辺技術
   太陽光発電システムの発電コストを低減するため長寿命・低コストの蓄電池、建材一体型モジュールの開発。

To realize the extensive utilization of photovoltaic power generation systems, efforts to improve BOS (balance of system) elements of the entire system terms of performance and cost are essential. The technological development of solar cells must also be continued.

Considering these tasks, various system-related technological development activities are being carried out as follows:

1. Demonstrative research on PV power generation systems
   Feasibility studies with demonstration tests on the application of utility grid-connected PV and wind power hybrid systems to isolated islands.
   Research work to identify possible problems arising from multiple PV system-to-grid connections and to find solutions.
2. System evaluation technologies
   Establishment of integrated testing and evaluation methods to accurately determine the performance of BOS technologies, such as inverters and storage batteries.
   Establishment of system evaluation methods and design techniques to improve comprehensively the efficiency of PV power generation systems.
3. Application systems and peripheral (BOS) technologies
   Development of long-lasting, low-cost storage batteries and building material-integrated solar cell modules for lower PV power generation cost.

■太陽光発電システム技術開発スケジュール
Schedule for Technological Development of Photovoltaic Power Generation Systems

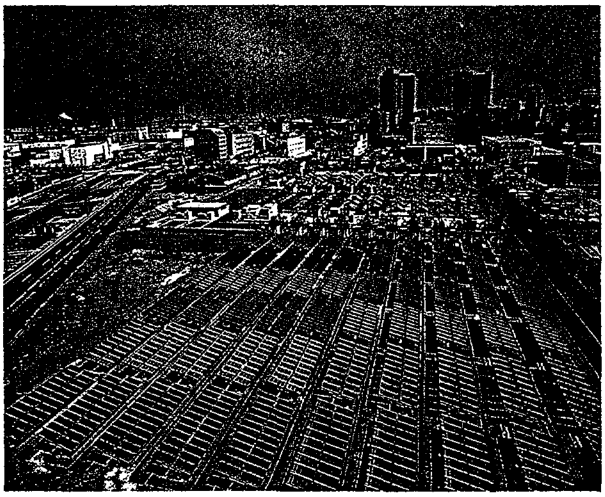



## 1. 太陽光発電システム実証研究（1990～）

平成9年度からは、離島用電源として、太陽光発電システムと風力発電システム及び既存電源を連系したマルチハイブリッドシステムの適用可能性の研究や配電系統へ高密度に太陽光発電システムが系統連系した場合の問題の把握・対策技術の実証研究を六甲新エネルギー実験センター等で行っています。

## 1. Demonstrative Research on Photovoltaic Power Generation Systems (since 1990)

In addition to feasibility studies conducted since 1990 on the application of grid-connected photovoltaic and wind power hybrid systems on isolated islands, demonstrative research activities have been carried out at the Rokko New Energy Test Center and other locations since 1997, both to identify various difficulties arising from the connection of many PV power systems to distribution lines and to find solutions.



高密度連系技術の研究（六甲新エネルギー実験センター）
Demonstrative research on multiple PV system-to-grid connection and control technologies [the Rokko New Energy Test Center]

太陽電池と実験用配電線（六甲新エネルギー実験センター）
Solar cells and distribution network for testing

## 2. システム評価技術の研究開発（1988～）

### (1) システム設計のための解析・評価

太陽光発電システムの最適設計を行うためには、システムの構成、設置地域、設置状況、使用状況等による影響を解明する必要があります。

そのため、静岡県浜松市に系統連係型や独立型の各種実証システム（出力合計100kW程度）を建設し、エネルギーフローからインバーター損失や最大電力点からのずれ、システム構成機器の劣化等の各損失を解析することで、設計を行う際に評価する必要のある各種パラメータ・補正係数を明らかにする研究を行っています。このパラメータ・補正係数は、適正な設備容量選定及び運転方法を実現するための指針を与えます。

また、太陽光発電システムの実使用状態における発電特性や地域依存性・設置状況による性能の差異等の設計手法の最適化に必要な知見を得ることを目的として、全国各地域で既に導入されている住宅用太陽光発電システムからバランスよく100システムを選定してデータ計測装置を付加し、システム運転データの収集・解析・評価を行っています。

本研究開発で得られた成果は、多種多様な太陽光発電システムに対応可能であり、それぞれ最適設計に活用されます。

## 2. Research and Development of System Evaluation Technology (since 1988)

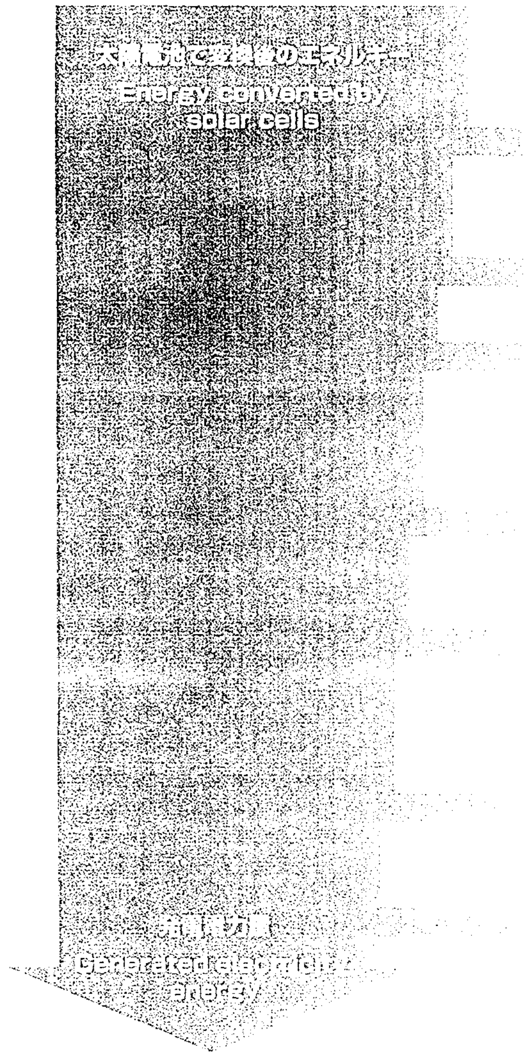
### (1) Analysis and Evaluation for System Design

To optimize the design for photovoltaic systems, it is necessary to determine the effects of system structures, installation locations, installation conditions, operation conditions, and so on. Therefore, various demonstrative systems (approx.100kW) including both grid-connected and stand-alone systems were installed in Hamamatu, Shizuoka Prefecture. The various Parameter Correct Coefficients, essential for superior design will be determined by analyzing each loss such as inverter loss, maximum power point discrepancy, degradation of system equipment, and the like, as a result of energy flow. This Parameter Correct Coefficient will indicate appropriate facility capacities and operational procedures.

In parallel with this, to acknowledge factors for the optimum design procedure such as power generation characteristics on actual operation of photovoltaic power generation systems and differences in performance by regional dependency and installation conditions, data measurement equipment have been developed set up with 100 installed house photovoltaic generation systems which were selected at random throughout the country. The system operational data have been collected, analyzed and evaluated.

The results from these investigation will be applicable for various kinds of photovoltaic power generation systems, and the optimal design for each variation will be utilized.

## ■太陽光発電エネルギーフロー
Energy Flow of Photovoltaic Generation




損失低減方法について Loss Reduction Procedure (s)

1.インバータ損失　Inverter loss
(1) 無効電力(力率)制御方法の改善
Improvement of ineffective electricity (power factor) control procedure
(2) 日射条件及び負荷に見合った容量の選定
Selection of the capacity suitable for solar radiation and load

2. Pmaxミスマッチ　Pmax mismatch
(1) アレイ接続数の適正化等により定電圧モード運転の抑制
Control of the rated electricity mode by proper array connection quantity

3.アレイ回路アンバランス　Array circuit unbalance
(1) 製造技術の向上によるセル・モジュール特性のバラツキの低減
Reduction of cell module character dispersal by improving array installation technology
(2) アレイ設置工法の改善によるモジュール温度のバラツキ低減
Reduction of module temperature dispersal by improving array installation procedure (s)
(3) ACモジュールの使用
Application of AC module (s)

4. 温度上昇損失　Loss due to temperature increase
(1) 空気式ソーラーシステムとの併用
Utilization with air-type solar system
(2) 光熱ハイブリッドシステムの採用
Adoption of solar heat hybrid system

5. 汚れ・劣化等による損失　Loss from dirt and degradation
(1) モジュール表面処理方法の改善
Improvement of module surface finishing procedure
(2) フレームレスタイプモジュールの採用
Adoption of frameless module
(3) モジュール構成材料の耐久性向上
Improvement of module material durability

6. 部分日陰、積雪等の影響　Effect (s) from partial shade and snow
(1) 設置場所のきめこまかい事前検討
Careful considerations on installation locations
(2) 融雪アレイの採用
Adoption of snow-melting array

7. その他　Others

### (2) 太陽電池の評価に係る技術の開発

太陽電池の導入普及の拡大のためには、太陽電池の効率向上のみならず長期信頼性の確保が重要となってきます。また、それに伴って開発された様々な太陽電池の信頼性を短期間で証明する手法が必要となります。

そこで、太陽電池を各種気候下に曝露することで、太陽電池の長期にわたる挙動・性能に関するデータを収集し、不具合等をフィードバックするとともに、それらのデータをもとに短期間の試験で長期信頼性を確認する「加速劣化試験手法」の開発を行っています。

さらに、近年多様化する太陽電池の性能を統一的に評価するために、長波長まで近似度の高いソーラーシミュレータの開発を行っています。

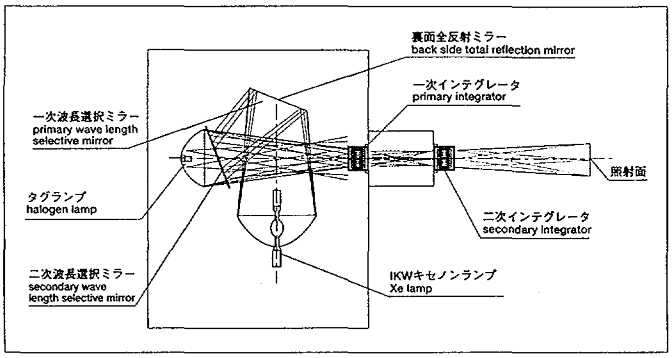
### (2) Technology Development Associated with Evaluation of Solar Cells

In order to promote introduction and dissemination of solar cells, long-term reliability as well as increase performance are significant. In addition, it will be necessary to demonstrate reliabilities of various solar cells developed through these activities.

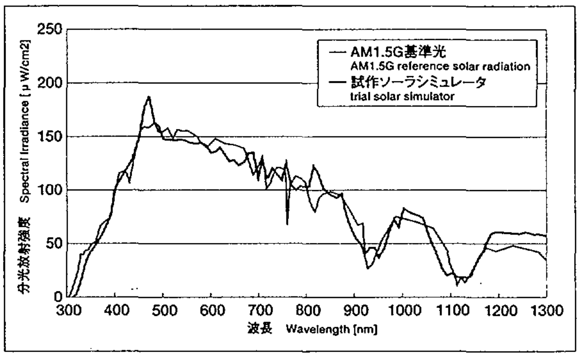
For these purposes, we are collecting data concerning the long-term behavior and performance of solar cells, by exposing the solar cells to various climates, and feedback defaults during the operations. In addition to this activity, we are also conducting development of the Accelerated Degradation Test to confirm long-term reliability through a short-term test.

Furthermore, in order to conduct an overall evaluation of solar cells which recently have shown many variations, Longer Wavelength Range of Super High Fidelity Solar Simulator has been developed.

■ソーラーシミュレータ光学系
Optical System




■基準光と高近似・大面積ソーラシミュレータの比較
Comparison between Reference Solar Radiation and Large Area



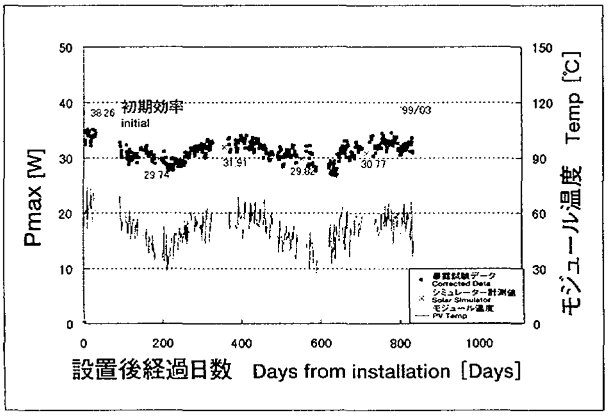

## ソーラーシミュレータ

インテグレータユニットを直列に配置するダブルインテグレータ方式の採用によって、照射面積を2m角まで拡大しても、照射不均一度±2%以内を実現しました。また、光源・フィルタ等の光学系の開発により、1100nm以上の長波長領域でも近似度の高いシステムとなっています。

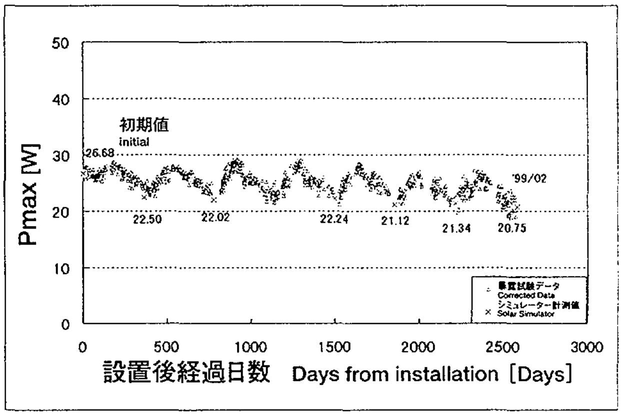
## Solar Simulator

By adopting the dual integrator method, that is, coupling two integrators, irradiation nonunifomity of ±2% was attained. In addition, the system achieved high fidelity in longer wavelength ranges (<1100nm) through the development of optical systems involving light sources filters.

■アリススプリングスサイト：アモルファスシリコン（4005cm²）
曝露開始日：平成8年12月16日
Alice Springs：a-Si（4005cm²）
Beginning day of exposure：Dec.16 1996




■鳥栖サイト：a-Si
曝露開始日：平成4年2月6日（開始前14日間の曝露履歴有）
Tosu site
Beginning day of exposure:Feb.6 1992




## 曝露試験

長期曝露試験の結果より、a-Si系モジュールの初期劣化後の出力挙動は、温度変化に同期して季節変動を繰り返していますが、大幅な性能低下は認められないことが確認されています。

## Exposure Test

The results of the exposure test revealed that the performance of the a-Si modules, after initial degradation, repeat seasonal fluctuation in synchrony with temperature variations. However, the results did not show any significant decrease in module performance.

## 3. 利用システム・周辺技術

太陽光発電の発生電力は、直流で日射量に左右されるといった特徴があるため、太陽光により発電した直流電力を交流に変換する電力変換装置、出力変動の吸収のための蓄電池等の周辺装置が必要です。このため、電力変換装置の評価、長寿命・低コストの蓄電池等の開発など周辺装置の研究開発を進めるほか、建材と太陽電池とを一体化し、太陽電池モジュールコストと設置工事費の低減を可能とする建材一体型太陽電池モジュールの開発を進めています。

## 3. Application Systems and Peripheral Technology

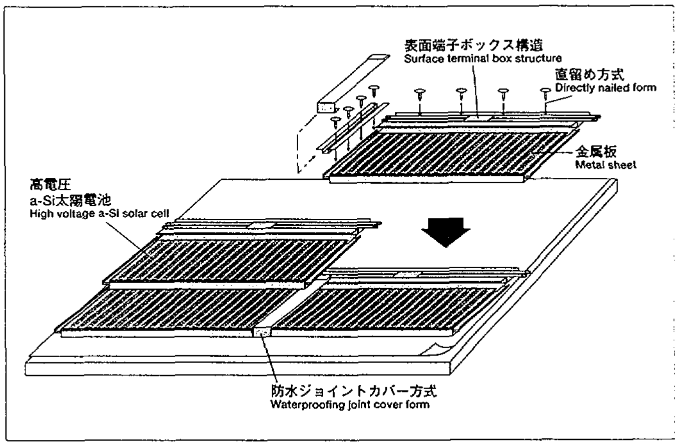
Because the power generated by photovoltaic systems is direct current and can fluctuate depending on the weather, devices for converting direct current to alternating current and storing generated power are needed if photovoltaic systems are to be practically applied. For this reason, research and development of converting devices and storage batteries, as well as the establishment of methods to evaluate these technologies, are being carried out. The goal is to maintain the cost-effectiveness of photovoltaic systems. Research and development on building-integrated systems are also in progress with the aim of reducing costs.

建材一体型実証棟（高耐久性屋根パネル方式）
Demonstration of house roof-integrated PV module (high-durable roof panel system)

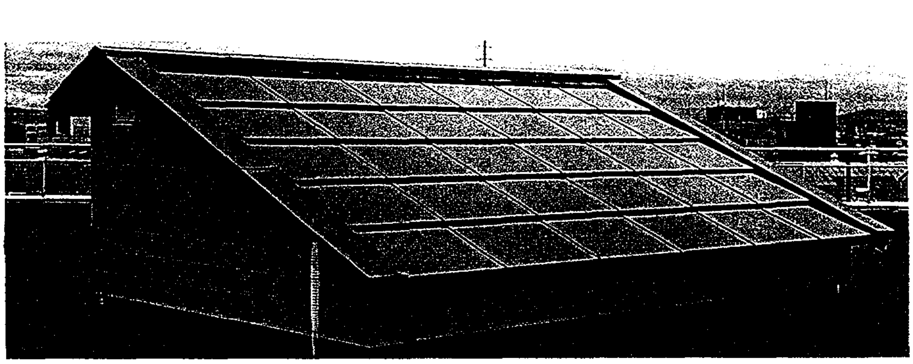
施工状況
Under installation

建材一体型太陽電池モジュールの開発では、個人住宅等の用途に対応出来る、太陽電池モジュールと屋根建材を一体化した住宅用屋根一体型太陽電池モジュールを2方式、また中高層ビルや東京ドームのような膜構造建築物などの広範囲な用途に対応出来るビル等建築物一体型太陽電池モジュール3方式の研究開発を行っています。

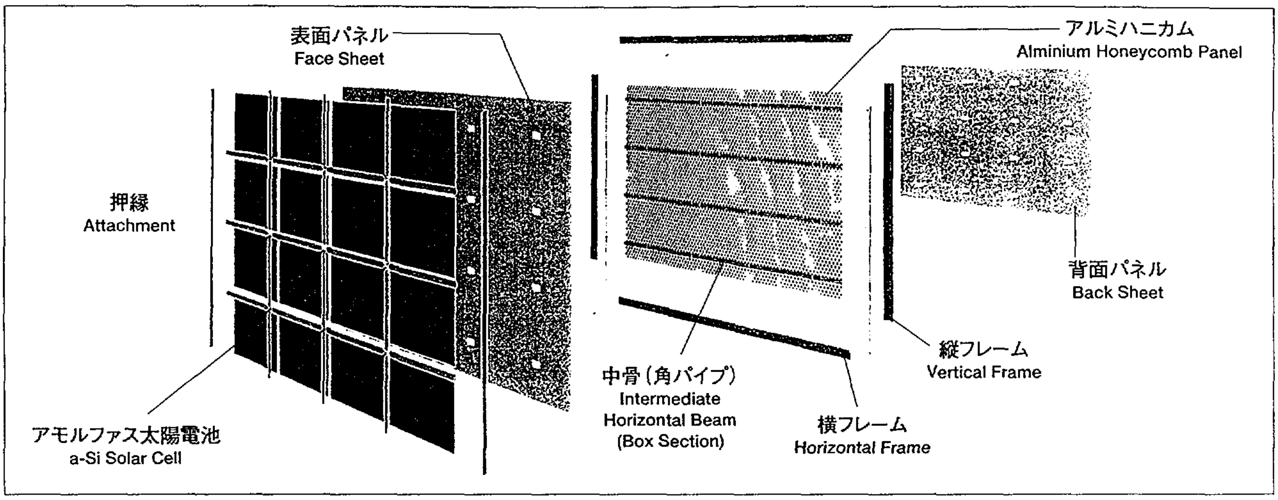
The research and development on "Architecturally-integrated Photovoltaic Modules" has been conducted. It includes two different kinds of House Roof-integrated PV Modules, one being roof materials integrated with solar cell modules for private residences. It also includes three different kinds of integrating construction materials with PV modules for a wide range of applications such as membrane structure buildings, namely Tokyo Dome, and medium and high-rise buildings.



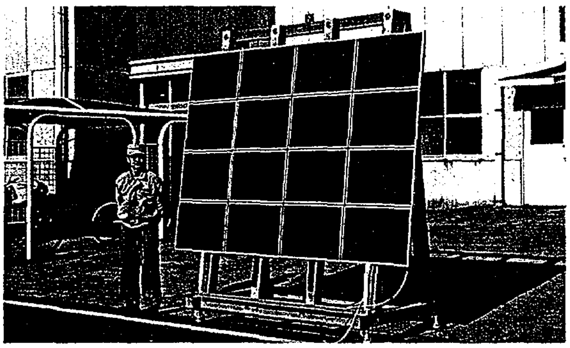

住宅用屋根一体型太陽電池モジュール
（高耐火性平板モジュール）
Structure of House Roof-integrated PV Module
(flat, highly fire resistant PV modules)



住宅用屋根一体型太陽電池モジュール 施工試験用屋根カットモデル（高耐火性平板モジュール）
House Roof-integrated PV Module Roof Cut Model for Installation Test (flat, highly fire resistant PV modules)




ビル等建築物一体型太陽電池モジュール構成図
（高強度・軽量・大面積モジュール）
Structure of Office and Other Building-integrated PV Module
(high strength/light-weight/large PV modules)



ビル等建築物一体型太陽電池モジュール
試作モジュール（高強度・軽量・大面積モジュール）
Office and Other Building-integrated PV Module Test model
(high strength/light-weight/large PV modules)

## ■我が国の太陽光発電研究システム一覧表（NEDO研究開発）
Solar Power Generation Systems in Japan

太陽光発電システムの早期実用化に向けての技術開発の一環として、太陽光発電のメリットを活かし、その利用用途を拡大するため、下記のような様々なシステムを建設して、実証研究を実施しました。

As part of the technological development effort to promote the commercialization of photovoltaic power generation, systems with various applications have been built and demonstrative research activities have been conducted. These systems are classified into grid-connected type and stand-alone type and are shown in the table below.

| 連系型 Grid-Connected | | | |
|---|---|---|---|
| 項目 Type of System | 研究場所 Location of Research | 設備規模 Facility Scale | 研究開発期間 Period of Research |
| 個人住宅用 Private House System | 神奈川県横須賀市 Yokosuka, Kanagawa Pref. | 3kW | 1980～1984 |
| 集合住宅用 Apartment House System | 奈良県天理市 Tenri, Nara Pref. | 20kW | 1980～1984 |
| 学校用 School System | 茨城県（筑波大学） Ibaraki Pref. (Tsukuba University) | 200kW | 1980～1986 |
| 工場用 Factory System | 静岡県湖西市 Kosei, Shizuoka Pref. | 100kW | 1980～1986 |
| 集中配置形 Power Plant Centralized-Type | 愛媛県西条市 Saijo, Ehime Pref. | 1,000kW | 1980～1989 |
| 分散配置形 Power Plant Dispersed-Type | 千葉県市原市 Ichihara, Chiba Pref. | 200kW | 1980～1986 |
| 離島用電力供給 Power Supply for Remote Islands | 沖縄県座間味村、渡嘉敷村 Zamami and Tokashiki, Okinawa Pref. | 50kW +200kW | 1984～1990 |
| 太陽光発電システムの実証研究 Demonstration Study | 沖縄県城辺町 Gusukube, Okinawa Pref. | 750kW | 1990～1996 |
| マルチハイブリッド形 PV & Micro Hydro Power Hybrid Power | 鹿児島県隼人町 Hayato, Kagoshima Pref. | 30kW | 1987～1990 |
| 過負荷対応分散配置形 Villa Use | 沖縄県渡嘉敷村 Tokashiki, Okinawa Pref. | 6kW (2kW×3) | 1987～1990 |
| 光熱ハイブリッド PV & Solar Thermal Hybrid System ・集光形 (Concentrated Type) ・平板形 (Flat Plate type) | 広島県坂町 Sakamachi, Hiroshima Pref. | 電気5kW 熱 25kW | 1980～1984 |
| | 神奈川県平塚市 Hiratsuka, Kanagawa Pref. | 電気3.2kW 熱 24kW | 1985～1989 |

| 独立型 Stand-Alone | | | |
|---|---|---|---|
| 項目 Type of System | 研究場所 Location of Research | 設備規模 Facility Scale | 研究開発期間 Period of Research |
| 洋上用 Marine System | 大分県上浦町（佐伯湾・海洋牧場） Kamiura, Oita Pref. (Marine Ranch, Saeki Bay) | 10kW | 1984～1988 |
| 山間僻地用 Mountain and Remote Area System | 富山県大山町 Oyama, Toyama Pref. | 5kW | 1984～1987 |
| 木材発電ハイブリッド PV & Lumber Power Generation Hybrid System | 静岡県水窪町 Mizukubo, Shizuoka Pref. | 5kW | 1984～1988 |
| メタンガスハイブリッド PV & Methane Gas Generation Hybrid System | 鹿児島県隼人町 Hayato, Kagoshima Pref. | 30kW | 1984～1988 |
| 放送サテライト Broadcasting Satellite System | 北海道蛇田郡真狩村 Makkari, Hebitagun, Hokkaido | 36kW | 1985～1988 |
| トンネル照明 Tunnel Lighting System | 宮崎県南郷町（夫婦浦トンネル） Nango, Miyazaki Pref. (Meotoura Tunnel) | 17kW | 1985～1988 |
| 離島用海水淡水化 Sea Water Desalination System ・電気透析法 (Electrodialysis) ・逆浸透法 (Reverse Osmosis) | 長崎県福江市（黄島） Fukue, Nagasaki Pref. | 25kW | 1985～1988 |
| | 広島県因島市（細島） Innoshima, Hiroshima Pref. (Hosojima) | 30kW | 1985～1988 |
| かん水利用淡水化 Brackish Water Desalination System (Electrodialysis) | 長崎県福江市 Fukue, Nagasaki Pref. | 65kW | 1988～1992 |
| 風力発電ハイブリッド PV & Wind Hybrid System ・潅漑用負荷 (for Irrigation Pumps) ・山小屋負荷 (for Mountain Lodges) | 鹿児島県知名町（沖永良部島） China, Kagoshima Pref. (Okinoerabu-jima) | 32kW | 1988～1992 |
| | 長野県白馬村、富山県宇奈月町 Hakuba, Nagano Pref./ Unazuki, Toyama Pref. | 70kW | 1988～1992 |
| 大型農事プラント電力供給 Agricultural Factory System | 北海道上士幌町 Kamishihoro, Hokkaido | 300kW | 1988～1992 |
| 防災 System for Character-Image Display | 静岡市（地震防災センター） Shizuoka (Earthquake Disaster Prevention Center) | 15.6kW | 1989～1992 |

# エネルギー使用合理化シリコン製造プロセス開発

## Development of a Low Energy Consumption Manufacturing Process for Solar Grade Silicon

1998年に見直しをされた「長期エネルギー需給見通し」では、2010年に累計で500万KWの太陽光発電を国内に導入する目標を掲げており、この対応として実用化が進んでいる結晶シリコン太陽電池の量産化を図る必要があります。

現在、この結晶シリコン太陽電池の原料については、半導体産業から発生するスクラップシリコンを用いていますが、その供給量には限界があり、今後の太陽光発電の本格的な導入・普及に備えるための原料の確保が必要となります。

このため、結晶シリコン太陽電池の低コスト化、安定供給を目指して、高純度金属シリコン(99.5%)を出発原料とした高品質かつ低消費エネルギー型の太陽電池用シリコン(SOGシリコン)量産化技術の開発を行っています。

### 太陽電池用シリコン製造プロセス

市販の高純度金属シリコン(99.5%)を原料として、これに含有される不純物を冶金的な精製プロセスを用いて除去しSOG-SiとするNEDO溶融精製法の量産化技術により、60トン／年生産規模のパイロットプラントを設計・製作し、これの実証運転試験を行っています。

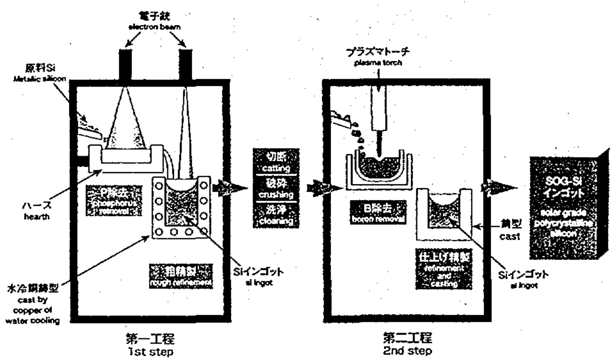
不純物のうち、燐(P)はエレクトロン・ビーム真空溶解で行い、硼酸(B)と炭素(C)はプラズマを用いた溶融シリコンの酸化精錬で行い、その他の金属元素、鉄(Fe)、アルミニウム(Al)、チタン(Ti)、カルシウム(Ca)は主として一方向凝固精製で除去します。また、仕上げ精製されたシリコン・インゴットをスライスし直接、太陽電池用多結晶シリコン基板として用いることを検討します。

In 1998, the Japanese government revised a national policy entitled "Long-term Energy Supply/Demand Outlook". According to this guideline, Japan is expected to increase the installation capacity of PV systems to 5,000MW (accumulative) by FY 2010.

As a part of achieving this objective, a sufficient supply of raw material for crystal-silicon solar cells must be ensured in the future. Scrap silicon from the semiconductor industry is used at present, but the availibility is limited.

To satisfy the expected future demand for solar cells, research and development on a manufacturing process for solar grade silicon (SOG-Si) from highly pure metallic silicon (99.5%). The aim to realize a low-cost process which consumes little energy is being conducted.

量産化製造のフロー Mass Manufacturing Process




### NEDO SOG-Si manufacturing process

A mass-production process for SOG-Si, using the NEDO-MP process, will be developed by designing and manufacturing a pilot plant with a production capacity of 60 tons/y and then conducting a study through verification operation.

In the NEDO-MP Process impurities in commercially available, high-purity MG-Si are removed by a metallurgical refining process. Phosphorus (P) is removed by electron-beam melting, boron (B) and carbon (C) are removed by the oxidation refining of molten silicon, and other impurities (Fe, Al, Ti, Ca, and other metal elements) in silicon are removed by unidirectional solidification. To reduce costs, technology to produce wafers by directly slicing refined silicon ingots without remelting will be examined as well.

### ■開発スケジュール
Time Schedule of the Research Project

| 年／Year | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|
| SOG-Si製造量産化プロセスの開発<br>Development of solar grade silicon production process | 基礎開発(20kg装置)<br>New Sun Shine (NSS) project | | | | |
| ●リン除去・粗精製工程プロセス開発<br>Phosphorus removal and 1st step directional solidification | | パイロット・プラント(60t/年)<br>pilot plant (60t/year) | 実験／解析<br>Experiment and analysis | | |
| ●ボロン除去・仕上げ精製工程プロセス開発<br>Removal of boron and carbon and 2nd step directional solidification | | | パイロット・プラント(60t/年)<br>pilot plant (60t/year) | 実験／解析<br>Experiment and analysis | 総合運転研究<br>Integrated operation test |
| mc-Siウエハ製造プロセス開発<br>Development of multi-crystalline silicon (mc-Si) wafer production process | 基礎開発(20kg装置)<br>New Sun Shine (NSS) project | | | | |
| ●mc-Siインゴット製造プロセス(EMCプロセス)開発<br>mc-Si ingot making process (Electro-Magnetic Casting Process) | | | | 装置改良<br>Improvement of equipment | 運転研究<br>Operation test |
| ●スライシングプロセス開発<br>Slicing process | | パイロット・プラント<br>Pilot plant | 運転研究<br>Operation test | | |
| ●製品品質評価<br>Quality evaluation of the product | | | 製品基礎評価<br>Fundamental evaluation of the product (laboratory base) | 量産化製品評価<br>Evaluation of the product (pilot plant base) | |

Solar Energy Utilization Technology

# 即効型高効率太陽電池技術開発

## Development of The Practical Technology for High-Efficiency Multi Crystalline Silicon Solar Cells

太陽電池の導入普及を経済的にも大きな負担を掛けずに実施していくためには、既存電力の価格に対し許容できる程度の価格まで、早期に太陽光発電のコストを低減する必要があります。

現在、最も導入普及が進んでいる太陽電池は多結晶および単結晶シリコン太陽電池ですが、実用化されている太陽電池の技術レベルでは、生産規模から類推した量産効果だけで低下コスト化を実現することは困難であり、更なる画期的コスト低減技術が必要となっています。

「即効型高効率太陽電池技術開発」は、平成11年度より平成14年度までの４年間で、1) キャスト法による高品質インゴット製造技術の開発、2) 薄型・大面積多結晶基板スライス技術の開発、3) 薄型高品質基板を生かす高効率セル化技術開発を実施することにより、早期に高効率化、低コスト化を可能とする事となっています。また、これらに加えて総合的な環境影響をLCA手法によって評価します。

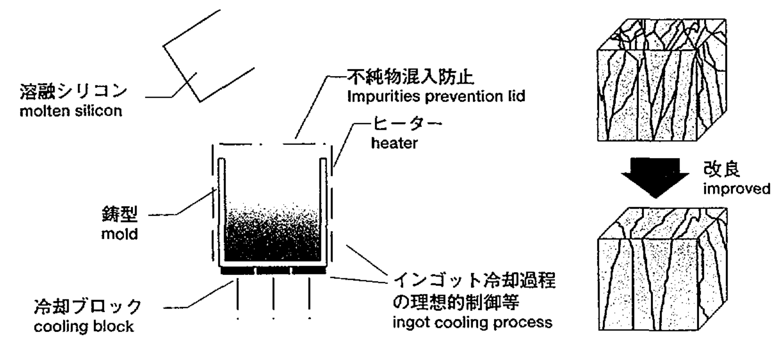
Presently, the majority of the solar cells consist of multi and mono (single) crystal silicon. As it is difficult to reduce cell's cost exclusively through mass production, alternative technology to curtail their cost is in great demand.

The "Development of Practical Technology for High-efficiency Multicrystalline Silicon Solar Cells" will be executed over the four-year period from 1999 to 2003. This project is intended to develop the technology for 1) manufacturing high quality cast ingots, 2) slicing multicrystalline thin and large-scale substrates, and 3) fabricating high-efficiency cells utilizing high quality and thin substrates. Consequently, higher efficiency and lower cost will be realized in the near future. Along with these endeavors, the aggregate environmental effects will be evaluated by the LCA (Life Cycle Assessment) method.

**プロジェクト目標 Target of the project**

- 基板サイズ Size of the substrate ：15cm×15cm
- 基板厚み Thickness of the substrate ：150 μm
- 基板切り代 Cost of slicing the substrate ：150 μm
- セル変換効率 Cell conversion efficiency ：20%以上 over 20%
  (多結晶シリコン基板単一の構造)
  (structure of single multicrystalline silicon substrate)
- モジュール製造コスト Cost of manufacturing the module
  ：147円/W以下 below ¥147/W
  (条件として年産100MW以上の場合)
  *(under the condition of over 100MW/year production)*

**高品質インゴット製造技術開発 High Quality Ingot Fabrication Technology Development**

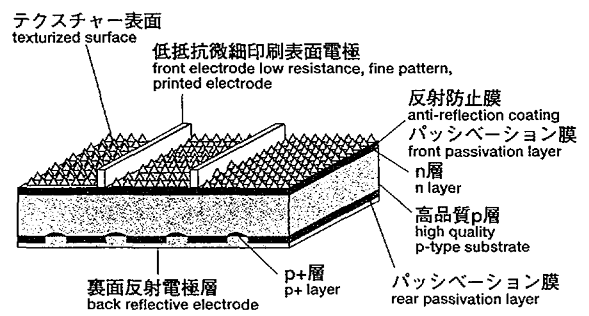



キャスト法によるインゴット製造の諸条件と太陽電池特性の関係の明確化

Clarify relation between ingot fabrication in casting method and solar cell performance by:

- 不純物混入防止技術 impurities prevention technology
- 結晶粒の大径化 grain size enlargement
- 結晶粒界の制御 grain boundary control
- 結晶粒内欠陥の制御 grain defect control

**高効率セル化技術開発 Super-high-efficiency Cell Fabrication Technology**

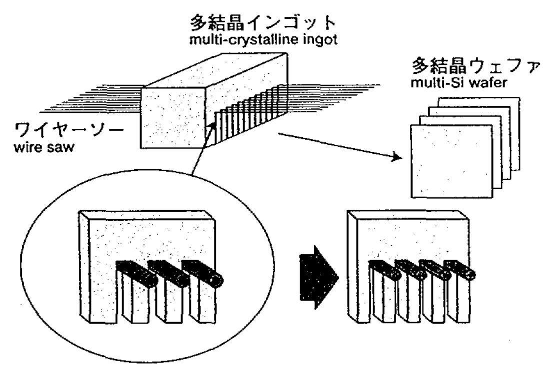



高品質基板を生かす高効率セル化技術

Super-high-efficiency cell fabrication technologies utilizing high quality substrate:

- パッシベーション（基板欠陥不活性化）技術の開発 passivation technology
- 接合形成技術の開発 junction formation technology
- 電極形成技術の開発 electrode formation technology
- 光閉じ込め技術の開発 light trapping structure

**薄型大面積多結晶基板スライス製造技術開発**
**Super-thin-multi-crystalline Substrate Slicing Process Technology**




ウェファー厚、切り代の大幅減少

*Reduction of wafer thickness and cutting loss by:*

- 極細・高耐久性ワイヤーの開発 super-thin and high endurance wire fabrication technology
- 切削用スラリーの改良 slurry improvement
- 高耐久性ローラー等スライス技術開発 slicing technology e.g. high endurance roller
- スライス後基板処理技術の開発 sliced super thin substrate processing technology

# 海外事業

# International Cooperation Projects


NEDOの太陽技術開発室では、以下の3つの海外事業を実施しております。

**1. 太陽光発電システム国際共同実証開発**

我が国の環境、エネルギー対策にとって有効なだけでなく、発展途上国にとっても有益である太陽光発電システム技術について、各国の自然条件、社会システムを利用して、太陽光発電システムの性能と信頼性向上を図るため実証試験を実施。

**2. 国際協力事業**

太陽光発電の技術開発を推進するとともに導入のための環境整備を促進していくため、太陽エネルギー開発国との技術協力、情報交換および国際共同研究プログラム作成等を実施。

**3. 国際研究協力事業**

発展途上国のみの研究開発能力では実現困難な発展途上国固有の技術開発課題に即した研究開発を、我が国の技術力及び研究開発能力を活用しつつ、相手国の研究機関との研究協力により実施。

In NEDO's Solar Energy Department, three international projects have been undertaken as follows:

**1. International Cooperative Demonstration Project for Photovoltaic Power Generation systems**

The technologies of photovoltaic power generation systems are beneficial not only for the environment and energy situation of Japan but also for those in developing countries. Therefore, the demonstration projects are to be implemented under the natural conditions and social systems in each country, in order to improve the performance of photovoltaic power generation systems and their reliability.

**2. International Cooperation Projects**

To promote technology development for photovoltaic power generation systems and the environmental equipment for their introduction, information exchange and international cooperation projects ate to be organized.

**3. International Research Cooperation Projects**

Along with tasks of technology development which are particular to the developing countries and difficult to accomplish with their present technological ability, research and development is to be implemented in cooperation with research organizations in those countries utilizing NEDO's technology, and research and development capability.

## 1. 太陽光発電システム国際共同実証研究

## International Demonstrative Research on Photovoltaic Power Generation Systems (Since 1993)

太陽光発電システムの性能及び信頼性の向上を図るため、NEDOとベトナム、タイ、ミャンマー、ネパール、モンゴル及びマレーシアの研究機関と共同で、相手国の自然条件及び社会システムを利用して次の6件の実証研究を実施しています。
(( ) 内は、相手国の研究協力機関を示す。)

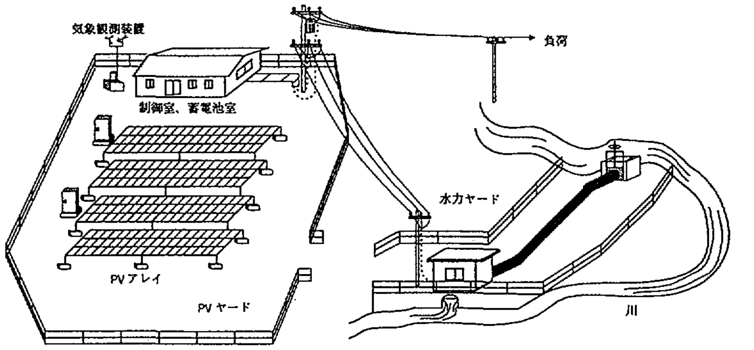
With the aim of improving the performance and reliability of PV power generation systems, NEDO has conducted six demonstration research projects in cooperation with research institutes in Nepal, Mongolia, Thailand, and Malaysia, (and is currently conducting one project in) Vietnam and Myanmar. Demonstration research projects are structured to utilize the natural conditions and social systems in the respective counterpart country. (The name of the cooperative research institute of organization in each country is mentioned in parentheses.)

## (1) 太陽マイクロ水力ハイブリッドシステム実証研究（ベトナム国電力公社）　1997〜

**Demonstrative research on a hybrid system of photovoltaic power generation and micro hydro power generation (Electricity of Vietnam, Socialist Republic of Vietnam)**

太陽光発電及び水力発電は、共に二酸化炭素等の地球温暖化ガスを発生しないクリーンな発電方式であるが、気象依存的な不安定性を有する。しかし、その気象依存性は相互補完関係にあると考えられる。そこで、両者をハイブリッド化して、互いの短所を補う安定電源としてのシステムを構築し、ベトナム国で実負荷運転を行うことにより、当該システムの最適化、高性能化および信頼性の向上を図る。

Photovoltaic and hydroelectric power generation systems are very clean and do not emit greenhouse gases such as $CO_2$, but they are weather dependent and therefore can have unstable output. Each system has unique strengths, however, which can compensate for the weaknesses of the other system. By constructing a hybrid plant which compensates for the weakness of each individual system, stable generation can be achieved. The objective of the project in Vietnam is to enhance the efficiency and reliability of a hybrid photovoltaic-micro hydro power generation system by operating the induction generator.




## (2) 太陽光系統連系システム実証研究（タイ・ミャンマー）　1999〜

**Demonstrative Research on a Grid-connected Photovoltaic Power Generation Systems (Thailand / Myanmar)**

小規模電力系統が存在するタイおよびミャンマーにおいて、太陽光発電系統連系システム実証研究を行い、今後の我が国の離島でのシステム構築に役立てます。

タイでは、ACモジュール等の太陽光発電システムが多数連系した場合の系統にもたらす影響の定量的把握を行います。

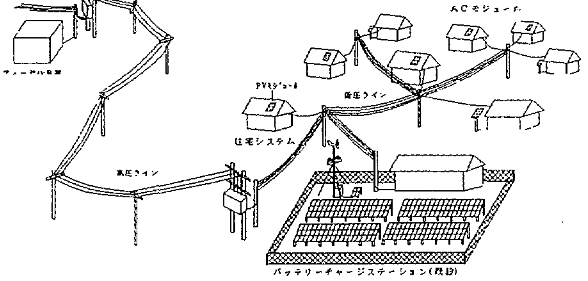
また、ミャンマーでは、太陽光発電設備等の再生可能エネルギーで電力を供給した場合の出力変動を水ポンプ等の電力負荷（需要）側の需要調整により吸収すること等を検証します。

In Thailand (Kingdom of Thailand) and Myanmar (Union of Myanmar) where small-scale electric power systems presently exist, demonstrative research on grid-connected photovoltaic power generation systems is to be implemented with the results applied to future system construction on Japanese remote islands.

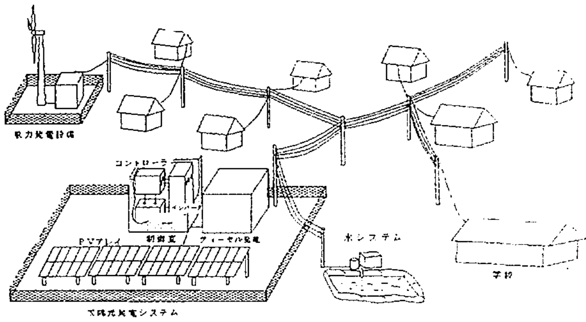
In Thailand, the effects on the grid are to be determined through quantitative analysis when numerous photovoltaic systems, for instance AC modules, are interconnected.

In Myanmar, the power generation fluctuation range absorbed on the demand side at loads such as water pumps is to be investigated when the electricity is supplied with renewable energy (photovoltaic power generation systems).

[タイ]




[ミャンマー]

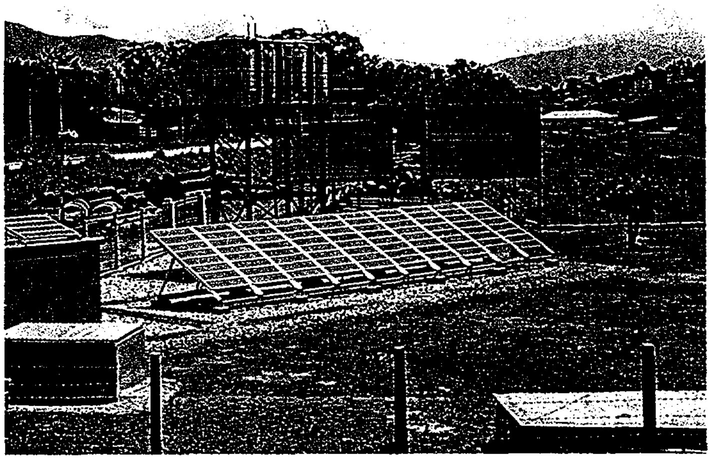


### (3) 高地条件利用加速実証研究（ネパール国王立学科アカデミー） 1992～1996

Accelerated demonstrative research utilizing highland weather conditions (Royal Nepal Academy of Science & Technology, Nepal)

ネパールの温度差の激しい高地の自然条件を利用して、太陽光発電を電源とする水ポンプシステムを運転し、太陽電池の効率劣化、材料劣化及び周辺機器の経時変化を調べることにより太陽光発電システムの信頼性の向上を図った。

The highlands in Nepal are subject to unusually wide temperature fluctuations. A water pump system using solar cells as the power source was operated under these severe natural conditions to measure the deterioration of the efficiency and materials of the solar cells and the time - serial changes of the peripheral devices. The obtained data was subsequently used to improve the reliability of photovoltaic power generation systems.

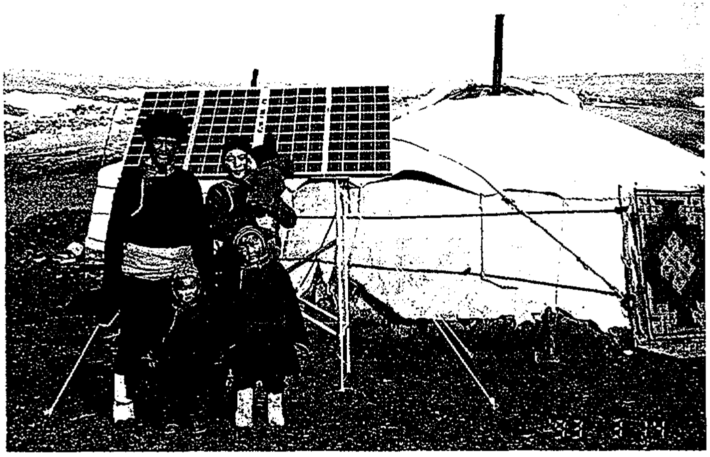


### (4) 携帯発電システム実証研究（モンゴル国燃料エネルギー省） 1992～1996

Demonstrative research on portable photovoltaic power generation systems (Ministry of Fuel and Energy, Mongolia)

生活様式として移動テント（ゲル）が定着しているモンゴルの社会システムを利用して、遊牧生活と一体となった携帯用太陽光発電システムを運転し、システムの小型軽量化、可搬性、信頼性の向上を図った。

In Mongolia, nomadic life is an established lifestyle. Portable photovoltaic power generation systems were test-operated to assess the possibility of making them lighter and more compact and improving their portability and reliability.

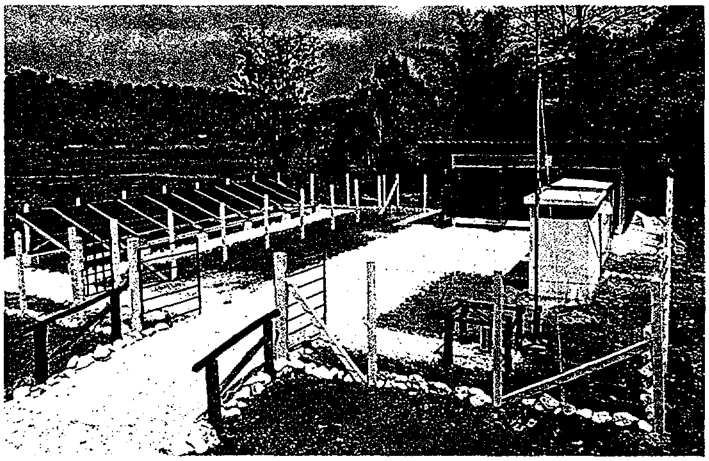


### (5) バッテリーチャージステーション用太陽光発電システム実証研究（タイ国エネルギー開発促進局） 1992～1997

**Demonstrative research on photovoltatic power generation system for battery charging stations (Department of Energy, Development and Promotion, Thailand)**

タイでは、ディーゼル発電などによって充電した自動車用バッテリーを自宅に持ち帰り電気製品を使用している村落がある。このような社会システムを利用して、充電制御装置を含むバッテリーチャージステーション用太陽光発電システムを運転し、太陽光発電システムの性能の向上を図った。

In Thailand, there are villages where car batteries, charged by diesel engine generators, are used to power home electric appliances. Utilizing this unique social system, a photovoltaic power generation system for a battery charging station, including charging controls, was test-operated to help improve the efficiency of photovoltaic power generation systems.



### (6) 熱帯条件利用加速実証研究（マレーシア国エネルギー通信郵政省） 1992～1997

**Accelerated demonstrative research under tropical weather conditions (Ministry of Energy, Tele Communications and Posts, Malaysia)**

太陽光発電システムの発電効率は、温度上昇に伴い低下する特性を有していることからマレーシアの熱帯の自然条件を利用して、太陽光発電システムの運転を行い、自然通風、散水などによる冷却効果について研究し、夏場の太陽光発電効率の向上を図った。

The efficiency of a photovoltaic power generation system declines as the ambient temperature rises. In view of this, a photovoltaic power generation system was test-operated under high temperatures in Malaysia to study the effect of cooling the system by natural ventilation, water, etc. in an attempt to improve the efficiency of the system in hot weather conditions.

## 2. 国際協力事業
## International Cooperation Projects

二国間協力事業として、日豪エネルギー技術協力を遂行するとともに、オマーンにおいても長期耐久試験(Long-Term Endurance Test)事業を行っています。さらに、日仏間、日米間、日西間等の太陽エネルギー技術協力実施協定に基づき技術交流を図っています。

オーストラリアでは太陽電池モジュールの屋外曝露試験(Exposure Test)事業及び薄膜多結晶シリコン製造・評価技術に関する情報交換事業を平成8年度から実施しています。 曝露試験事業においては、パースにあるマードック大学エネルギー研究所(Murdoch University Energy Research Institute)との技術協力により、ダーウィン・アリススプリングス・パースの3個所で試験を実施しています。ここで得られたデータの解析を行い太陽電池モジュールの劣化の特徴・傾向を把握するとともに、加速劣化試験方法開発のための基礎データとしての活用を進めています。

また、情報交換事業ではシドニーにあるニュー・サウス・ウェールズ大学と1年半に1度ワークショップを開催しています。

さらに、オマーンとの長期耐久性試験事業では、マスカットにあるスルタン・カブース大学(Sultan Qaboos University)との技術協力により、薄膜太陽電池を中心とする屋外曝露試験を平成10年度より開始しました。

多国間協力事業として、IEA太陽光発電プログラム(PVPS)およびIEA太陽冷暖房・給湯プログラム(SHCP)に関する情報収集なども行っています。

IEA/PVPSでは世界の太陽電池の研究・開発動向、生産・導入動向等に関する報告書類の発行を行っています。また、システムのデータベース比、離島用等独立電源、あるいは系統連系電源、建築物一体電源としての太陽光発電システムの研究を行っています。さらには砂漠等を活用した大規模太陽光発電の研究、開発途上国との協調による太陽光発電技術の普及についても活動が開始されています。

In regards to cooperative project between two countries, Photovaltaic Energy Technology Cooperation has been initiated with Australia, and Long-term Endurance Test Program in Oman has been undertaken. Moreover, based on implementing agreements between Japan and France, Japan and United States of America, and Japan and Spain, technology exchange has been conducted.

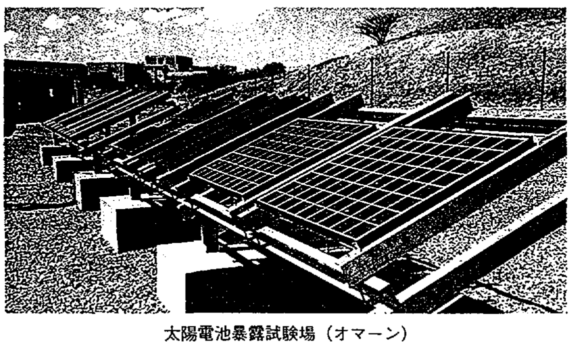
In Australia, an Outdoor Exposure Test Project for solar cells and an Information Exchange Program for manufacturing and evaluating thin-film poly-crystalline silicon have been under way since 1996.

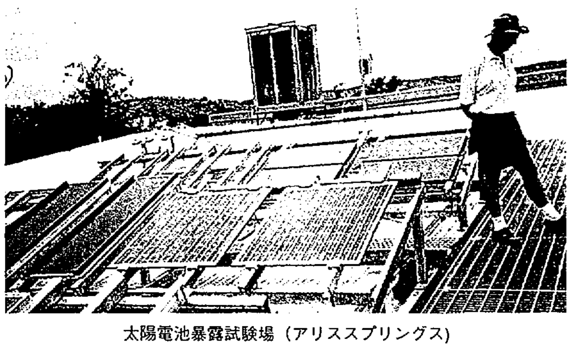
The Exposure Test Program has been implemented at three sites, (Darwin, Alice springs, Perth) in cooperation with Murdoch University Energy Research Institute in Perth. The accumulated data is being analyzed and utilized for developing accelerated degradation test technology. In the meantime, the Information Exchange Program offers periodic workshops once in every year and a half, in cooperation with University of New South Wales in Sydney.

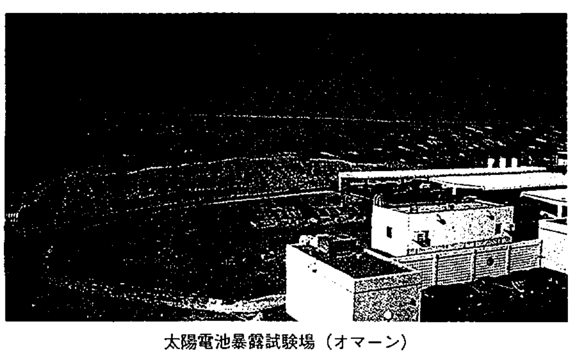
In the line with this, in Long-term Endurance Test Program in Oman, an Outdoor Exposure Test on mainly thin-film solar cells was initiated 1998 in cooperation with University of Sultan Qaboos in Muscat.

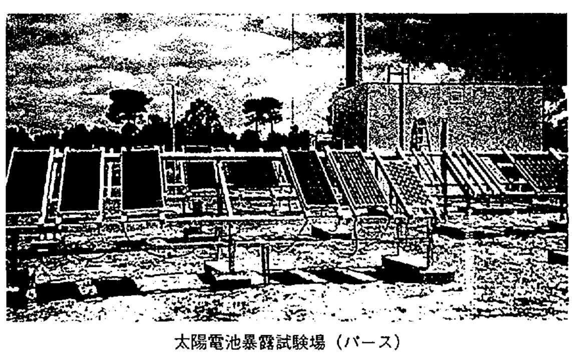
In regards to cooperative program between several countries, information concerning the IEA Photovaltaic Power Systems Program (PVPS), the IEA Solar Heating and Cooling Program (SHCP) and others have been complied.

IEA/PVPS has published reports regarding international trends pertaining to research and development, and manufacturing and introduction of solar cells. In addition, research has been carried out on a system database, photovaltaic power generation systems as an independent power sources on remote islands, as well as grid-connected power sources and building-integrated power sources. Moreover, various IEA Tasks have been conducted including installation of large-scale photovaltaic power generation systems in deserts, and the promotion of photovaltaic power generation technology in cooperation with developing countries.


太陽電池暴露試験場(オマーン)
Solar cell exposure test site (Oman)


太陽電池暴露試験場(アリススプリングス)
Solar cell exposure test site (Alice Springs)


太陽電池暴露試験場(オマーン)
Solar cell exposure test site (Oman)


太陽電池暴露試験場(パース)
Solar cell exposure test site (Perth)

■IEA（国際エネルギー機関 International Energy Agency）

IEA

CERT エネルギー研究技術委員会 Committee on Energy Research and Technology

REWP 再生可能エネルギー技術作業部会
Working Party on Renewable Energy Technologies

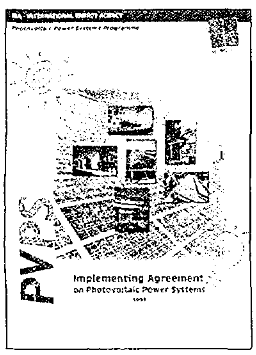
太陽光発電システム研究協力実施協定（PVPS）
Photovoltaic Power Systems Programme

太陽冷暖房・給湯プログラム（SHCP）
Solar Heating and cooling Programme

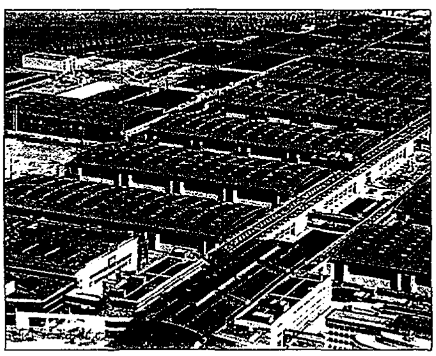
風力研究開発プログラム（WIND）
Wind Energy Programme

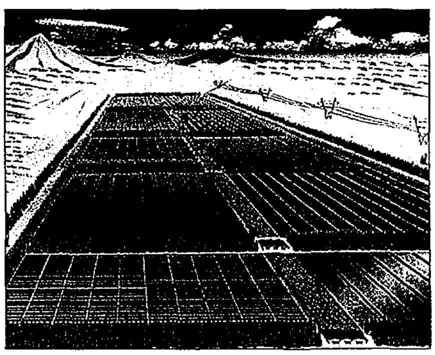
■IEA／太陽光発電システム研究協力実施協定各タスクの概要
IEA／Photovoltaic Power Systems

| | | |
|---|---|---|
| タスクⅠ task | 太陽光発電システムに関する情報の交換と普及<br>Exchange and dissemination of information on photovoltaic power systems | 1998～ |
| タスクⅡ task | 太陽光発電システム及びサブシステムの運転性能と設計<br>Operational performance and design of photovoltaic systems and subsystems | 1998～2002 |
| タスクⅢ task | 独立型及び離島用太陽光発電システムの応用<br>Use of photovoltaic power systems in stand-alone and island applications | 1999～2003 |
| タスクⅣ task | 系統強化用分散型太陽光発電システムの設計<br>Modelling of distributed photovoltaic power generation in support of the electric grid | 未実施<br>No activity |
| タスクⅤ task | 屋根設置型等分散型太陽光発電システムの設計と系統連系<br>Grid interconnection of building intergrated and other dispersed photovoltaic power systems | 1999～2001 |
| タスクⅥ task | 大規模発電所用標準太陽光発電プラントの設計と運用<br>Design and operation of modular photovoltaic plants for large-scale power generation | 1997年終了<br>completed in 1997 |
| タスクⅦ task | 建築事業における太陽光発電<br>Photovoltaic power systems in the built environment | 1997～2001 |
| タスクⅧ task | 砂漠等未利用地を利用した大規模太陽光発電に関する可能性調査研究<br>Very large scale photovoltaic power generation systems in remote areas | タスク6-5として1998<br>タスク8として1999-2001<br>Task VI-5 in 1998, Task VIII for 1999～2001 |
| タスクⅨ task | 発展途上国との協調による太陽光発電技術の普及<br>Deployment of photovoltaic technologies in cooperation with developing countries | 1999～2004 |



IEA／PVPS／Task I


IEA／PVPS／Task V


IEA／PVPS／Task Ⅷ

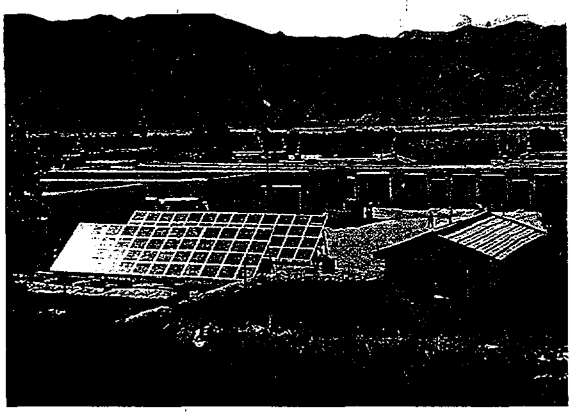
## 3. 国際研究協力事業
## Cooperative Research Promotion Project

### 地域適合型太陽光発電システムの実用化に関する研究協力
### R&D Cooperation in Practical Application of Locally Oriented Photovoltaic Power Generation Systems

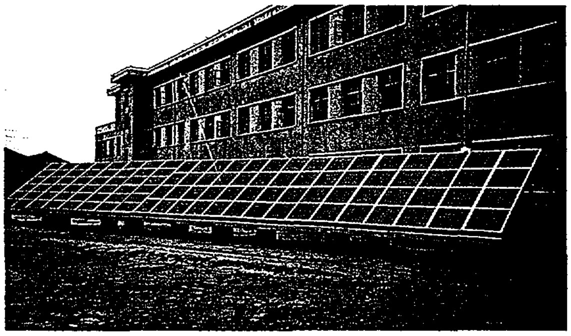
現在、中国の無電化人口は約７千万人ともいわれ、こうした地域への電力供給は、貧困問題の改善という観点からも大きな課題となっています。一方、中国国内では経済の急成長による電力需要の急激な増加が予想され、その対応を国内の豊富な石炭でまかなうものと考えられます。このため、中国における二酸化炭素の排出量の増加が予想され、二酸化炭素の排出増加に対して対策が講ぜられることが期待されています。この中にあって、太陽光発電の開発・導入について我が国が技術的協力を行うことは重要な課題の一つとなっています。

この研究協力は、中国内陸部等の系統電化が困難な地域又は電力不足が続く地域において、太陽光発電の普及を図るため、地域の自然環境、生活環境等に適合した太陽光発電システムを効率的に設計するためのプログラムを中国側と共同で開発するとともに、中国における太陽電池の評価技術について研究協力を行うことを目的としています。

研究期間は、平成10年～13年度までの４年間で、学校などの公共施設及び村落の電化、太陽電池評価の技術移転を行うこととしています。



西蔵自治区拉薩市拉木郷完全小学校
Lamu Township, Lasa City Tibet Autonomous Region
Lamu Township Wanguan Primary school



寧夏回族自治区隆徳県沙塘中学校
Jiangde County, Ningxia Hoizu Autonomous Region
Shatang Secondary school

In China today, it is said that approximately 70 million people do not have access to electricity. Electricity availability is a significant factor in helping people rise above poverty. At the same time, it is predicted that rapid economic growth will cause a sharp increase in electric power demand, and this demand will be covered by abundant domestic coal reserves. Consequently, a considerable increase in carbon dioxide emission is anticipated, against which adequate measures are expected to be taken. In the midst of such circumstances, it is important for Japan to offer technological cooperation and support to China in the introduction of photovoltaic power generation.

Aimed at the extensive use of photovoltaic power generation in areas where power supply from the grid is difficult, or where power shortages are rampant such as inland of China, this joint research and development will effectively design photovoltaic power generation systems that suit local natural and social environments. It also includes technical assistance in solar cell evaluations in the country.

This joint project is being carried out from fiscal 1998 to 2001, during which will be installed at photovoltaic power generation systems schools, other public facilities and villages. Transfer of existing solar cell evaluation techniques to NEDO's Chinese counterpart is planned as well.

Solar Energy
Utilization
Technology

# 産業用等ソーラーシステム実用化技術開発

# Research and Development of Technology for Solar Energy Systems for Industrial Use

ソーラーシステムは、太陽エネルギーを熱源として利用するシステムであり、そのシステムは、太陽エネルギーを効率よく集める集熱器、雨天、夜間など太陽エネルギーを利用できない場合使用する蓄熱槽、熱を効率よく輸送する配管等の熱伝達系、熱を効率よく利用する熱変換器（吸収式冷凍機等）から構成されています。

システムを用途から分類すると、民生用と産業用の２つになり、民生用については、普及・実用化の段階にあります。一方産業用等については、熱消費量が多くまた、高度な熱管理及び低温から高温まで多種多様な熱工程を有するため、未だ研究開発課題が多数残されているのが実状です。

このため、NEDOでは、産業用分野等の太陽熱利用技術であって、将来実用化が期待され、かつ民間ではリスクが大きく研究開発が進みにくいものを対象として、実用化技術開発に取り組んでいます。

A solar energy system utilizes solar energy as a heat source. It consists of: a heat collection facility; a heat storage tank for when solar energy is not available such as at night or rainy days; a heat transfer subsystem including piping for efficient transportation of heat; a heat exchanger (absorption refrigerator,etc.) for efficient utilization of the heat; thermal insulation; and other peripheral devices.

Solar energy systems are divided by their intended end-uses into two classes: consumer systems and industrial systems. Consumer systems have already reached the stage of practical application. Industrial systems are currently being developed for applicability to industrial processes involving large amounts of heat consumption, sophisticated heat management and various kinds of heat processes ranging from low to high temperture.

NEDO's research is focusing on technologies which can be used practically but are as of yet too risky for the private sector to invest its own resources.

## ■ソーラーシステムの構成
## Types of Solar Energy Systems

ソーラーシステム
Solar Energy Systems

アクティブ "Active" System
・集熱器 Heat Collector
・蓄熱槽 Heat-storage tank
・熱輸送配管類 Heat-transport piping
・熱変換機 Heat exchanger
・断熱材 Heat-insulating materials

パッシブ "Passive" System
・調光材 Light-modulating materials
・透明断熱材 Transparent heat-insulating materials
・導光材 Light inducing materials

## ■産業用ソーラーシステム開発スケジュール
## Schedule for Industrial Solar Energy System Development

| 年度 Fiscal year | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|
| 1．アドバンスト・ヒートプロセス型システムの開発<br>Advanced heat process type solar energy system<br>①高効率太陽熱冷凍技術の開発<br>High-efficiency chemical refrigeration system using solar heat | | | | | |
| 2．パッシブ・ソーラーシステムの開発<br>Passive solar energy system<br>①アドバンスト・グレージングの研究開発<br>Development of advanced glazing materials | | | | | |
| 3．ソーラーシステムの調査研究<br>Research of solar energy system | | | | | |
| 4．太陽エネルギー利用システム国際共同技術開発<br>Joint international development of solar energy technology | | | | | |

## 1．高効率太陽熱冷凍技術

概要

Ｆ級温度レベル（－20℃以下）の冷凍需要は非常に大きいにもかかわらず、太陽熱を利用して得られる冷凍温度レベルは、－５℃～－10℃程度でした。このため、－20℃以下の冷熱を得ることを目的として、水素吸蔵合金と水素との反応熱を利用する冷凍技術を開発中です。その他本技術は、フロンガスを使用しないため環境破壊の恐れのないクリーンな冷凍システムが可能、水素ガスの形態で高効率長距離熱輸送が可能という特長があります。

技術開発のポイント

① Ｆ級冷凍温度レベルの低温度域で冷凍材料に必要となる諸特性（平衡特性、反応速度、寿命特性）を有する新しい高性能水素吸蔵合金を開発する。

② Ｆ級冷凍温度レベルの低温度域で高伝熱量、高断熱性、低熱容量という特性を持つ、新型熱交換器、新型水素吸蔵合金充填容器を開発する。また、冷凍システムの高効率化を図るため、熱回収制御、切替運転制御技術等の制御技術を開発する。

## High-efficiency Chemical Refrigerating System Using Solar Heat

Outline

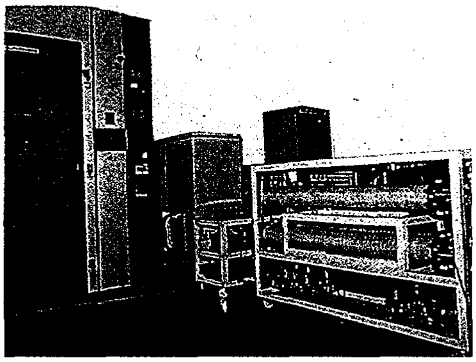
Although there is a high demand for refrigerating systems which can attain the F class refrigerating temperature level (-20℃ or lower), systems which utilize solar heat have not been able to reach that temperature so far. NEDO has been developing technology to output refrigerating heat with solar power by means of the reaction between a hydrogen absorbing alloy and a metal hydride. Because no freon gas is used, the system does not damage the environment. Also, by using hydrogen gas as the heating medium, the heat can be transported with high efficiency over a long distance.

R&D Targets

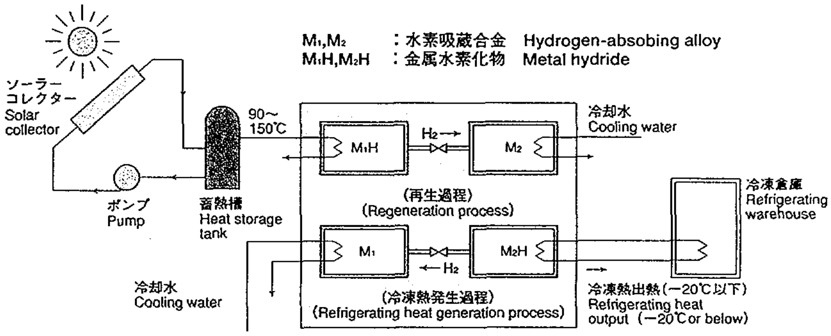
① A new, high-performance metal hydride having superior characteristics regarding equilibrium, reaction speed and durability will be developed for application as a refrigerating material at the F class refrigerating temperature level.

② A new heat-exchanger and metal hydride charging vessel capable of high thermal conductivity with low thermal capacity in the F class refrigerating temperature level are to be developed. Technologies for controlling heat recovery and changeover operation are also to be developed to increase the efficiency of the refrigerating system.

■高効率太陽熱冷凍システム
High-efficiency Chemical Refrigeration System Using Solar Heat



■原理図
Operating Principle




## 2．空気集熱方式による乾燥システム Drying System by Air Heat Collection

概要

広く太陽エネルギーの利用を促すため、太陽エネルギーに恵まれた諸外国との太陽熱利用システムの共同開発を進めています。
その一環として、インドネシア共和国との間で「空気集熱方式による乾燥システム」の共同技術開発を実施しています。

Outline

To facilitate the expansion of solar energy applications, joint technological projects with other countries are being implemented. The project entitled "Drying System by Air Heat Collection" is being conducted in cooperation with Indonesia.

■木材乾燥実証プラント
Demonstration Plant (Indonesia)

# 離島用風力発電システム等技術開発

# Development of Advanced Wind Turbine Systems for Isolated Islands

風力エネルギーは、無尽蔵な自然エネルギー源として太陽エネルギーとともに最も有望視されている再生可能エネルギーのひとつです。

しかし、風向・風速の変動に大きく左右され、エネルギー密度も低いため、その膨大なエネルギーの中で、実際に利用できる量はごくわずかにすぎません。

近年の酸性雨や地球温暖化などの環境問題への関心が高まるにつれ、風力においても日本の実情にあった地形条件や地表条件の下での風力エネルギー利用技術の開発が積極的に進められています。

日本の風力発電システムの技術開発は、通商産業省工業技術院ニューサンシャイン計画推進本部の下で、「ニューサンシャイン計画」として進められています。

Wind energy offers great potential as an energy source because, like solar energy, it is relatively inexhaustible.

However, wind energy can be influenced easily by fluctuations in wind direction and velocity, and it also has a low energy density. As a result, despite the existence of an enormous quantity of wind energy, only a small part of it is available for practical use.

With increased publicity regarding acid rain and greenhouse gas effects, more and more people are becoming aware of environmental problems. This is helping to spur the development of wind power technologies in Japan.

Taking into account Japan's geography and ground surface conditions, NEDO is focusing on developing large-scale systems in order to lower costs and increase effective land utilization.

Technology developments of wind power generation systems in Japan has being implemented under the New Sunshine Program by New Sunshine Program Promotion Headquarters at Agency of Industrial Science and Technology in MITI.

## 1. 離島用風力発電システム等技術開発

NEDOでは、平成10年度に終了した大型風力発電システム開発の成果を踏まえて、平成11年度から平成15年度まで離島用風力発電システム等技術開発を進めていく計画です。離島用風力発電システム等技術開発では、1. 離島における風力発電システムの開発、2. 局所的風況予測モデルの開発を行います。

### (1)研究開発目的

クリーンで再生可能な風力エネルギーの我が国への導入を拡大することを目的として、我が国の自然・社会条件を考慮し、我が国の風力資源に適した風力発電システムに関し、以下の技術開発を行います。

① 離島における風力発電システムの開発

高コストの重油ディーゼル発電に依存しており、潜在的な風力資源に恵まれている国内中小規模離島等への風力発電の導入普及を促進するため、その特有の立地・自然条件に適合した風力発電システムの技術を確立する。

② 局所的風況予測モデルの開発

風力発電サイトの最適な立地地点選定のため、我が国の複雑な風況に適応できる風況予測モデル(シミュレータ)を開発する。

## 1. Development of Advanced Wind Turbine Systems for Isolated Islands

Based on the results from the Research and Development of Large-scale Wind Power Generation System which was closed in 1998, NEDO is proceeding with the Development of Advanced Wind Turbine Systems for Remote Islands from 1999 through 2004. This new undertaking includes development of: 1) Advanced Wind Turbine Systems for Isolated Islands; and 2) Local Area Wind Energy Prediction Model.

### (1) Research and Development Objectives

To propagate the introduction of clean and renewable wind energy domestically taking into account our natural and social condition, it is essential to develop wind power generation systems suitable for existing wind energy resources. The development of the technologies are as follows:

① Development of Advanced Wind Turbine Systems for Isolated Islands

To establish technology for wind power generation system suitable for particular local and natural conditions, aiming at the introduction and promotion of wind power generation on small and medium-sized remote islands of Japan currently relying on expensive diesel generation.

② Development of Local Area Wind Energy Prediction Model

To develop a wind energy prediction model (simulator) capable of accommodating the complex wind condition in Japan the objective of selecting the most appropriate sites for wind power generation systems.

## (2)研究開発内容

① 離島における風力発電システムの開発

建設が容易であり、かつ従来機を上回る耐強風速性能をもつ風車について、翼材質、ハブ形式、設置工法等の要素技術開発及び風車の設計・試作試験を行うとともに、風力発電を最大限に系統に連系するための運転研究を行う。

② 局所的風況予測モデルの開発

気象データ（GPV等）と地形データをもとに、風車の建設候補地点近傍の正確な風況をシミュレーションできるモデルを開発する。

## (3)研究開発期間

① 離島における風力発電システムの開発
平成11年度～平成15年度（5年間）

② 局所的風況予測モデルの開発
平成11年度～平成14年度（4年間）

## (2) Research and Development Subjects

① Development of Advanced Wind Turbine Systems for Isolated Islands

To develop fundamental technology such as blade materials, hub type and construction methods, as well as design and testing of a wind turbine easy to construct while maintaining superior endurance with regards to wind velocity. Also, to research operating grid-connected wind power generation systems at full capacity.

② Development of Local Area Wind Energy Prediction Model

To develop a model based on the meteorological (e.g. Grid Point Value) and geographical data to enable the simulation of accurate wind conditions in the vicinities proposed for wind turbine erection.

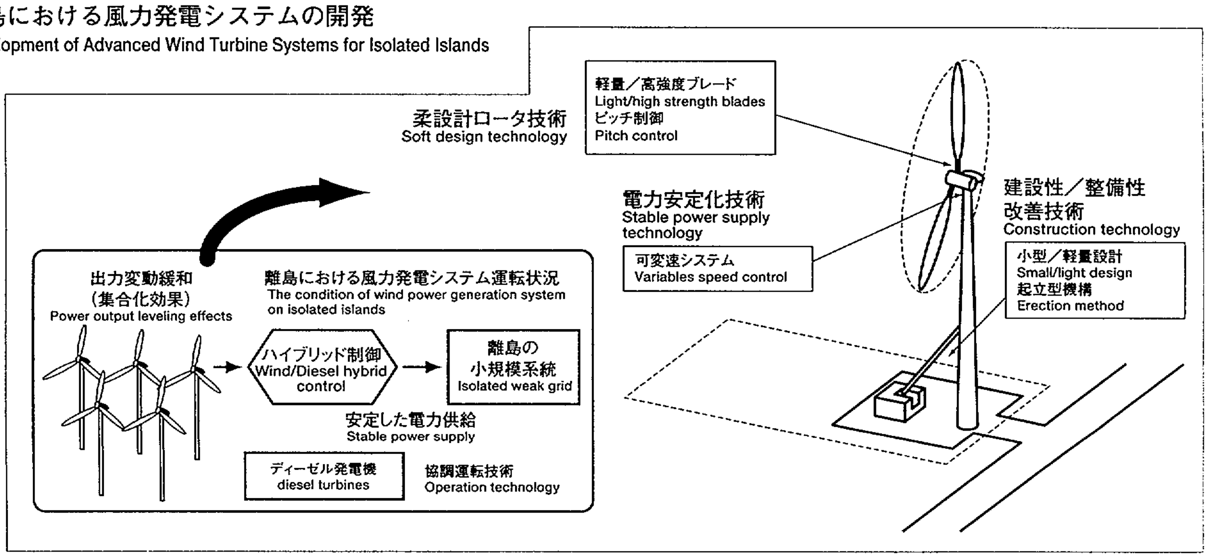
## (3) Research and Development Period

① Development of Advanced Wind Turbine Systems for Isolated Islands : From 1999 to 2004 (5 years)

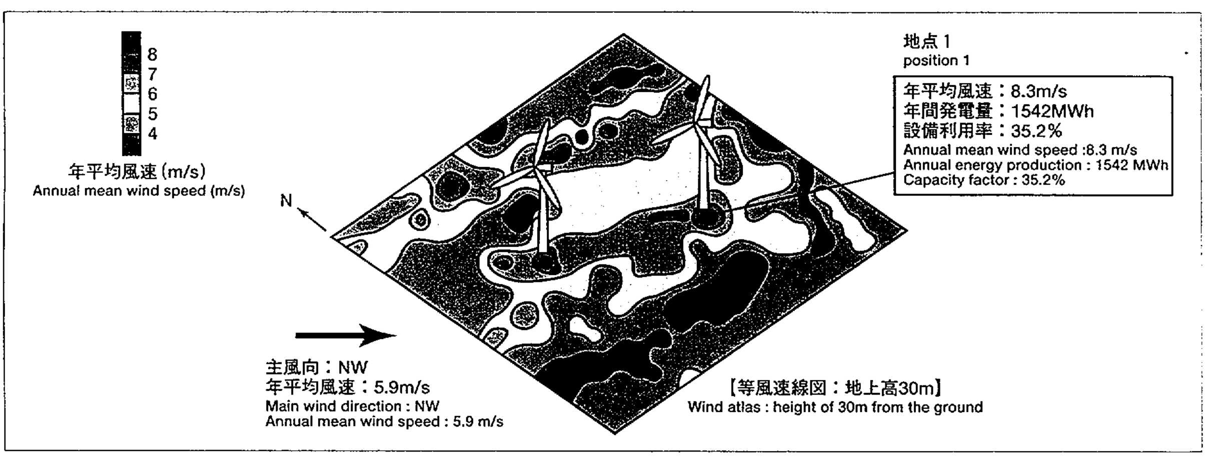
② Development of the Local Area Wind Energy Prediction Model : From 1999 to 2003 (4 years)

## (4)研究開発概要のイメージ
Research and Development Overview

離島における風力発電システムの開発
Development of Advanced Wind Turbine Systems for Isolated Islands




局所的風況予測モデルの開発
Development of Local Area Wind Energy Prediction Model



## 2．これまでの研究成果

### (1)大型風力発電システム（500kW）の開発

コストの低減及び土地の有効利用を図るため、剛構造・３枚翼で出力500ｋＷの大型風力発電システムの開発を行いました。

### (2)集合型風力発電システムの制御技術の開発

風力エネルギーを有効に利用する風力発電システムの実用化を目的として、沖縄県宮古島で集合型風力発電システムの系統連系運転等における制御技術の開発を行いました。

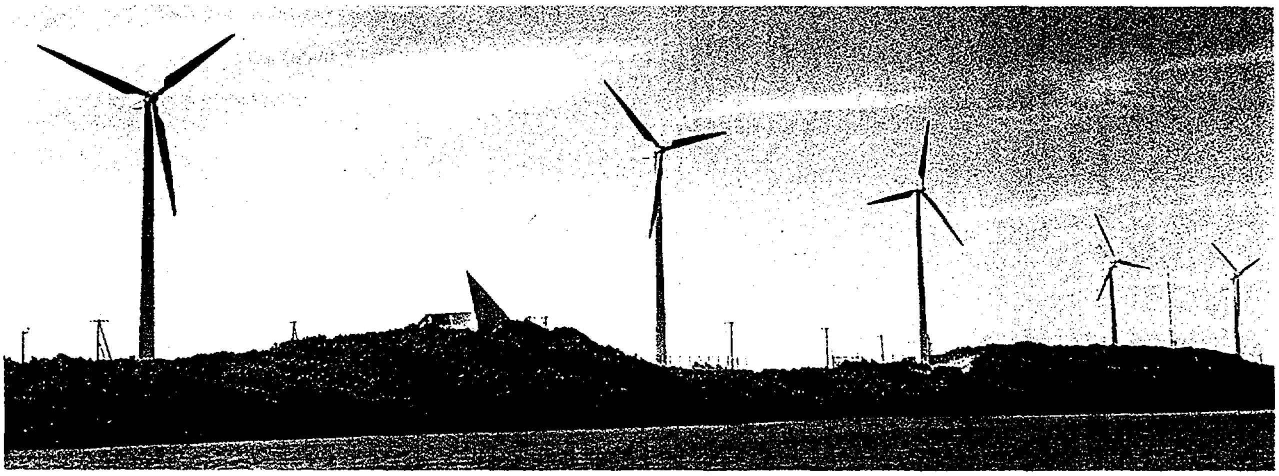
### Development of a Large-scale Wind Power Generation System (500 kW)

NEDO has developed a large-scale wind power generation system, rated at 500 kW and characterized by three rigid blades, in order to reduce costs and increase the effective use of land.

### Development of Control Technologies for Collective Wind Power Generation Systems

To practically apply wind power generation systems to the grid, NEDO has been engaged in developing control technologies for collective wind power generation systems at Miyako Island in Okinawa Prefecture.

宮古島風力発電システム　Wind Power Generation Systems at Miyako Island



### (3)風況観測

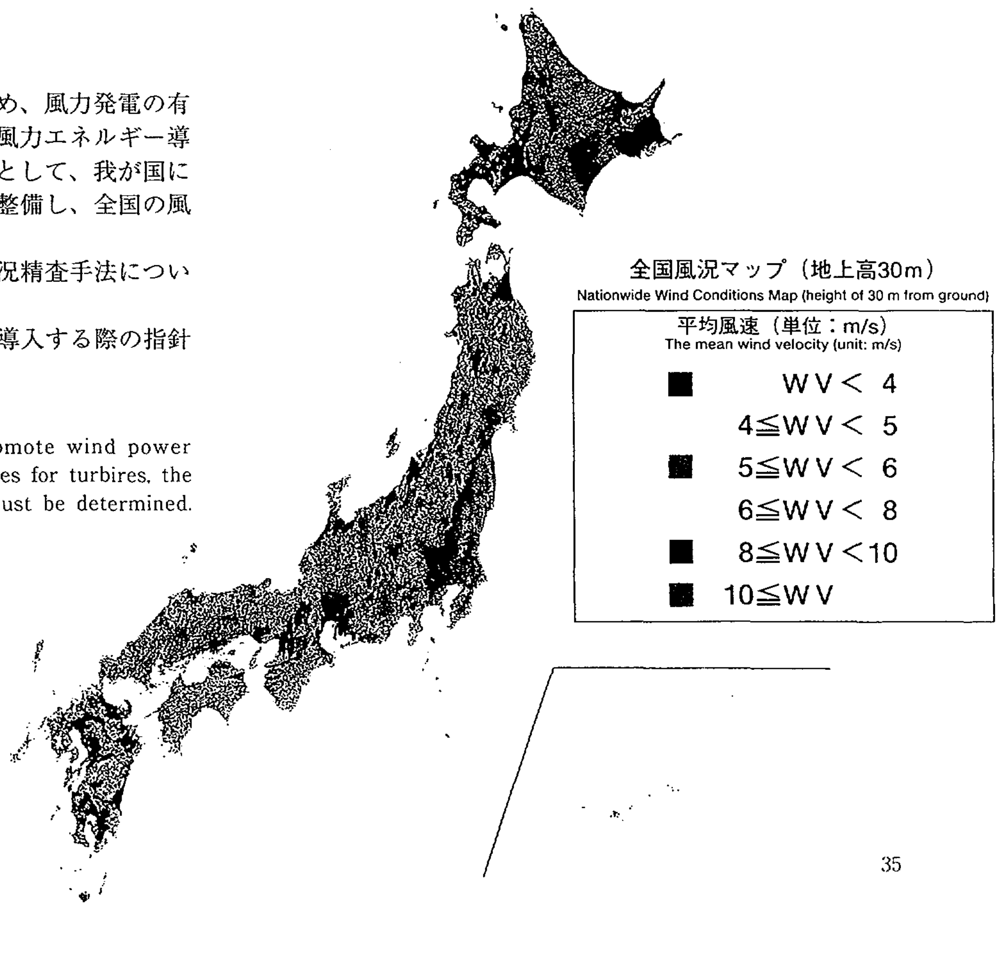
風力発電の導入の促進をするため、風力発電の有望地域を明らかにするとともに、風力エネルギー導入可能量等を評価することを目的として、我が国における風況に関する基礎データを整備し、全国の風況マップの作成を行いました。

さらに、高層風況予測手法や風況精査手法についても開発しました。

これらの技術は、我が国の風車導入する際の指針として、活用されています。

### Survey of Wind Conditions

To effectively introduce and promote wind power generation and identify candidate sites for turbires, the available capacity of wind energy must be determined. NEDO has collected basic data on the wind conditions in Japan and has created a nationwide wind conditions map methods for forecasting aeronomic wind conditions and a manual on studying wind corditions in detail have also been developed.



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*Expert Group Meeting*
*on*
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*Cairo, 26-28 April 2000*

# ***Jordan***

# Photovoltaic Activities and Applications in Jordan

**National Energy Research Center**

## 1. Abstract

About 3% of Jordan total population live in the rural and desert area which is about 80% of the total country area. These areas suffer the lack of basic electric and water networks. In 1980 the Renewable Energy Research Center (RERC) at the Royal Scientific Society (RSS) started research and development activities in the field of PV applications in Jordan for rural electrification and water pumping. In 1985, "Solar Photovoltaic Pumping Program" was initiated by installing the first PV water pumping pilot station. The results had shown a high degree of reliability for such systems, the fact that encouraged local and international sponsors to support this program.

The yearly average of solar irradiance in Jordan is about 6.42 kWh/m$^2$.d on a 40$^o$ tilted fixed surface, which makes Jordan a very attractive environment for solar applications. Moreover, after many years of intensive applied research, it is found that water pumping using PV as a power supply is the most feasible among the known pumping technologies in Jordan when the required equivalent hydraulic energy is less than 3800 m$^4$/day. Results have shown that, the cost of the cubic meter produced by PV technology is a bout half the cost that Jordan government pays by using traditional methods.

This paper briefly describes the Jordan PV program, existing applications, market, training program, collaborative links, and other information about Jordan activities related to PV applications.

As a case study, this paper presents the main results of the techno-economic study that was carried out on one of the PV water pumping projects in Jordan. This project consists of 7 PV-water pumping stations of 47.52 KWp total capacity.

## 2. PV Program

Jordan started its PV research program in 1980 by RERC. The main objectives of this research program were to study the technical and economical feasibility and reliability of PV systems to be used in rural areas in Jordan. In addition, it aims at introducing PV technology to the private and governmental sectors, which can be achieved by installing pilot projects covering the main applications of the PV technologies. Due to the fact that most of the rural areas of Jordan lack of access to clean drinking water for themselves and their cattle, the first research project was a PV water pumping system. The success of this project and other applications of photovoltaic technology encouraged international agencies to subsidize Jordan PV program by sponsoring long term international research projects to be installed in Jordan. As a result, data bank of all necessary parameters for many years is now available, which forms a solid base for PV program in Jordan. On the other hand, these research projects have played a major role in building personnel capabilities to serve as experts not only on the local or the regional level but also on the international level.

The main activities of PV program on both local and international levels are : system design technical and economical feasibility studies, installation, operation, evaluation, and maintenance. As a result of these activities many PV driven systems were installed such as : water pumping, electrification, water desalination ...etc.

Training is also one of the main important activities of the Jordan PV program. It is started by building up the RERC staff capabilities through training in many institutions and agencies in Europe and other countries. Then the transfer of know-how through training other local and regional groups on PV technology and applications was carried out. Several training courses were organized and executed for local concerned groups and for other groups from Arab countries.

## 3. Existing PV Applications

Many PV systems were installed in Jordan for research development and commercial objectives. A complete list of these systems including detailed information is annexed to this paper. The followings are the major PV applications in Jordan with the systems total peak power:

- Water pumping : 103.284 kWp
- Communications : 18.601 kWp
- Police stations: 16.606 kWp
- Schools: 1.750 kWp
- Teachers residences: 1.016 kWp
- Clinics: 6.491 kWp
- Mosques: 0.317 kWp
- Others: 15.892 kWp

- **Total** : 163.957 kWp

## 4. Size of the Market

Feasibility studies for the PV market in Jordan has shown that, PV applications are economically feasible in remote area where no electricity networks are available. It is believed that the market is still limited to rural areas for electrification, water pumping, desalination and other applications.

In general, more demand on water pumping and some electrification applications are expected. New applications such as water desalination, powered by PV, in remote areas are expected to have a place in the Jordan PV market.

## 5. Centers of Expertise

The National Energy Research Center is the main entity who is responsible for renewable energy research and applications in Jordan. This center has replaced the Renewable Energy Research Center (RERC) at the Royal Scientific Society (RSS), and the Renewable Energy Department (RED) at the Ministry of Energy and Mineral Resources (MEMR) which was in charge for renewable energy applications and policy in Jordan for many years. Well trained, qualified people are working in this field for many years. Those experts working in the center have very good experience in executing research projects on local, regional and international levels.

## 6. Industry Capacity

Jordan does not have any PV industry. On the other hand, Studies about manufacturing PV modules in Jordan had been conducted.

## 7. Areas of Need

In Jordan, we believe manufacturing PV cells is not prospective. However, in Jordan, more concentration on PV applications and researches that based on system performance and development is concerned. This is actually of high importance since well-optimized system may provide 40 to 50 % higher efficiency than poor optimized systems. This issue requires long experience in both theoretical and practical system behavior.

In this regard, personnel working in this field should get acquainted with every innovation or new product or new manufacturer in this field. It is worth mentioning that some of the PV system components could be produced locally.

## 8. Training Program

A yearly training program in the field of PV technology and applications is scheduled in Jordan. This serves local and international participants

A high tech Lab for design and simulation of PV systems is available in Jordan. This Lab can be efficiently utilized for such training courses .It has a PV simulator and other additional features that enable trainee to conduct several models of different applications (stand alone, water pumping ...etc.).

## 9. Collaborative links

Renewable energy applications in Jordan have started as research projects. For that it was necessary to cooperate with different international institutions in both technical and financial aspects. On the international level, distinguished cooperation has been established with the following institutes and ministries:

- German Agency for Technical Cooperation (GTZ)
- German Federal Ministry for Economic Cooperation (BMZ)
- German Federal Ministry for Research and Technology (BMFT)
- Deutsche Forschungsanstalt fuer Luft-und Raumfahrt e.v. (DLR)
- Research Institute for International Technical and Economic Cooperation (FIZ)
- Solar Institute Juelich (SIJ)

On the national level, cooperation is represented in consultation and services that are provided to different sectors such as Water Authority of Jordan, Public Security Department, Ministry of Health, ...etc. In addition, Ministry of Planning has financed a comprehensive project for renewable energy application to serve as Research and Regional Training Center.

## 10. Case Study

- **Application**: PV water pumping systems in remote areas
- **Project Name**: Eldorado PV Water Pumping Systems
- **No. Of Systems**: 7
- **Total PV power**: 47.520 kWp
- **Target Groups**: Bedouins and their cattle
- **Location**: Desert area of Jordan
- **Description**: Economical analysis based on actual figures

Technical maturity, reliability and economic feasibility are the most common perquisites for dissemination of any technology. Photovoltaic pumping systems have provided an attractive reliable solution for water supply in rural areas. However, in comparison to other alternatives, costs are still the decisive factor. In this regard, an economic study has been conducted to clarify this issue.

After the installation of all the systems related to this project (Eldorado), detailed economical study has been conducted based on actual data outputs and real cost calculations. This study has implied three scenarios for interest rate. The first one, which is more realistic, is 0% interest rate. This represents governmental aspect like the case of this project. The second case has considered interest rate of 5%, representing a local fund of low interest rate or an international fund. The third Scenario, which represents a fund from the local market, has considered an interest rate of 10 %.

In addition, four different policies for the proposed selling price of the output water unit (JD/ $m^3$) has been considered as follows: 1.0JD/ $m^3$, 0.65JD/ $m^3$, 0.35 JD/ $m^3$ and 0.1 JD/ $m^3$) [1.0 $ = 0.7 JD]. This method gives the cost of the output cubic meter at any value of the mentioned interest rates when the net present value goes to zero.

All necessary data have been collected and depicted in sheets and graphs so as to estimate the situation at any considered water unit price and interest rate. Based on experience, lifetime of PV modules has been considered as 30 years with 10 % power loss after 10 years and 15 % after 20 years). For other components like pumps and inverters, lifetime of 7 years is considered. For a comparison objective, another study considering 20 years as PV modules lifetime is also analyzed.

Moreover, two cases for estimated running cost have been considered. The first one which is the most common way did not consider Operators / Guards for the stations since these systems are fully automatic. The second case has considered salaries for two Guards for each station.

- **Main results**:

  - The cost of output cubic meter is 0.2JD
    (interest rate = 0%, lifetime of PV modules = 30 years, no guards).

  - The cost of output cubic meter is 0.37 JD
    (interest rate = 0%, lifetime of PV modules = 30 years, 2 guards for each station).

  - The cost of output cubic meter is 0.24JD
    (interest rate = 0%, lifetime of PV modules = 20 years, no guards).

  - The cost of output cubic meter is 0.42JD
    (interest rate = 0%, lifetime of PV modules = 20 years, 2 guards for each station).

  - The cost of output cubic meter is 0.4JD
    (interest rate = 10%, lifetime of PV modules = 30 years, no guards).

  - The cost of output cubic meter is 0.45JD
    (interest rate = 10%, lifetime of PV modules = 20 years, no guards).

  - If the water is sold at a price of 0.65JD/ $m^3$, the total profit of this project will be around 1,890,982 JD under the following conditions:
    interest rate = 0%, lifetime of PV modules = 30 years, no guards.

  - If the water is sold at a price of 0.65JD/$m^3$, the total profit of this project will be around 759,451 JD under the following conditions:
    interest rate = 5%, lifetime of PV modules = 30 years, no guards.

  - If the water is sold at a price of 0.65JD/$m^3$, the total profit of this project will be around 303,203 JD under the following conditions:
    interest rate = 10%, lifetime of PV modules = 30 years, no guards.

# Installed Photovoltaic Pumping Systems in Jordan

| | Well | Pump | | Inverter | | Photovoltaic Field | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station No. | Name | Name | Rated motor power kW | Name | Rated power KVA | Name | Peak power W | Pumping Head m | Daily Output $m^3/d$ | Date of operation | Remarks |
| 1. | Umari | Grundfos SP4-8 | 1.10 | Grundfos | 1.40 | AEG PQ 10/40 | 1613 | 36 | 40 | June, 85 | |
| 2. | AL-Hazeem 1 | Grundfos SP4-8 | 1.10 | Grundfos | 1.40 | Setek | 1764 | 19 | 60 | Jan., 87 | |
| 3. | AL-Hazeem 2 | Grundfos SP4-8 | 1.10 | Grundfos | 1.40 | Solarex | 1680 | 19 | 50 | Jan., 87 | |
| 4. | Rahmeh | Grundfos SP4-8 | 1.10 | Grundfos | 1.40 | Siemens 50 | 2226 | 35 | 40 | April, 86 | |
| 5. | Al-shomari 1 | Pleuger NE62-4 | 2.20 | Solar Verter 3 | 3.00 | AEG PQ 10/40 | 2150.40 | 13 | 70 | Aug. 89 | |
| 6. | Al-Shomari 2 | Pleuger NE62-4 | 2.20 | Solar verter 3 | 3.00 | AEG PQ 10/40 | 2150.40 | 13 | 70 | Aug., 89 | |
| 7. | Tal Hassan | GrundfosUPA100/ 4-19 | 3.70 | Sun Power | 5.00 | Al Mansour | 5880 | 75 | 40 | Jan., 90 | Replaced by 23 |
| 8. | Wadi El Buttom 1 | Netzsdch,2NQ14 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 1800 | 50 | 22 | Dec., 91 | |
| 9. | Wadi El Buttom 2 | KSB UPA 100B 4/12 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 3600 | 50 | 28 | Dec., 91 | |
| 10. | Wadi El Ritem | KSB UPA 150-3-5 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 4500 | 30 | 86 | June, 92 | |
| 11. | Hazeem El Dahek | KSB CORA 7-56-12 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 3600 | 25 | 77 | June, 92 | |
| 12. | Sarq El Hasa | KSB CORA 4-89-22 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 6300 | 85 | 47 | June, 92 | |
| 13. | Umrug 2 | KSB CORA 7-56-12 | 2.20 | Simovert P Sol | 3.5 | Siemens 50 | 4500 | 55 | 45 | June, 92 | |
| 14. | Fidan 6 | PLEUGER NE 44-12 | 2.20 | AEG Solar Verter3 | 3.00 | AEG PQ 10/40 | 4200 | 45 | 38 | Feb., 92 | |
| 15. | Breekah S-32 | KSB UPA 150-3-3 | 1.50 | AEG Solar-Verter 3 | 3.00 | AEG PQ 10/40 | 2800 | 37 | 57 | Feb., 92 | |
| 16. | Jafr 7 | PLEUGER NE 44-12 | 1.50 | AEG Solar-Verter 3 | 3.00 | AEG PQ 10/40 | 4200 | 35 | 64 | Feb., 92 | |
| 17. | Jafr 1 | PLEUGER NE 44-8 | 2.20 | AEG Solar-Verter 3 | 3.00 | AEG PQ 10/40 | 2800 | 25 | 66 | Feb., 92 | |
| 18. | Abour 6 | Grundfos SP8A-30 | 5.5 | Simovert | 7.5 | SM55 | 9900 | 56 | 75 | Sept., / 99 | |
| 19. | Hasa Al-Tanour | Grundfos SP4A-18 | 5.5 | Simovert | 7.5 | SM55 | 9900 | 44 | 117 | Sept., / 99 | |
| 20. | Retired serv. 2 | Grundfos SP8A-10 | 2.2 | Simovert | 7.5 | SM55 | 3960 | 33 | 34 | Sept., / 99 | |
| 21. | Al- Reesheh | Grundfos SP8A-37 | 5.5 | Simovert | 7.5 | SM55 | 9900 | 115 | 41 | Sept., / 99 | |
| 22. | Al-Lajoun no. 9 | Grundfos SP14A-7 | 2.2 | Simovert | 2.2 | SM55 | 4950 | 13 | 109 | Sept., / 99 | |
| 23. | Tal Hasan | Grundfos SP8A-37 | 5.5 | Simovert | 7.5 | SM55 | 5940 | 75 | 40 | Sept., / 99 | |
| 24. | Breekah 2 | Grundfos SP8A-10 | 2.3 | Simovert | 2.2 | SM55 | 2970 | 37 | 35 | Sept., / 99 | |
| | **Total** | | | | | | **103284** | | **1351** | | |

| | | | | |
|---|---|---|---|---|
| 1 | RAMA MOSQUE | 120 | ELECTRIFICATION | 1987 |
| 2 | REESHEH MOSQUE 1 | 77 | ELECTRIFICATION | 1987 |
| 3 | REESHEH MOSQUE 2 | 120 | ELECTRIFICATION | 1988 |
| | TOTAL | 317 | | |

## TEACHERS RESIDENCE

| No. | Station Name | Peak Power [W] | Application | Installation year |
|---|---|---|---|---|
| 1 | GREEGRA (teachers residence) | 150 | ELECTRIFICATION | 1987 |
| 2 | GREEGRA (teachers residence) | 100 | ELECTRIFICATION | 1987 |
| 3 | GREEGRA (headmasters residence) | 100 | ELECTRIFICATION | 1987 |
| 4 | REESHEH (teachers residence) | 154 | ELECTRIFICATION | 1988 |
| 5 | QATER (teachers residence) | 106 | ELECTRIFICATION | 1990 |
| 6 | AL-MOJEB (teachers residence) | 300 | ELECTRIFICATION | 1996 |
| 7 | AL-GMMAID (teachers residence) | 106 | ELECTRIFICATION | 1995 |
| | TOTAL | 1016 | | |

## OTHER APPLICATIONS

| No. | Station Name | Peak Power [W] | Application | Installation Year |
|---|---|---|---|---|
| 1 | KING TALAL DAM | 77 | EARTHQUAKE WARNING | 1986 |
| 2 | GHORE EL SAFI -BOTASH | 365 | HARVESTING ENGINE | 1986 |
| 3 | RAS YOUSEF | 225 | CONTROL SYSTEM | 1995 |
| 4 | AL REFAEYEH | 225 | CONTROL SYSTEM | 1995 |
| 4 | WADI FINAN CAMP | 3000 | ELECTRIFICATION | 1998 |
| 5 | PRODUCTIVE MADABA FOREST-BUILDI | 4200 | ELECTRIFICATION | 1998 |
| 6 | HAZARDOUS WASTE TREATMENT CENT | 7800 | ELECTRIFICATION | 2000 |
| | TOTAL | 15892 | | |

| No. | Station Name | Peak Power [W] | Application | Installation Year |
|---|---|---|---|---|
| 1 | AL-SALAMANI STATION | 600 | ELECTRIFICATION | 1993 |
| 2 | OMARI STATION | 742 | ELECTRIFICATION | 1993 |
| 3 | HAZEEM STATION | 742 | ELECTRIFICATION | 1993 |
| 4 | WEASAD STATION | 742 | ELECTRIFICATION | 1993 |
| 5 | HUSAIDA STATION | 848 | ELECTRIFICATION | 1993 |
| 6 | ANQA STATION | 742 | ELECTRIFICATION | 1993 |
| 7 | AL-HEABER STATION | 742 | ELECTRIFICATION | 1993 |
| 8 | HEADALH STATION | 954 | ELECTRIFICATION | 1994 |
| 9 | ROQBAN STATION | 954 | ELECTRIFICATION | 1994 |
| 10 | BOSTANA STATION | 954 | ELECTRIFICATION | 1994 |
| 11 | AL-ARTEAB STATION | 954 | ELECTRIFICATION | 1994 |
| 12 | AL-MASHAKEK STATION | 954 | ELECTRIFICATION | 1994 |
| 13 | AL-SAQRIAT STATION | 954 | ELECTRIFICATION | 1994 |
| 14 | E'NAZEH STATION | 954 | ELECTRIFICATION | 1997 |
| 15 | AL-MATWY STATION | 954 | ELECTRIFICATION | 1997 |
| 16 | BAYER 1 STATION | 954 | ELECTRIFICATION | 1997 |
| 17 | BAYER 2 STATION | 954 | ELECTRIFICATION | 1997 |
| 18 | MESHASH HODROGE STATION | 954 | ELECTRIFICATION | 1997 |
| 19 | AL-ENNAB STATION | 954 | ELECTRIFICATION | 1997 |
| | TOTAL | 16606 | | |

## MOSQUES

| No. | Station Name | Peak Power [W] | Application | Installation Year |
|---|---|---|---|---|

## CLINICS

| No. | Station Name | Peak Power [W] | Application | Installation Year |
|---|---|---|---|---|
| 1 | GREEGRA CLINIC | 1344 | ELECTRIFICATION | 1986 |
| 2 | RAHMEH CLINIC | 465 | ELECTRIFICATION | 1986 |
| 3 | REESHEH CLINIC | 3072 | ELECTRIFICATION | 1987 |
| 4 | BEER MATHKOUR CLINIC | 538 | ELECTRIFICATION | 1987 |
| 5 | MA'MORA CLINIC | 1072 | ELECTRIFICATION | 1991 |
| | TOTAL | 6491 | | |

## COMMUNICATION SYSTEMS

| No. | Station Name | Peak Power [W] | Application | Installation Year |
|---|---|---|---|---|
| 1 | FEIAN PHOSPHATE | 1760 | RELAY STATION SYSTEM | 1985 |
| 2 | UM-GHOZLAN | 1760 | RELAY STATION SYSTEM | 1985 |
| 3 | RAHMEH | 2162 | NON DIRECTIONAL RADIOBEACON SYSTEM | 1988 |
| 4 | REESHEH | 2162 | NON DIRECTIONAL RADIOBEACON SYSTEM | 1988 |
| 5 | UM-MATHLA | 2182 | RELAY STATION SYSTEM | 1990 |
| 6 | AL-SALAMANI | 400 | RADIO COMMUNICATION SYSTEM | 1992 |
| 7 | AL- RAJEF | 2025 | MICROWAVE COMMUNICATION SYSTEM | 1995 |
| 8 | QATER | 600 | MICROWAVE COMMUNICATION SYSTEM | 1995 |
| 9 | QREEQRAH | 600 | MICROWAVE COMMUNICATION SYSTEM | 1995 |
| 10 | RAHMEH | 1275 | MICROWAVE COMMUNICATION SYSTEM | 1995 |
| 11 | BEER MATHKOUR | 1275 | MICROWAVE COMMUNICATION SYSTEM | 1995 |
| 12 | BATTEN EL-GHOOL | 1200 | REPEATER STATION | 1996 |
| 13 | MODAWRA | 1200 | REPEATER STATION | 1996 |
| | TOTAL | 18601 | | |

## POLICE STATIONS

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *ESCWA*
# *Lebanon*

The ICS Expert Group Meeting on

NETWORKING OF PHOTOVOLTAIC SYSTEMS
AND APPLICATIONS

Cairo, 26-28 April, 2000

# STATUS OF PHOTOVOLTAIC APPLICATIONS AND THE RENEWABLE ENERGY PROMOTION MECHANISM IN THE ESCWA REGION

By

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## STATUS OF PHOTOVOLTAIC APPLICATIONS AND THE RENEWABLE ENERGY PROMOTION MECHANISM IN THE ESCWA REGION

*CONTENTS*

# STATUS OF PHOTOVOLTAIC APPLICATIONS AND THE RENEWABLE ENERGY PROMOTION MECHANISM IN THE ESCWA REGION

## 1. INTRODUCTION

In spite of the major role of the energy sector in the economy of the ESCWA region, the exploration, production and distribution processes in the ESCWA energy sector have their serious adverse environmental impacts on natural resources mainly air, water and soil, urban environment, as well as the ecosystems, marine life and demographical set-up. Therefore the need for developing mitigation measures for environmental impacts of the energy sector is crucial for sustainable development in the region. It is due to this situation that the energy sector is facing two main challenges. The first is the need for a transition to a more sustainable production and use of energy. The second is building and strengthening links in the field of energy among ESCWA-MS by promoting sub-regional and regional cooperation among them in the field.

To achieve such challenges and in view of the fact that all countries in the region enjoy tremendous indigenous Renewable Energy (RE) resources, the member States need to: (a) promote the use of cleaner fuels and technologies; (b) promote a cost effective mix of fossil fuel and RE resources and (c) mitigate to the maximum possible the environmental impacts of the energy sector.

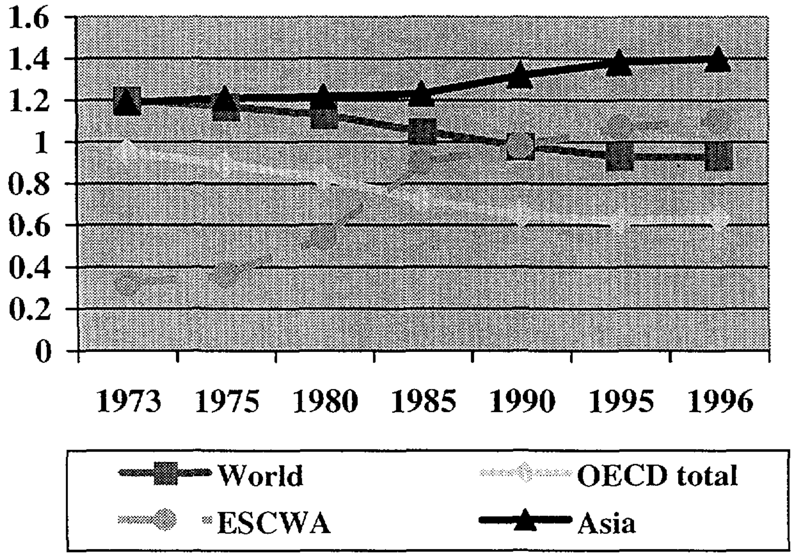
In addition almost 67 percent of the region's population (105 million) are living in the rural areas with limited or no accessibility to appropriate electric supplies. This fact puts emphasis on the importance of the RE development, particularly photovoltaic applications as an essential option for sustainable development in the region. Renewable energy applications in rural areas of the ESCWA region can bring a number of benefits including: (1) Diversification of energy resources; (2) contribution to poverty alleviation; (3) improvement of women's situation and response to gender perspectives; and (4) secure water supplies and creating better environmental conditions.

Meanwhile, many countries in the ESCWA region are characterized by high per capita fossil energy consumption together with high energy intensities, a situation which is not appropriately servicing the economic development but rather wasteful. Moreover, it can lead to more pollution, both locally and globally through GHG emissions, particularly $CO_2$ emissions.

The average energy intensity in the region reached 0.549 kgoe/US$ in 1996 counting for 1.7 times the world means. On the country level, it varied between 1.42 kgoe/US$ in Bahrain to 0.284 in Oman. This situation creates an urgent need in the region to develop and realize policies, regulations that targets more productive, environmentally friendly resources and technologies as well as better energy consumption patterns.

The total $CO_2$ emissions from fuel combustion in the ESCWA region have increased from 102.4 mt $CO_2$ in 1973 to 661.3 mt in 1996 (6.46 times) at an average growth rate of 8 percent. In the period 1975 to 1985, Figure (1) shows that, while $CO_2$ /GDP at other world group started to decline, the $CO_2$ /GDP at the ESCWA region increased drastically during the same period to exceed that of OECD and world average. This emphasizes the need for more efficient use of energy and the development of technologies that are environmentally clean, particularly photovoltaic electricity in rural and remote areas.

**Figure (1). $CO_2$ Emissions/ GDP by Region**
($Kg\ CO_2/US\$$)




This paper presents a survey of the current status of the photovoltaic development and use in the region covering areas of; (1) R&D and planning; (2) Demonstration and field testing, (3) existing industrial and marketing capabilities and (4) the commercialization status of the different photovoltaic applications. The paper will also touch on the institutional framework, strategies and policies that are relevant to the photovoltaic development in selected countries of the region as well as the constraints facing the development and widespread use of photovoltaic systems in the region.

In addition, the activities of the UN-ESCWA and its possible contribution to the development of photovoltaic applications in the region will be discussed together with the prospects for regional cooperation in the field.

The paper will also put emphasis on the rational, objectives, membership and current development status of the ESCWA Renewable Energy promotion Mechanism (REPM) established by ESCWA as a mechanism for networking activities among countries in the region, which can have an active role in supporting the proposed photovoltaic networking process.

## 2. THE PHOTOVOLTAIC SYSTEM AND APPLICATION STATUS

As given earlier, 67 percent of the ESCWA people live in remote and rural communities whose supply of energy (particularly electricity) is inadequate. It is the policy of several Governments in the region to provide all citizens with access to electric power in order to support socio-economic development. It is for this reason that solar PV applications have received different levels of attention in ESCWA-MS over the past 15 to 20 years.

### 2.1 Photovoltaic R&D and Planning

Since the late 1970's, several universities and research institutions in the region have directed efforts towards investigating PV technologies and applications. The research work had covered both theoretical and experimental investigations on components and system, however, the majority were linked to the performance evaluation of the demonstrated systems.

In Egypt, Jordan, and the Palestinian Authority, the PV potential application and markets were the subject of several planning studies, particularly in connection with rural electrification programmes. Most of the studies proved that PV for rural electrification has a high potential in many countries in the region.

### 2.2 Photovoltaic Demonstration and Field Testing

Different PV systems were demonstrated in several ESCWA-MS within the scope of bilateral and multilateral cooperation programmes. The main applications were water pumping, cathodic protection, desalination, clinical refrigerators, ice-making machines, telecommunication facilities and village electrification. Some of the demonstrated projects were effectively evaluated, others were just used as pilot plants, which may have been tested but not yet further developed nor replicated.

The total demonstrated PV capacity can reach over 1500 Kwp distributed between the different application with capacities from few watts up to about 200 Kwp each. The following are examples of the PV demonstration projects in the ESCWA-MS:

**In Egypt,** the PV demonstrations of around 400 Kwp include: (1) more than 10 water pumping projects with capacities varying between 2 Kwp and 10 Kwp; (2) several clinical refrigerators in the rural areas (5 Kwp); (3) microphone, battery charger, TV and telephone repeater stations; (4) a 200 Kwp central electrification system for a land reclamation farm at Owinat; (5) a hybrid PV diesel system of 34 Kwp for ice-making; and (6) remote village electrification project with a total capacity of 28 Kwp, serving 20 households street lighting and water pumping. As a result of these demonstrations, PV systems with higher capacities were applied.

**In Jordan,** PV systems were demonstrated and used in Jordan for a total capacity of more than 100 Kwp including: (1) Five (5) repeater stations for civil defense, each has 160 Wp; (2) water pumps for Bedwins with capacities varying between 1.4 to 6.3 Kwp per system; (3) PV village electrification systems in remote areas with system capacities varying from 1 Kwp to 4.5 Kwp; (4) a train crossing signal of 1760 Wp power; and (5) a radio transmitter situated at the Dead Sea of 3 Kwp capacity.

**In Kuwait,** demonstrated PV for operating water pumps, battery chargers for vehicles, fire-engines and police cars; Cathodic protection and few pumping stations are using PV for corrosion protection (1 Kwp); more than 5 PV operated pumps, one in KISR (6 Kwp), and 4 in various agricultural farms near Kuwait city, (5 Kwp) each. The total installed power exceeds 70 Kwp.

**In Oman**, several PV projects were installed within estimated total power of 50 Kwp. The applications are telecommunications, cathodic protection and water pumping for mountainous and scarcely populated areas.

**In Saudi Arabia,** PV demonstration and use including: (1) A 30 Kwp Fence electrification system for the 80 km long King Khalid Military City. (2) A 20 Kwp for lighting car park Jeddah International Airport. (3) A 10 Kwp tunnel lighting in the mountainous region of Abha. (4) A 100 Kwp PV units for cathodic protection and oil pumping station are used in most remote areas since 1965. (5) A 50 Kwp, highway telephones. (6) A 10 Kwp (RO) desalination, in Jeddah by the Red Sea.

**In Syria,** five villages were electrified by PV and a total of 30 Kwp used for park lighting, sea-shore beacon lighting and few water pumping.

**In the United Arab Emirates,** a 10 Kwp PV is used to light a tunnel and several PV units are used for cathodic protection and pumping in refinery oil stations (25 Kwp).

**In Yemen,** about 30 Kwp are used to supply electricity to the weather station, emergency lights, a small clinical refrigerator; and a demonstration PV pump was installed in a mountainous area in southern Yemen for pumping water.

In addition, systems with limited numbers and capacities totaling around 100.0 Kwp have been installed, demonstrated and tested in Bahrain, Iraq, Lebanon, the Palestinian Authority and Qatar.

## 2.3 Photovoltaic Commercial Status

In spite of the efforts directed to the development of PV technologies in the ESCWA-MS, its widespread use and commercialization were faced by a number of constraints that limited its commercial applications. In most of the cases, PV systems did not go beyond demonstration with the exception of the applications of telecommunication and traffic signals. The total 1998 installed capacity in the region was estimated at 3500 Kwp mainly in Egypt, Jordan and Saudi Arabia.

The Egyptian PV programme has remarkable objectives, it includes the PV village electrification programme targeting 30 villages to be electrified by 2005. In addition to a 60 MW central PV plant is being negotiated with Japan for use in project at Toshka land reclamation area.

## 2.4 Photovoltaic Technology Transfer and Local Manufacturing

In spite of the large number of foreign cooperation programmes and the demonstration projects implemented through it, an effective technology transfer of PV technologies was not effectively realized. However, the transfer of PV technologies was targeted mainly by Egypt and Iraq since the mid 1980's, mostly limited to encapsulation and module production. In Egypt, only one locally financed company Egycel is assembling PV modules since 1994 through an agreement with the Siemens Corporation, and marketing complete systems. The present production line has 150 Kwp annually as a break-even point, and the nominal line capacity is 500 Kwp annually. The information is not clearly available about other facilities in the region.

## 2.5 Photovoltaic Standards, Codes and Certification

Standard specifications and codes of practice for PV technologies and systems have received limited attention. The only standards for PV cells and panels are being developed in Egypt. In spite of the above, testing and certification centers, particularly EREDO/Egypt and RSS/Jordan, are testing and certifying PV components and systems according to the international standards and codes of practice.

## 2.6 Photovoltaic Training, Information and Awareness

During the last 20 years the countries of the region have directed efforts towards the upgrading of its capabilities in the RE field. Such efforts were mainly concentrating on building the specialized manpower capabilities, particularly in the R&D sector. Efforts towards training and awareness were much less directed to the parties that can have an effective role in deploying RE including photovoltaic to the market place, mainly decision-makers, bankers, industrialists, distributors and the targeted users of the technology.

The information dissemination activities were mainly conducted by the R&D community in organizing seminars and conferences dealing with the state-of-the-art of the technologies and applications. No doubt that the academic experience was had built up, and to a less extent the technological capabilities in the region, however it was very rarely directed to the wider group of parties participating to the development process.

## 2.7 Potentials of Renewable Energy Electricity

Several preliminary studies have estimated the potential for the applications of different RE technologies in the region, including ESCWA countries.

One of the most reliable studies was performed in collaboration between the EU/DGXII and the southern Mediterranean countries (SMC). The study presented an analyses of the situation and prospects for energy and electricity demand and supply in the SMC as well as a scenario for the large-scale development of RE for electricity generation, in view of the technologies status and development prospectives.

- The study evaluated the market potential for electricity production with RE is very large in the MNC. It has been estimated that, at horizon 2020, a production of 95 Twh could be achieved by power plants using RE with a total capacity of about 27 GW, distributed as

10 GW of wind systems, 2.5 GW of photovoltaic systems, 6.0 GW of solar thermal and 8.0 GW of biomass system;

- The estimated market potential of 2.5 GW for PV plants, is expected to produce 5 Twh, representing 1% of the total electricity production in the SMC, which constitutes a very large market for PV.

The benefits of utilizing such potentials would be large with fossil fuels savings representing more that 18 Mtoe/year of fossil fuels savings. Moreover, the reduction in $CO_2$ emissions would amount to 65 Mt/year, thus contributing to limiting GHG emissions. Another major benefit is linked to job creation which will contribute to social development in rural areas where the plants will be located.

## 3. RENEWABLE ENERGY INSTITUTIONAL FRAMEWORK

In spite of the diverse activities that have been taken by most of the ESCWA-MS in the RE field, an effective institutional framework for RE development is either not existing yet or still not sufficiently developed. The following overview the current situation in the ESCWA region regarding issues related to the RE institutional framework.

### 3.1 Renewable Energy Strategies, Policy Issues and Legislation

During the past two decades, most of the RE activities in the region were mainly linked to the R&D activities of the academic community in the countries, and were not considered as an integral element of the national energy plans. In addition, limited strategies and policy issues were adopted to facilitate the dissemination of RE applications.

Few countries, mainly Egypt, Jordan, and Syria have taken steps towards formulation of strategies, policies and plans for RE Development.

**In Egypt**, the government, in the early 1980's has formulated a national strategy for the development of RE applications and energy conservation measures as an integral element of its national energy planning,.

The strategy targets the development of RE including photovoltaic technologies/applications to supply five per cent of national primary energy. The PV contribution to such savings is assumed to be 80.0 t.o.e.

Egypt has also adopted a number of policy objectives to support RE development including: (1) To support RE as an integral element within the energy mix of Egypt; (2) adopt technology/applications that are approaching maturity and have a wide-scale replicability; (4) upgrade the local RE capabilities and localization of its technologies; and (5) maximize utilization of RE to electric power sector as appropriate.

**In Jordan**, the government adopted a number of policy issues to encourage RE development, it includes mainly: (1) development and adoption of RE technologies, particularly in remote areas; (2) upgrading R&D local capabilities; (3) increase designs and production capabilities for RE equipment; and (4) building testing facilities for RE equipments.

Currently, some regulations concerning tax and customs exemption of RE equipment and its pricing policy are being considered by the Government of Jordan (GOJ) for adoption.

**In Syria**, the higher committee on RE adopted a number of recommendations and guidelines for RE promotion

For the other member States, only policy guidelines encouraging R&D in the RE field are recorded, which do not constitute part of a specific strategy or policy towards integration of RE within the overall national energy policies and plans.

### 3.2 Institutional Structure

Within the framework of energy sector capacity building, some of the ESCWA countries have established specialized renewable energy (RE) institutions, while in other member States, the RE activities are undertaken mainly by universities, research institutes, and/or departments within different ministries. Where RE equipment manufacturing has started, local industrial firms are involved in the production, installation and maintenance of equipment. Being one of the core areas in the RE, photovoltaic systems development and applications are managed within the mandate of such institution.

Table (1) provides a list of the main institutions engaged in photovoltaic/renewable energy development in the ESCWA member countries, together with a brief outline of the mandate or specific fields of activity of each institution relevant to photovoltaic systems development. The institutions identified in the table are those that have remained active in this field and are expected to contribute to the future development of photovoltaic in their countries. As a result, the following can be noticed on the status of RE institutional framework in the region:

- Although all ESCWA-MS have national public and private organizations that are involved in different types of RE activities, however, in many cases, these organizations have no specific mandate for RE development or even sustaining their activities in the field;

- It is to be noted that the meteorological and natural resource organizations in the ESCWA region are conducting solar resource assessments. They are not listed in table (1) as solar resource assessments do not constitute their primary focus;

- In addition to the universities and research organizations, there are several specialized agencies that have been established in the ESCWA-MS to assume a wide scope responsibility for RE development from R&D to commercialization. These agencies include the New and Renewable Energy Authority (NREA) in Egypt, the Renewable Energy Research Center (RERC) at the Royal Scientific Society (RSS) in Jordan, the Palestinian Energy and Environment Research Center (PEC), the Renewable Energy Office (REO) in the Syrian Arab Republic;

- Testing and evaluation of photovoltaic systems have been carried out at several universities and research institutions in the region, mostly in connection with demonstration projects. The two most recognized, equipped and specialized are the Egyptian Renewable Energy Development Organization (EREDO) and the RERC in Jordan.

- Limited efforts were directed by the regional or subregional organizations in the region towards facilitating regional cooperation in the field of photovoltaic. ESCWA has initiated action to establish a framework for fostering regional cooperation through the exchange of information, expertise for further development of renewable energy in the region through the establishment of a Renewable Energy Promotion Mechanism (REPM) as will be described later in this paper.

## 4. CONSTRAINTS FACING THE DEVELOPMENT OF PHOTOVOLTAIC SYSTEMS AND APPLICATIONS

In spite of the efforts directed by the member States during the last two decades to the development of PV technologies and applications, their widespread use and market penetration are still faced by a number of constraints, some of common nature as those facing all other RE technologies, and some are specifically relevant to PV technology and the targeted application; such constraints include the following:

### 4.1. Lack of Proper Institutional Framework

The development of photovoltaic systems and applications as a part of the RE technology has often suffered from the lack of appropriate institutional framework. The absence of core specialised institutions in some countries and the limited coordination of activities in others, are key constraints for formulating appropriate policies, strategies, plans and programmes to promote the use of PV for different applications, and follow up on its implementation. In addition, there is an urgent need for an adequate legislation and incentive schemes as effective tools for such promotion.

### 4.2 Photovoltaic Technologies, Cost and Marketability

Most of the RE technologies, in particular photovoltaic, suffer from high costs and low volume of sales. The challenge is thus to promote a market in order to achieve high volumes and low costs. The specific market constraints linked to photovoltaic are dispersed potential users and to the structure of the local market which can only be developed through a coordinated effort of the government, local authorities, utilities and manufacturers, as well as national and international financing institutions.

The high cost of PV systems is another constraint and could be reduced by technology improvements, standardization of Balance Of System (BOS) component and local manufacturing including modules.

### 4.3 Economic and Financial Constraints

One of the major constraints facing the market deployment of PV technologies is related to the absence of adequate financing schemes. The first difficulty in the financing of a PV project is related to the comparison of the costs versus conventional options where a number of obstacles emerge related to:

- High capital cost of PV systems versus conventional options;
- Absence of the accountability of social and environmental benefits related to RE technologies;
- Lack of accumulated experience with long existing systems in similar conditions as to validate the economic evaluations;
- Subsidies for conventional energy supplies creating market distortions for PV as well as other RE options.

For this matter, specific financing schemes adapted to PV projects must be put in place, along with financial support to "buy down" its cost to help their market introduction, and also to take into account the benefits related to social and environmental aspects, (e.g., the grants offered by the GEF to buy down the incremental costs of RE projects).

For example, in rural areas, the problem is the lack of financial resources of rural households, and the tariff systems in many countries of the region are often based on cross subsidy principle to enable the rural population to have access to electricity. If prices would properly reflect reality, they should be superior in many regions, enabling thus the PV systems to become competitive in these regions.

### 4.4 Lack of Local Manufacturers

Since several PV systems and applications have been proved and the market starts to progressively develop, it is important to promote schemes for the transfer of the technology and/or technology sharing, as well as local manufacturing. This would contribute to local job creation, limit the need for foreign currencies, and enable cost reduction due to cheaper labour and absence of import taxes.

### 4.5. Lack of Awareness Regarding the Technologies Status

Often the actors (government, utilities, bankers, community cooperatives and NGO's) involved in the development of PV projects are not fully aware of the benefits related to PV use nor of the prospects for possible improvement and cost reduction of the technologies. Also, there is a lack of information, communication, dialogue and coordination between actors.

In addition, utilities and/or end users may not always be aware of the results of demonstration plants that can be applicable to them, and financing agencies and banks often do not know that PV projects may be profitable and represent investment opportunities, thus discourage them from considering such projects. Therefore, intensive efforts should be undertaken to disseminate results of projects already carried out and to inform concerned parties of the technologies available. Training programmes are also needed at all stages.

It is required that the public be made aware of the PV technologies availability and that persons making decision have accurate and up-to-date information. Potential purchasers need to understand cost effectiveness; and installers need to know appropriate installation techniques. In brief, an information dissemination effort aiming at making all parties aware of the RE technologies within the spectrum described above is crucially needed in the region.

## 5. ESCWA CONTRIBUTION TO RE DEVELOPMENT: THE CASE OF PHOTOVOLTAIC

In connection with its mandate to support the promotion of appropriate technologies for the economic and social development in the region, ESCWA has contributed to the development of RE in the region including photovoltaic systems and applications. Such contribution has included performing studies, providing advisory services as requested by member States, implementing field projects, as well as organizing Expert Group Meetings (EGM), seminars and conferences on related subjects. ESCWA activities in the RE field can be classified as follows:

### 5.1 Studies and Technical Publications

In the period 1982-1997 several studies were prepared to assess and evaluate the potential of RE resources and applications in the ESCWA member States. The progressive development of RE activities in the field was regularly assessed and considered as appropriate. Such studies can be classified into two main groups shown below.

- Planning and programme development studies, directed towards the evaluation of the various aspects of RE that can influence the formulation of development plans and programmes of RE utilisation. Emphasis was put on RE systems for rural development, particularly photovoltaic systems;

- Technologies and application studies, evaluating RE technologies and its potential applications relevant to the conditions in ESCWA member States and covering solar, wind and biomass technologies.

During the last four years (1996-1999), the Energy Issues Section (EIS) of ESCWA has directed concerted efforts towards RE including photovoltaic. These efforts have targeted the development of a systematic approach for assessing, evaluating and promoting the RE development status in the region. The main published studies on RE during this period are:

- Regional Programme for the Development of New and Renewable Energy Resources: Assessment and Prospects (1997). Document No. E/ESCWA/ENR/1997/14

- Promotion of New and Renewable Sources of Energy with particular Emphasis on Rural and Remote Areas (1999). Document No. E/ESCWA/ENR/1999/24

In addition, two studies are being completed for publication in year 2000, these are:

- Potentials and Prospects for Renewable Energy Electricity Generation in the ESCWA Region, the study puts emphasis on solar thermal and photovoltaic technologies.

- Regional Approach for Disseminating Renewable Energy Technologies, directed for promotion of the "REPM" and fund raising for the proposed projects completed in previous studies.

### 5.2 Formation of Regional and Subregional Project Proposals

In cooperation with various United Nations organizations and regional institutions, ESCWA has mobilised funds and implemented several renewable energy field projects, among which a photovoltaic demonstration project solar water pumping in Yemen.

In 1999 a project proposal for "Dissemination of Renewable Energy Services for Rural Villages in ESCWA-MS" was developed including five main activities: (1) Renewable energy assessment study; (2) Development of an awareness campaign on RE for sustainable development; (3) Capacity building activities; (4) Market development activities; and (5) Demonstration of photovoltaic rural electrification in the Yemeni villages, and ESCWA is currently working to raise funds for its implementation.

In addition ESCWA is currently finalising actions for the establishment and activation of the Renewable Energy Promotion Mechanism REPM as will be described in article (6) of this paper.

### 5.3 Advisory Services in the Field of Energy

ESCWA advisory services aim at assisting member States in their national development efforts. These services can provide technical support, assist in preparation and formulation of project proposals and documents, evaluate programmes and project proposals, and advise governments on various related issues.

Since 1984, the majority of the ESCWA regional advisory missions were on issues related to the renewable energy resources. Fifty six missions were undertaken on renewable energy issues for eleven member States, namely: Bahrain (1), Egypt (16), Iraq (2), Jordan (7), Lebanon (1), Oman (3), Qatar (3), Saudi Arabia (1), Syrian Arab Republic (7), United Arab Emirates (2) and Yemen (13), as well advisory services were provided to the Palestinian Authority.

### 5.4 Information Flows and Awareness

Recognising the importance of information exchange and dissemination between the concerned experts and institutions in the region, ESCWA is directing efforts towards organising Expert Group Meetings, training workshops and networking of RE entities in the region.

This year (2000), the EIS/ENRED is organising the following two events to be held in Beirut during the period (2-5) October 2000:

- The Expert Group Meeting on Dissemination of Renewable Energy Technologies, which will constitute a forum for discussing and exchanging views on how to alleviate the constraints facing the dissemination of RE technologies in the ESCWA-MS with particular emphasis on: (1) RE market prospects in ESCWA-MS; (2) Solar thermal electricity generation; (3) Photovoltaic electricity; and (4) Market penetration strategies, policies and measures.

The EGM is devoting one day for photovoltaic status and programmes in the region with particular emphasis on the potentials and prospects for PV applications.

- A one day seminar for the initiation of the REPM, will be held back to back with the EGM mainly to (1) present and discuss the compendium of country profiles prepared by ESCWA; (2) review the final status of project agreement endorsement; and (3) discuss the two year work programme of the REPM to be prepared by CU/ESCWA in consultation with the NFP's.

## 6. REGIONAL COOPERATION AND NETWORKING OF PHOTOVOLTAIC SYSTEMS AND APPLICATTIONS

The assessment of the current status of PV development in the region as reviewed in this paper indicates clearly that the prospects for PV development in the region are promising and PV would be an effective contributor to the future sustainable energy supplies in the region. However, its widespread use is faced by the constraints described earlier. Therefore, it is then the challenge of the countries and concerned organizations in the region to identify means and ways to overcome such constraints.

The removal of PV constraint would require the adoption of a set of well designed actions covering all areas of activities required and implement it in full coordination between the concerned parties on national, subregional and regional levels.

Over the last two decades, activities in the RE field, were through the bilateral cooperation programmes with developed countries, with very limited effective cooperation between the countries in the region. It became essential to promote cooperation between the countries in the region, specially based on environmentally-sound technologies, that are approaching the state of maturity and need to be pushed to the market place in a commercial scale.

Furthermore, many countries in the region have acquired intensive experience in the different RE fields, and some of them have been recognized as active participants to the technological development process in their countries of RE equipments, as well as having capable national institutions.

To this end, it is clear that fostering regional cooperation in the field of RE among ESCWA-MS is a vital need to enable them to utilize their resources and capabilities effectively and streamline it for their sustainable development.

In recognition of the above situation, ESCWA, in 1998, has proposed to its member States the establishment of a Renewable Energy Promotion Mechanism (REPM) to foster the regional and subregional cooperation in the field.

### 6.1 ESCWA Renewable Energy Promotion Mechanism (REPM)

The REPM core objectives are to overcome the constraints facing the widespread use of RE in the ESCWA-MS based on utilization of their common capability built during the last two decades. Meanwhile, the project basically addresses the need in the ESCWA region for the promotion of cooperation among MS for the development of renewable energy technologies (RET), particularly Solar, Wind and Biomass.

**The development objectives of the REPM** are to enhance the promotion of environmentally-sound RET to contribute to the economic development of the ESCWA-MS, based on the tremendous resources available and the capabilities built within the different countries as well as the ESCWA expertise and coordination links to the international agencies. Such objectives include:

(a) Accelerating the diffusion of environmentally sound renewable energy technologies to contribute in applications that are either highly replicable in the region or crucially required for remote and isolated areas;

(b) Fostering cooperation among the countries in the region by promoting the intraregional exchange of information and expertise and by raising funds for joint activities;

(c) Making use of existing capabilities in member countries to the benefit of each others. Particular attention would be given to the milestone experiences related to equipment standardization, certification, field testing, training and the development of local industries;

(d) The mechanism would put emphasis on capacity building in this field for concerned personnel and institutions from the decision making level to the systems operation and maintenance;

(e) Enhancing public awareness in the region with regard to RE applications and their environmental benefits;

(f) Developing the national, sub-regional and regional capabilities in areas contributing most effectively to rural development, support the establishment of small and medium size RE industries that can lead to the creation of job opportunities, conventional energy savings, and the realization of other economic, social and environmental benefits.

**The REPM organizational setup and coordination linkage** are shown in Figure (2). ESCWA secretariat will setup a coordination unit (CU) to mobilize and administer the REPM. The CU would be responsible for the following:

(a) Providing a forum that can be used by concerned national entities and companies in the region to make and maintain contacts and carry out consultations;

(b) Work with the national focal points to identify business opportunities that require cooperation between national entities;

(c) Coordinate the capabilities in each country so that the RE development objectives of individual ESCWA members anywhere in the region can be achieved with greater speed and efficiency;

(d) Create a central database that can be used to locate and promote business opportunities and to match capabilities with needs;

(e) Organize workshops, seminars and exhibitions in the ESCWA-MS to facilitate the exchange of experiences in the design, execution and management of RE projects;

(f) Promote technology transfer and manufactures' licensing arrangements for the benefit of the countries in the region;

(g) Identify barriers to the use of RET and recommend corrective measures and commercialization packages.

**The National Focal Points (NFP),** each member country joining the mechanism should select an entity to serve as its NFP. These focal points would be responsible for representing their respective Governments in the mechanism activities and operation; serving as liaison between the national entities and the coordination unit; exchanging with the coordinating unit the country data and other information required to facilitate effective intraregional cooperation and mobilization of joint activities; and identifying and regularly updating a list of national business entities qualified to participate in the programme. (These recommendations will place the focal points under no liability.)

## 6.2 The Current REPM Development Status

The current status for the initiation and activation of the REPM is as follows:

- An updated project proposal incorporating the views of ESCWA-MS was prepared and circulated to MS;

- Ten ESCWA-MS have agreed to join the mechanism and nominated their National Focal Points as shown in table (2).

The State of Bahrain and Saudi Arabia haven't responded to date, while the State of Qatar expressed its unwillingness to join the mechanism

- In 1999, EIS/ESCWA has prepared: (1) a framework for RE country profiles; (2) a model country profile (Egypt); and (3) the project memorandum of understanding. All were circulated to member States to prepare their RE country profiles;

- ESCWA is currently coordinating with member States regarding the preparation of RE country profiles identifying RE resources, institutions' activities, capabilities and needs. Based on such profiles, the:

- CU will prepare a compendium of the country profiles identifying possible areas of cooperation among ESCWA-MS based on the capabilities and needs identified by the country profiles;

- ESCWA is organizing an EGM for the NFP's to discuss: the updated proposal, and the compendium of the country profiles, as well as to endorse the project Memorandum of Understanding;

- ESCWA will assign the staff for the Coordination Unit of the Mechanism (CU), who will start to perform the tasks identified by article (6) of the proposal including the following:

(a) Continue the consultation with the remaining ESCWA-MS to join the REPM or to identify possible links with it;

(b) Develop an inventory of RE institutions, expertise and business entities;

(c) Prepare a two-year work plan for consultation with NFP's;

(d) Promote actions for implementation of the projects proposed by the current activities as a starting activity for REPM;

**Table (2). REPM, nominated National Focal Points (NFP's)**

| Member State | National Focal Point |
|---|---|
| Egypt | New and Renewable Energy Authority |
| Iraq | National Committee for Technology Transfer |
| Jordan | National Center for Energy Research |
| Kuwait | Ministry of Electricity and Water |
| Lebanon | Electricite du Liban |
| Oman | University of Sultan Qabous |
| Palestinian Authority | Palestinian Energy Authority |
| Syrian Arab Republic | Ministry of Electricity |
| United Arab Emirates | Ministry of Electricity and Water |
| Yemen | Ministry of Electricity and Water |

* REPM: ESCWA Renewable Energy Promotion Mechanism.

## 6.3 Conclusions and Recommendations

Based on the current status of PV systems and application in the ESCWA region described in this paper, the constraint facing its development and the experiences acquired by countries in the region, the following can be concluded:

(a) There are a reasonable market for PV systems and applications in the region that need to be utilized;

(b) Regional coordination and cooperation within the region, as well as with other Arab countries and international agencies, is crucially needed for development of the PV systems and application. Particular emphasis should be put on capacity-building, training, marketing development and raising awareness;

(c ) The ESCWA (REPM) is a step towards the objectives and it is recommended to coordinate efforts with other agencies to enhance the process particularly with UMA and UNIDO.

## TABLE (1) RENEWABLE ENERGY INSTITUTIONS IN ESCWA MEMBER STATES, THE RENEWABLE LINKS TO PHOTOVOLTAIC SYSTEMS DEVELOPMENT*

| ESCWA Member | Institution | Mandate/activities |
|---|---|---|
| **Bahrain** | University of Bahrain | Limited academic R&D activities. |
| **Egypt** | 1. Ministry of Electricity and Energy (MOEE) | |
| | New and Renewable Energy Authority (NREA) | Established in 1986 to be the core organization for RE development in Egypt on a commercial scale. It is entrusted to plan and implement RE programmes in coordination with other national institutions, its mandate include RE resource assessment, testing and certification of RE equipment and field projects, market and economic evaluation studies, feasibility studies, support of technology transfer and local manufacture, project implementation, as well as training and awareness programmes. |
| | 2. Ministry of Industry and Mineral Resources | |
| | (a) General Organization for Industrialization (GOFI) | Participates in the evaluation of industrial capabilities, possible modes for technology transfer, and possibilities for the local manufacture of R.E equipment. |
| | (b) The Egyptian Standardization Authority (ESA) | Responsible for developing and setting local standards, codes and testing procedures for RE equipment and systems. |
| | 3. Private Industry | Photovoltaic module assembly, and systems installation. |
| | 4. Ministry of Higher Education and Scientific Research | |
| | (a) Universities(*)<br>(b) National Research Center (NRC)<br>(c) Academy of Scientific Research and Technology (ASRT) | Resource assessment and planning studies; R&D activities relating to components and systems; demonstration and field testing research projects. |
| | 5. American University in Cairo (AUC) | |
| | Desert Development and Training Center (DDTC) | Demonstration, testing and training of R.E systems for desert development, particularly PV systems for lighting and irrigation. |

(*) Includes the Photoenergy Research Center, Ain Shams University.

| ESCWA Member | Institution | Mandate/activities |
|---|---|---|
| **Iraq** | 1. National Committee for Technology Transfer | R&D activities and previous activity in photovoltaic cells assembly. |
| **Jordan** | 1. Ministry of Energy and Mineral Resources | |
| | - The National Renewable Energy Center | Established in 1984 to formulate national policies to help Jordan achieve energy security. It is concerned with the formulation of RE policies, identifying priorities, supervising the establishment of standards and regulations, and implementing projects. |
| | 2. Royal Scientific Society (RSS) | |
| | - Renewable Energy Research Center, (RERC) | Main focus is on R&D activities, demonstration projects, testing and certifying the support of local industries in the development of components and system designs. |
| **Kuwait** | 1. Kuwait Institute for Scientific Research (KISR) | R&D on solar energy systems and demonstration and testing of equipment and systems. |
| | 2. Kuwait University | - R&D activities relating to solar photovoltaic (PV) systems. |
| **Lebanon** | 1. National Council of Scientific Research (CNER) | |
| | - National Centre Renewable Energy (CNRS) | Established in 1997 to help coordinate RE activities in Lebanon, conduct R&D in the field of RE, and develop RE equipment testing facilities. |
| | 2. Ministry of Hydraulic and Electricity Resources | Carries out planning studies on RE electricity production and shares coordination efforts in the field of RE in Lebanon. |
| | 3. Universities:<br>- American University in Beirut (AUB), Faculty of Engineering and Architecture | Resource assessment and planning studies; Academic R&D studies on solar and wind applications; and building climatization studies. |
| | - Lebanese University, Faculty of Engineering; and Faculty of Science | Educational programmes and R&D on photovoltaic cells. |
| | 4.Non-governmental organizations (NGO's) | |
| | - Lebanese Association for Energy Rationalization (ALME) | Studies on potentials for RE in Lebanon, including photovoltaic and promotion and awareness-raising activities. |
| **Palestinian Authority areas** | Palestinian Energy and Environment Research Center (PEC) | Established with the support of the EU SYNERGY Programme and entrusted with energy policy formulation and planning, the coordination of national and bilateral energy efficiency and RE activities, and the development of standards, regulations and laws. |

| ESCWA Member | Institution | Mandate/activities |
|---|---|---|
| **Qatar** | 1. Industrial Development Center<br><br>2. Qatar General Petroleum Corporation | Demonstration and field testing of solar desalination systems; and developing applications for photovoltaic systems. |
| **Saudi Arabia** | 1. Saudi Arabian National Center for Science and Technology (SANCST) | Funding and coordination of demonstration projects (such as the SOLERAS project). |
| | 2. Universities | R&D activities relating to solar thermal and PV technologies. |
| | 3. King Abdulaziz City for Science and Technology (KACST) | Coordinates activities in the field of RE and resource assessment. |
| **Syrian Arab Republic** | 1. The Syrian Ministerial Cabinet Renewable Energy Office (REO) | Established in 1988 to (a) formulate and coordinate RE development plans and establish implementation priorities; and (b) follow-up on implementation with concerned organizations. |
| | 2. Scientific Studies and Research Centre | Studies and development of analytical centre models for RE systems; and participation in the development of local RE equipment standards. |
| | 3. Syrian Arab Organization for Standardization and Measurements (SAOSM) | Developing standards and specifications for RE equipment. |
| **United Arab Emirates** | 1. Trade and Industry Department (Fujairah Emirate) | Resource assessment and planning activities. |
| | 2. Universities | Academic R&D activities and resource assessments. |
| **Yemen** | 1. Ministry of Electricity and Water Renewable Energy Department (RED) | Involved in formulating development plans, carrying out resource assessments, and following-up demonstration projects particularly for PV for rural areas. |
| | 2. Sana'a University | Academic studies. |

*Source*: Information obtained from various country reports. ESCWA documents and concerned authorities.

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**Proceedings of**

***Expert Group Meeting on "Networking of PV Systems and Applications"***
***Photoenergy Center, Faculty of Science, Ain Shams University,***
***Cairo, Egypt 26-28 April 2000***

**Organized by ICS in collaboration with the Photoenergy Center**

**Expert Group Meeting Directors**

**Mr. Anthony Bromley, Senior Officer, UNIDO/IEE/SES**

**Prof. Dr. Sabry Abdel-Mottaleb, Director, Photoenergy Center**

**Organizers**

**Mr. Gordon Thompson, ICS High Technology Consultant**

**Mr. Tatsushi Kurobuchi, ICS Programmer Officer, High Tech and New Materials area, Trieste, Italy**

**Prof. Dr. Sabry Abdel-Mottaleb, Director, Photoenergy Center**

## Collected Papers and Presented Materials

**Prepared by**
**Professor Dr. M. S. A. Abdel-Mottaleb**

**May 2000**

**Cairo, Egypt**

CONTRACT NO. 2000/062

**PART (3) <u>ANNEX B</u> (PROCEEDINGS OF THE EG MEETING): 3.2**
TWO PARTS IN TWO SEPARATE BOOKS
IT CONTAINS PAPERS AND MATERIALS PRESENTED

# *Part 2*

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *Morocco*

# PV activities in Morocco


- **Dr. A. Hanine BENALLOU**
- President
- SunLight Power Maroc


- **Networking of PV systems and applications.**
- **Cairo 26-28 April, 2000**

# Outline

- Overview of the energy sector in Morocco
- Existing PV applications and programs
- The market
- Organization of the sector :
  - Centers of experience and industry capacity
  - Areas of need and existing collaborations
  - Existing training programs

# Overview of the energy sector in Morocco

- Population : 30 M
- Rural : 48 %
- Rural electrification : 28%
- Energy consumption : 8.5 TOE
- Energy production : 0.8 TOE
- Energy deficit : 91%

# Electricity sector

- Installed capacity : 3450 MW
- Cocessional production
  - Thermal :1300 MW
  - Wind : 60 MW
- Grid interconnections : 300 MW
- PERG :
  - Grid : 100.000 Households per year

# PV applications and programs in Morocco

- Motivations
  - High dependence on oil
  - Negligible local production
  - Low rural electrification ratio
  - Good solar radiation

# PV applications and programs in Morocco

- Strategy
  - Communication and training
  - Demonstrations
  - Pilot projects
  - Market scale-up

# PV applications and programs in Morocco

- Communication and training
  - Awareness/Public sector
  - Introduction of renewables in training
  - Multi-sector / multi-use communication
  - General communication

# PV applications and programs in Morocco

- **Pilot Projects strategy**
  - **Large pilot programs :**
    - **show technical feasibility**
    - **Build public confidence**
    - **Identify areas of needed improvement**
    - **Determine show-stoppers**

# Project : SAER

**Schéma d'approvisionnement Energétique Régional**

- **Objectives : Private market start up in a region**
- **Target : Rural households / 1 province**
- **Equipment**
  - SHS of 40, 50 and 80 Wp
  - Solar battery charging station

# Project : SAER

**Schéma d'approvisionnement Energétique Régional**

- **Year : 1991**
- **Installed (1991) : 120 SHS + 1 SCS**
- **Total installations : 8.2 kWp**
- **Lessons :**
  - Subsidy
  - Local ASS

# Project : PPER

**Programme Pilote de pré-Electrification Rurale**

- **Objectives : Develop adapted solutions for rural electrification**
  - Technical
  - Institutional
  - Financial
- **Target : 3 provinces / 30 villages**
- **Equipment**
  - SCS, SHS, Micro-hydro, Diesel

# Project : PPER

**Programme Pilote de pré-Electrification Rurale**

- **Year : 1989-1994**
- **Installed : 35 kWp**
  - 13 SCS serving 800 households
  - 100 SHS
- **Lessons :**
  - New financial schemes
  - Institutional pattern
  - SCS limitations

# Project : Village Power

- **Objectives : Integrated village electrification**
  - Households : SHS + SCS
  - School
  - Mosque
  - Public lighting
  - Water pumping

- **Target : 15 villages**

# Project : Village Power

- Equipment
  - SHS of 50 Wp
  - SCS of 700 Wp
  - Schools : 100 Wp
  - Mosque : 100 Wp
  - Public lights : 100 Wp
  - Pumping : 750 Wp

# Project : Village Power

- Year : 1993-1996
- Installed : 30 kWp
- Lessons :
  - Importance of a viable business for local relays
  - Difficulty of managing integration

# Project : Solar pumps

- Objectives : Demonstrate feasibility in different regions of the country
- Target : 200 villages
- Equipment : 500 to 2000 Wp pumps
- Year : 1985-1996
- Total installed :
  - 200 pumps
  - 300 kWp

# Project : Solar pumps

- Lessons :
  - Feasible
  - Maintenance is capital
  - Revenue stream is essential
  - Public management is not feasible

# Project : HEALTH

- Objectives : Electrification of rural health centers
- Target : Different provinces in the country
- Equipment
  - Lights : clinic + house
  - Refrigeration

# Project : HEALTH

- Year : 1994 to date
- Installed : 15 kWp
- Lessons :
  - Feasible
  - Maintenance possible by health clinic personnel
  - Importance of local relays.

# Project : Rural schools

- Objectives : Provide electricity to remote schools
- Target : Rural schools in different regions of Morocco
- Equipment : 200 to 500 Wp

# Project : Rural schools

- Year : 1995 to date
- Installed : 80 kWp
- Lessons :
  - Subsidy
  - Local ASS

# Project : Railroads

- Objectives :
  - Railroad crossings protection
  - Land-train radio communication
- Target : Different remote locations
- Equipment : 250 Wp to 1 kWp per station

# Project : Railroa

- Year : 1988 to date
- Installed : 88 kWp
- Lessons :
  - Good solution
  - Maintenance feasible by railroad technicians

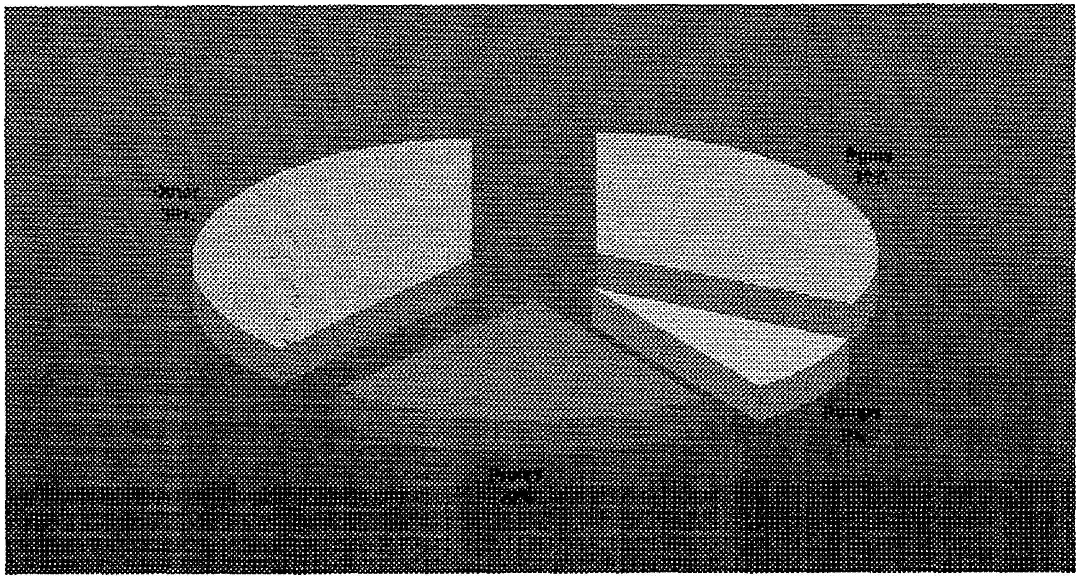
# Project : Telecommunications

- Objectives : Energy supply
- Target : Remote repeater stations
- Equipment : 400 kWp to 2 kWp per station
- Year : 1986 to date.

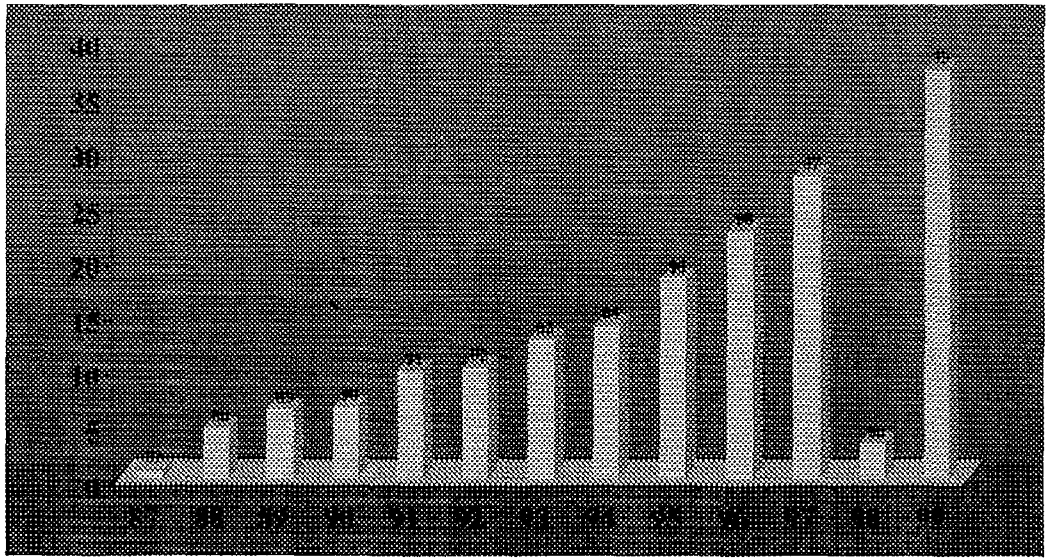
# Project : Telecommunications

- Installed :
  - Phone : 540 kWp
  - Radio/TV : 142 kWp
- Lessons :
  - Good solution

# Distribution of total installed capacity



# Market evolution



# Present projects

- PERG/PV
  - 200.000 hshlds/ 5yrs
  - Utility subsidy : US$300/hshld
  - Fee for service scheme
- Partners : Utility/Private

# Present projects

- **PVMTI**
  - UD$ 5million available
  - Long term loans to private
  - 3 companies selected
  - Starts : By end of June
  - Partners : WB, IFC, Private

# Present Projects

- Rural energy Houses
  - 200 energy houses for 2001
  - Subsidy covering 50% of investmennt
- Partners : ME, UNDP, Private

# Centers of expertise

- CDER :
  - Program development
  - Tests
  - Training
- Utility : Program development
- ME : Strategy development
- Private sector : Execution

# Industry capacity

- BOS :
  - Regulators
  - Lamps
  - Lamination (-)
- Contracting : Inst & ASS
- Eng : Tech, Fin, Inst, Field

# Areas of need

- Financing
- Technology partnerships
  - Quality manufacturing
  - Innovations
- Training

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *Palestine*

**Networking of PV system and applications, Cairo 26-28 April**

# Presentation of Palestine

*By H. HAMED & N. ATTILI*
*PEC, PALESTINE*

Due to absence of fossil fuel resources and due to several years of occupation, Palestine has to import about 95% of electrical energy from the IEC. About 120 villages still suffer from either lack of electricity or insufficient services, living in a rural area of about 60% of the whole area (6000 $km^2$). About 45 communities (50,000 inh.) have no electricity and about 73 communities (210,000 inh.) have partial services through decentralized diesel generators.
The municipalities and village councils are responsible for distribution and sale of electricity. The prices vary between 12 cent for imported to 50 cent/ kWh for locally generated.

Abundant of solar radiation (5.46 kWh/ $m^2$.day) enables solar energy installation to fulfill larger part of energy needs.

The Palestinian Energy & Environment Research Center (PEC) has started with pilot projects for PV applications through its clinic electrification program. In spite of the system high cost (15 $/ $W_P$), applications extended to electrify isolated schools, households, public establishments and publicity stations. More than 60 systems (35 kw) were installed. There is serious discussion with the Palestinian Telecommunication Co. to supply all remote stations with PV systems. Moreover, the Solar Demonstration Station is going to be established soon. Financing of these projects was by subsidies and international grants, local authority contribution, final users and combination.

The potential of PV market seems to be high. It is expected to electrify about 1000 Bedouin families, 40 publicity stations and 19 water pumping stations (30 kW). Investigations indicate that PV electrification is possible for about 60 villages of 1.2 MWp total power. The estimated cost is about 18 M $.

As PEC is the national institution responsible for renewable energies, it has the expertise, capacity and capability for promotion, design, installation and maintenance of PV systems. PEC can be considered as the center of PV activities. The role of private sector is limited to management of financial aspects (Banks) or supply of equipment (SOLNUR Co.). Non of the components of the PV system is locally manufactured, but available in the market.

Special training programs on PV applications are needed. Efficient technology like equalizing system for storage batteries, solar water pumps, technology for industry and telecommunication applications are also needed to be introduced.

Several collaborative links and joint activities have been established in order to promote and utilize PV technology:

- Palestine is a member in the World Solar Summit.
- Palestine is a partner in the EC projects for integration of PV for rural electrification (iresmed, intersudmed projects).
- Palestine is a partner in the MEDENER group for promotion of renewable energies.
- Palestine is cooperating with the Ministry of Baden Wuerttemberg/ Germany for a PV revolving fund project.
- Palestine involves in Eldorado German Program for promotion of PV technologies in developing countries.
- Palestine cooperates with UNIDO for promotion of renewable energy applications.
- Palestine involves in the PV exhibitions held in Mediterranean region.

The on going PV programs are:

1. Promotion of PV technology and applications through organizing periodic workshops for people and students, in addition to the demonstration system fixed on a car and always travel in the rural areas.
2. Preparation of technical and financial studies for maximum utilization of PV technology. Some of these studies are INTERSUDMED and IRESMED.
3. ELDORADO project: a German- National fund for public use aims to electrification of isolated clinics, schools, and threatened areas by Jewish Settlements. The capacity of this project is about 104 systems.
4. Baden Wuerttemberg project: a German revolving fund for private use aims to electrification of isolated houses and farms. The first phase capacity is about 90 SHS.

The installed PV Systems in Palestine through Eldorado and Baden projects are as follows:

**1- Eldorado Project**

19 schools Total Capacity =12 kw

12 clinics Total Capacity = 7 kw

24 Bedwin Sites Total Capacity = 5 kw

Public Establishments Total Capacity = 3 kw

**2- Baden Württemberg Project**
(Revolving Fund Project)

21 home systems Total Capacity = 8 kw

Total Installed Capacity = 35 kw

Problems and Obstacles of PV technology in Palestine:

PV is still a new technology.
The high cost of the system (moduels, batteries, inverters, etc).
Lack of experience of technical staff.
Lack of experience and bad use of the system by the clients.
Extreme regulation and rules of the Israeli occupation especially within what is called Area C.
Lack of investors and financing.
Difficult economic situation of the people.

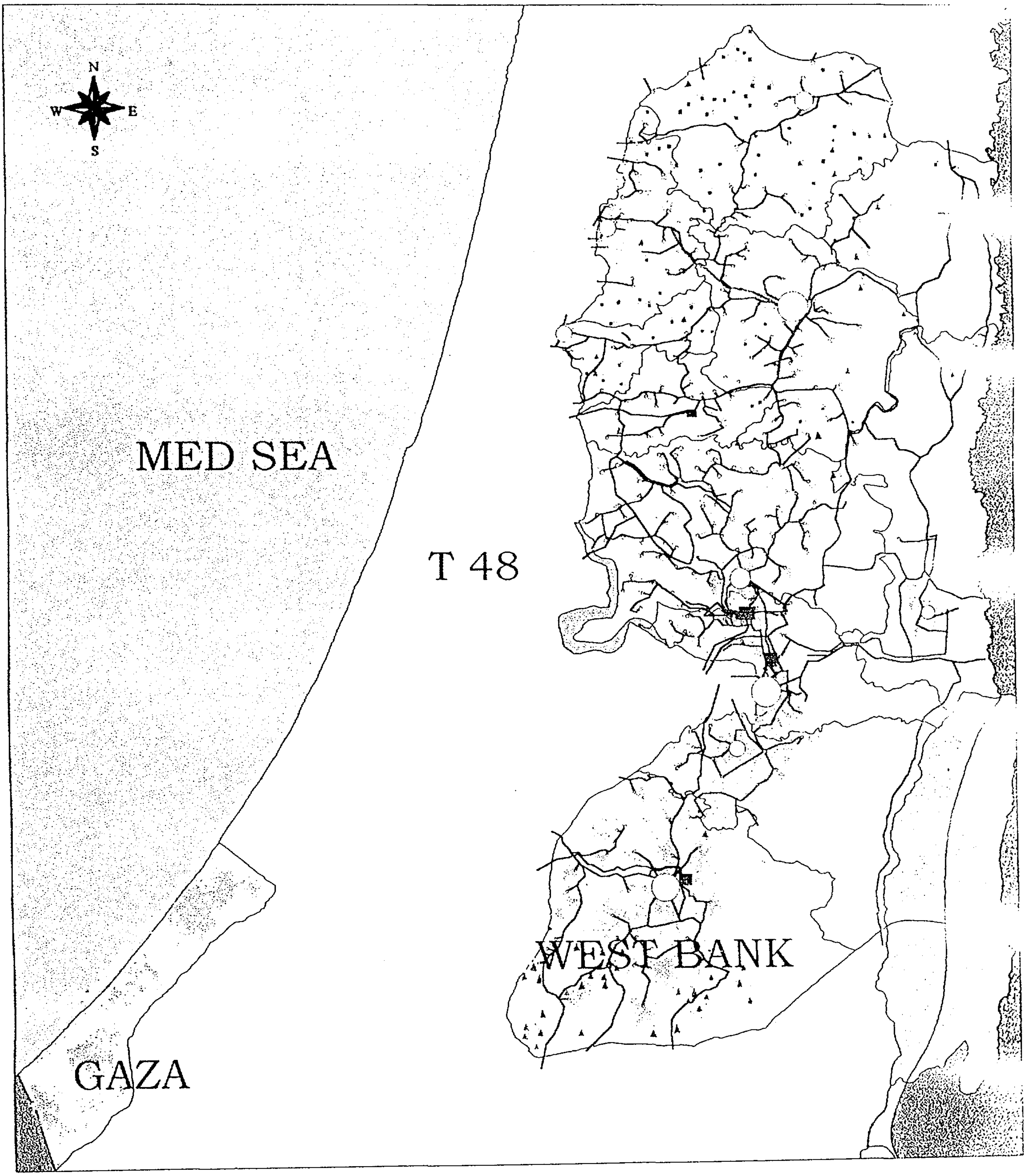
PEC

Palestinian Energy & Environment Research Center

# Networking of PV System and Applications

## Presentation of PALESTINE

# Network Map



# Palestinian Territories

- *Pales Territories : WB & GS* **(6000 km², 3 mill inh)**
- *Rural Area :* 60% , **120 villages**
- *Non Electrified :* 45 **(50,000 inh, 7550 houses)**
- *Partially Electrified :* 73 **(210,000 inh, 18,600 houses)**
- *Energy Resources*
  - **Electricity**
  - **Petroleum Products**
  - **SOLAR** 5.46 $kWh/m^2$.day
  - **Wind** 4 m/s, 600 $kWh/m^2$

# *Investment & Operation Costs*

| | | | |
|---|---|---|---|
| *LV (400 V)*<br>*2500 $/ km* | *PV*<br>*400 $/ module* | ***Diesel Gen.***<br>***130/ kW*** | *IEC network*<br>*8.9 cent/ kWh* |
| *MV (33 KV)*<br>*45,000 $/ km* | *Complete:*<br>*15 $/Wp* | ***Fuel cost:***<br>***13 cent/ kWh*** | |

| | | |
|---|---|---|
| *Customer P.O.V.* | *Electric* | *Non electric* |
| ***Yearly consumption*** | *517 kWh/ inh* | *3174 kWh/ inh* |
| ***cost*** | *12-50 cent/ kWh* | *3 cent/ kWh* |

# PV Applications

## Existing Applications:

- *Clinics , Schools & Establishments*
- *Houses , Publicity Stations*

## Prospects:

- *Telecommunication*
- *Water Pumping & Street Lighting*

## Financing:

- *Subsidies & International Grants*
- *Local Authority*
- *Final Users / Combination*

# Potential of PV Market

- Installed Capacity > 60 systems (35 Kw)
- Expectation:
  - 1000 Bedouin families
  - 40 Publicity stations
  - 19 Water pumping stations
- PV electrification is possible for 60 villages
  - Capacity : 1.2 MW
  - Cost : 18 M$

## Areas of Need

*Training:*

- ***Installation & maintenance for new applicat.***

*Technology:*

- ***New PV Applications***
- ***Efficient storage system, inverter, etc.***
- ***Powerful & less expensive system***

- *Non of the components of SHS is locally manufactured, but available in the market.*

# Organization Structure of PV Activities

***Regional & International***

*Technical & financial assistance*

***PEC***

*-center of expertise*

*- capacity for promotion & installation*

***Private Sector***

*-Solnur Co.*

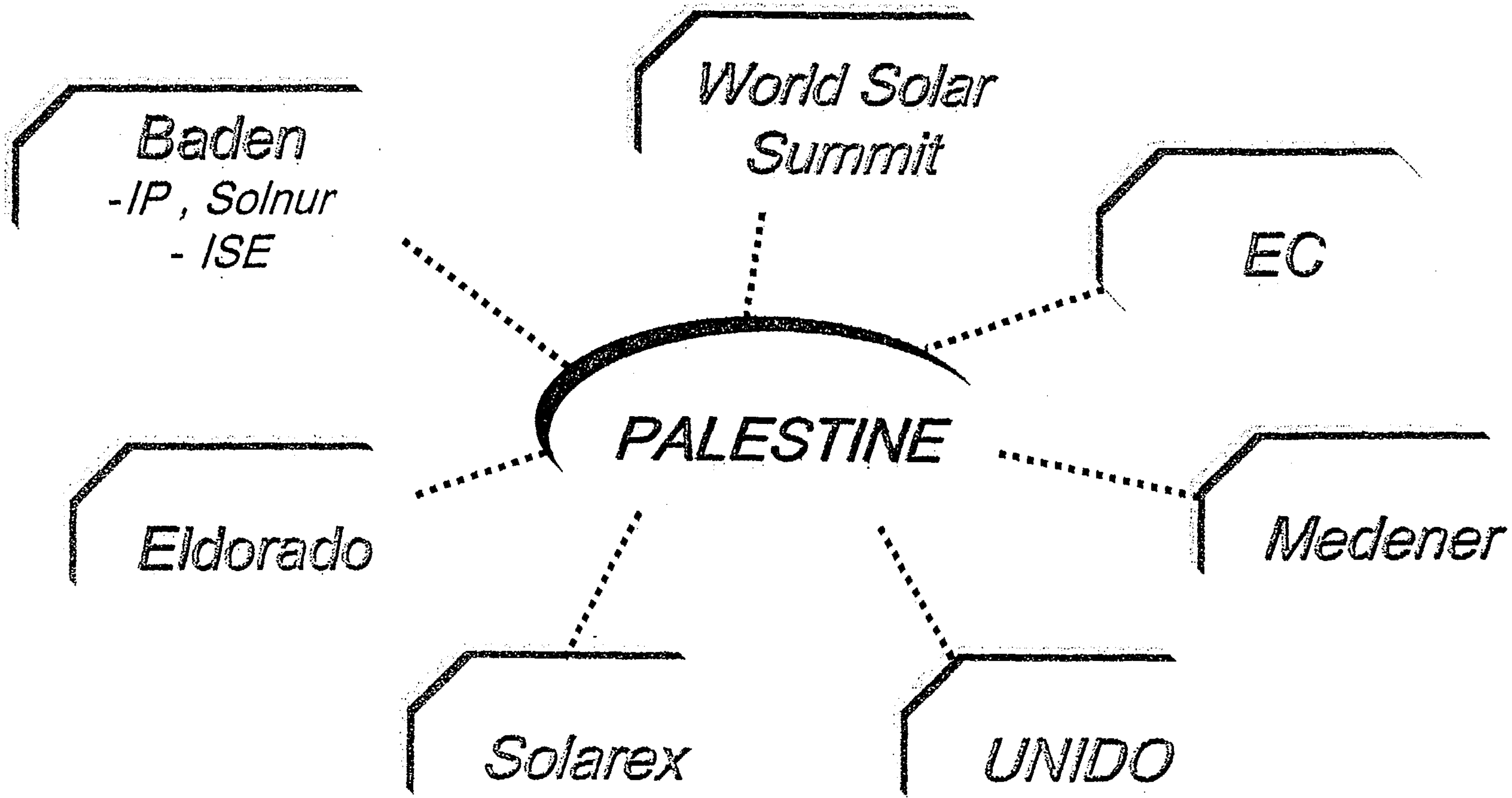
*-Banks*

***Government***

*-PEA*

*-MLG*

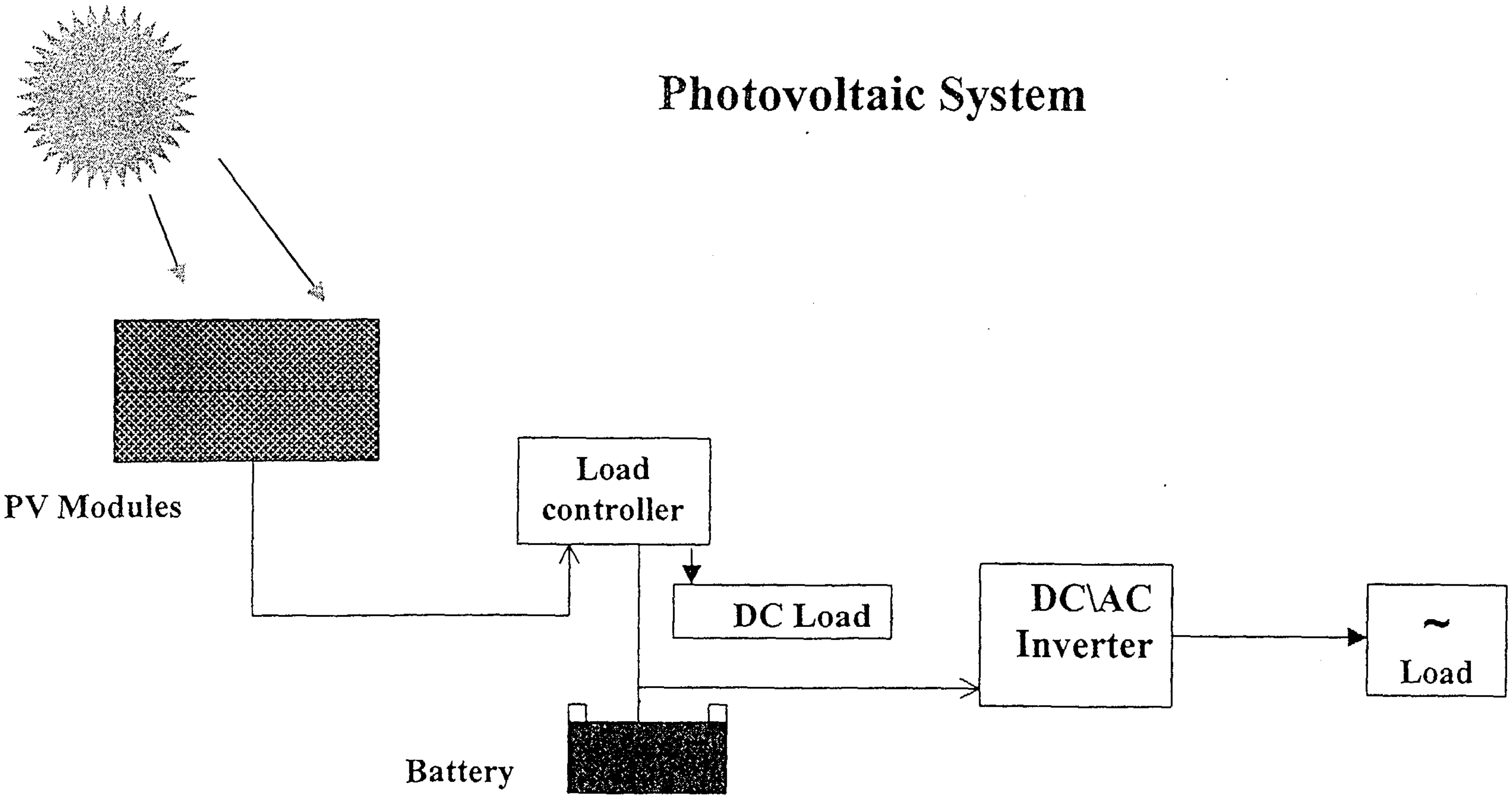
# Collaborative Links



# PV Programs

- Promotion of PV Tech. & Applications
- Preparation of Studies for Max. Utilization of PV
- Eldorado: German-National fund for public use
  - **Electrification of isolated clinics, schools, & threatened areas** (capacity 104 systems)
- Baden: German revolving fund for private use

# Photovoltaic System



# Installed PV Systems in Palestine

## 1-Eldorado Project

| | |
|---|---|
| 19 schools | Total Capacity =12 kw |
| 12 clinics | Total Capacity = 7 kw |
| 24 Bedwin Sites | Total Capacity = 5 kw |
| Public Establishments | Total Capacity = 3 kw |

## 2-Baden Württemberg Project

## (Revolving Fund Project)

| | |
|---|---|
| 21 home systems | Total Capacity = 8 kw |

**Total Installed Capacity = 35 kw**

# Sizing of PV System

| Calculation of PV-System - 220V~ | | | | | | | |
|---|---|---|---|---|---|---|---|
| Item | Quantity | Power Consumption | Time used | Daily Consumption | Module | | |
| | (no) | (W) | (hrs/day) | (Wh/day) | | | |
| lamp | 5 | 13 | 6 | 390.0 | Po er | (W) | 55 |
| TV | 1 | 100 | 5 | 500.0 | Voltage nominal | (V) | 12 |
| radio/recorder | 0 | 0 | 0 | 0.0 | Voltage at MPP | (V) | 17.5 |
| fridge | 1 | 100 | 7 | 700.0 | Current at MPP | (A) | 2.95 |
| appliances | 0 | 0 | 0 | 0.0 | Modul energy | (Ah/day m²) | 2.95 |
| lamp 2 | 0 | 9 | 4 | 0.0 | | (Ah/day) | 16.1 |
| losses | 0 | 0 | 0 | 0.0 | Battery | | |
| | | | | 0.0 | Type | | |
| | | | | 0.0 | Capacity | (Ah) | 100 |
| **Net Power Demand** | | | | **1,590.0** | | | |
| Total Power Demand | | (Wh/day) | | 1,590.0 | **Final Specification** | | |
| Losses | Inverter | 10% | | 1,749.0 | Modules | No | 8 |
| | Battery | 20% | | 2,067.0 | load controller | A | 23 |
| | Cables | 5% | | 2,146.5 | Inverter | VA | 305 |
| | Module | 5% | | 2,226.0 | Batteries | Ah/day | 318 |
| **Gross Power Demand** | | | **(Wh/day)** | **2,226.0** | | No | 3 |
| | | | **(Ah/day)** | **127.2** | | | |

Remarks:

No of batteries: max. discharge: 80%; spare days: 1

Module energy: 2.95 Ah at a radiation of 1 kWh/m² day

Actual radiation summer: 8.0 kWh/m² day

winter: 3.0 kWh/m² day

average: 5.5 kWh/m² day

Module Data for SM 55 Module

## Problems and Evaluation of the Installed Systems:

1-High prices of the systems
(12-15 US $ / kwp)
All components are imported plus the taxes

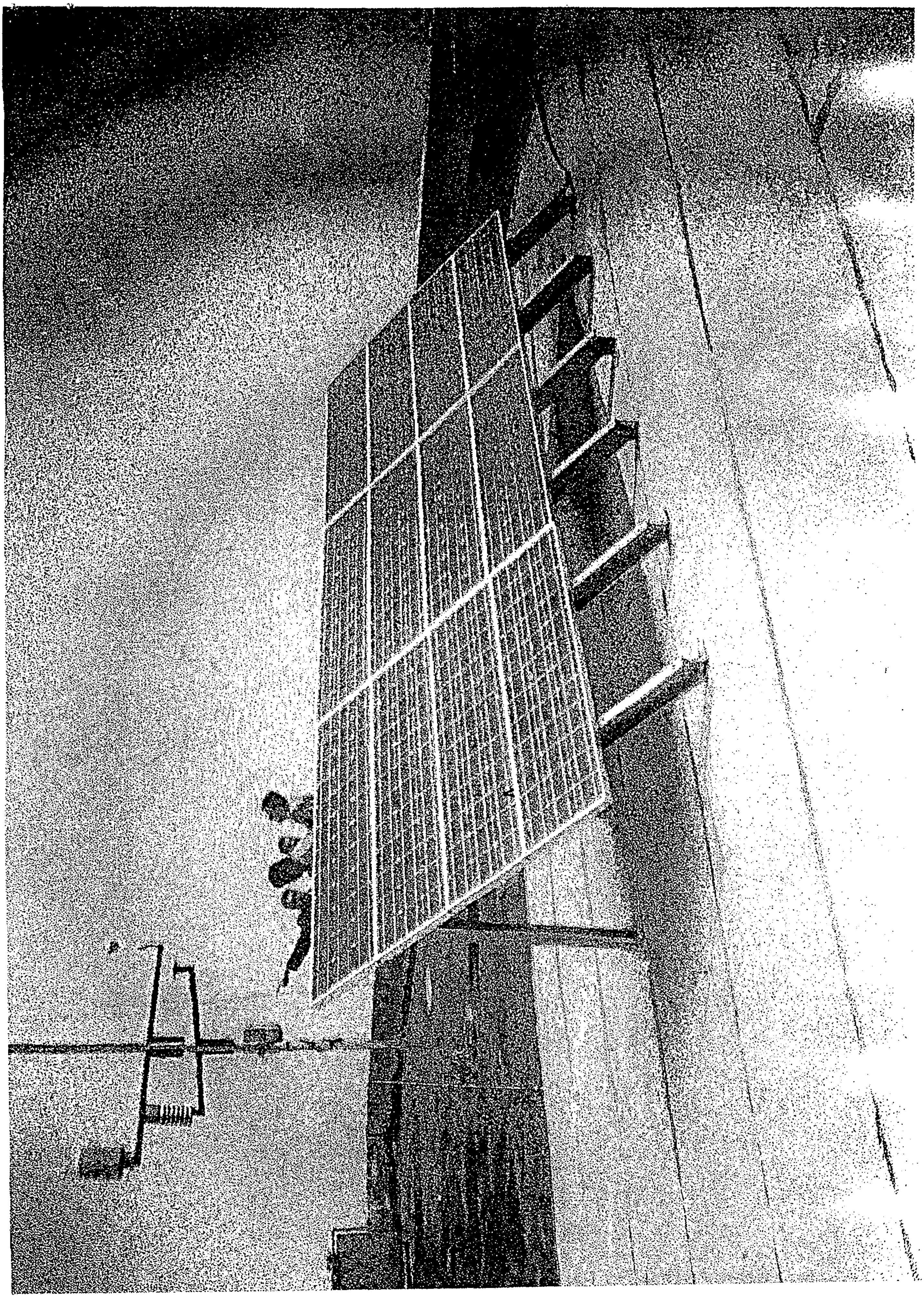
2-Client commitment to the operation and maintenance instructions

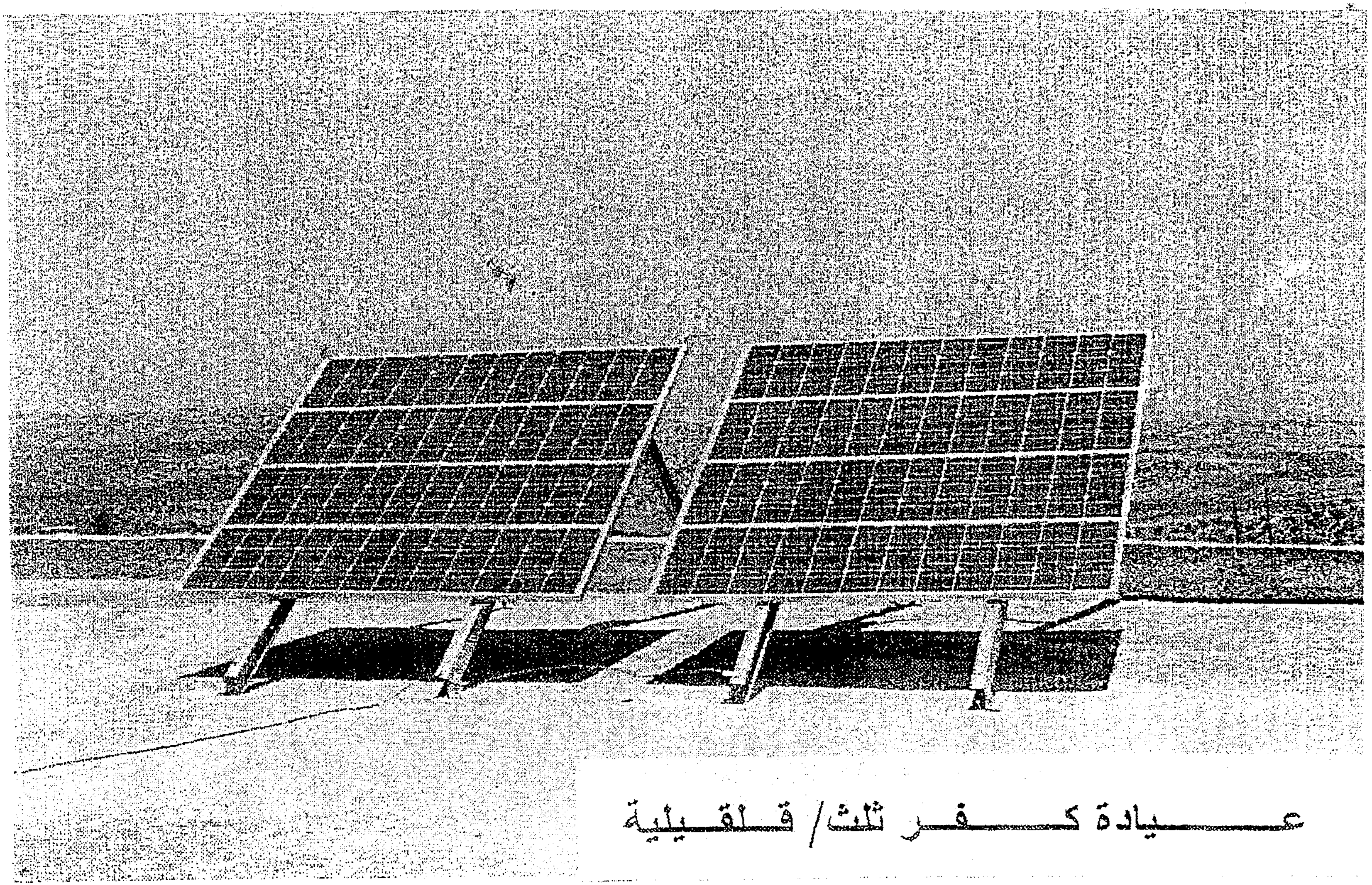
- quality and efficiency of appliance
- operation hours
- number and capacity of the appliances
- concerning maintenance ( checking the acid level in the battery & cleaning the modules for more efficiency)

3-Client commitment to pay the loans

Difficult economic situation of the Palestinians

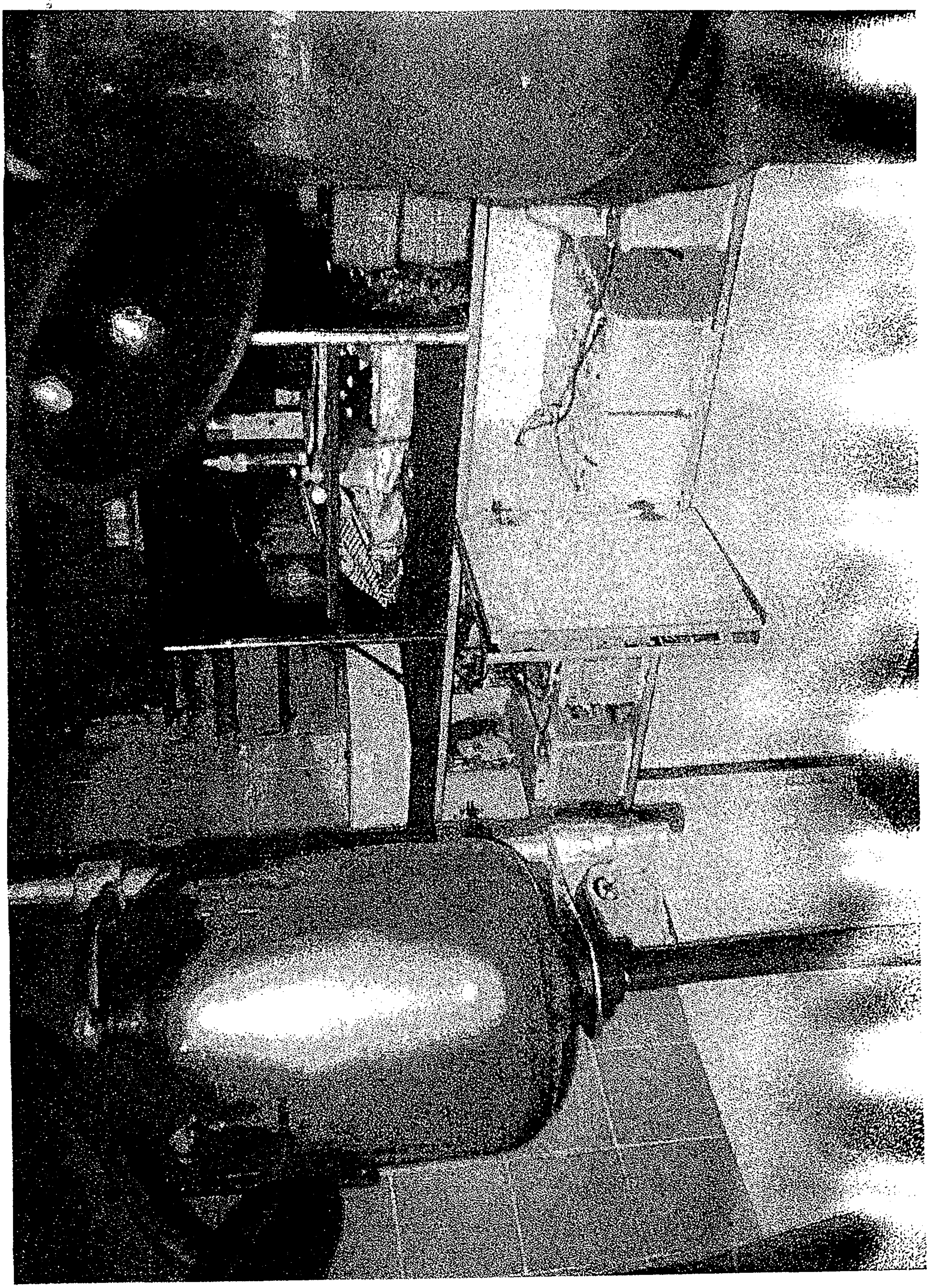
4-The high price limits the size of the system, which means limited capacity ⇨limited appliances

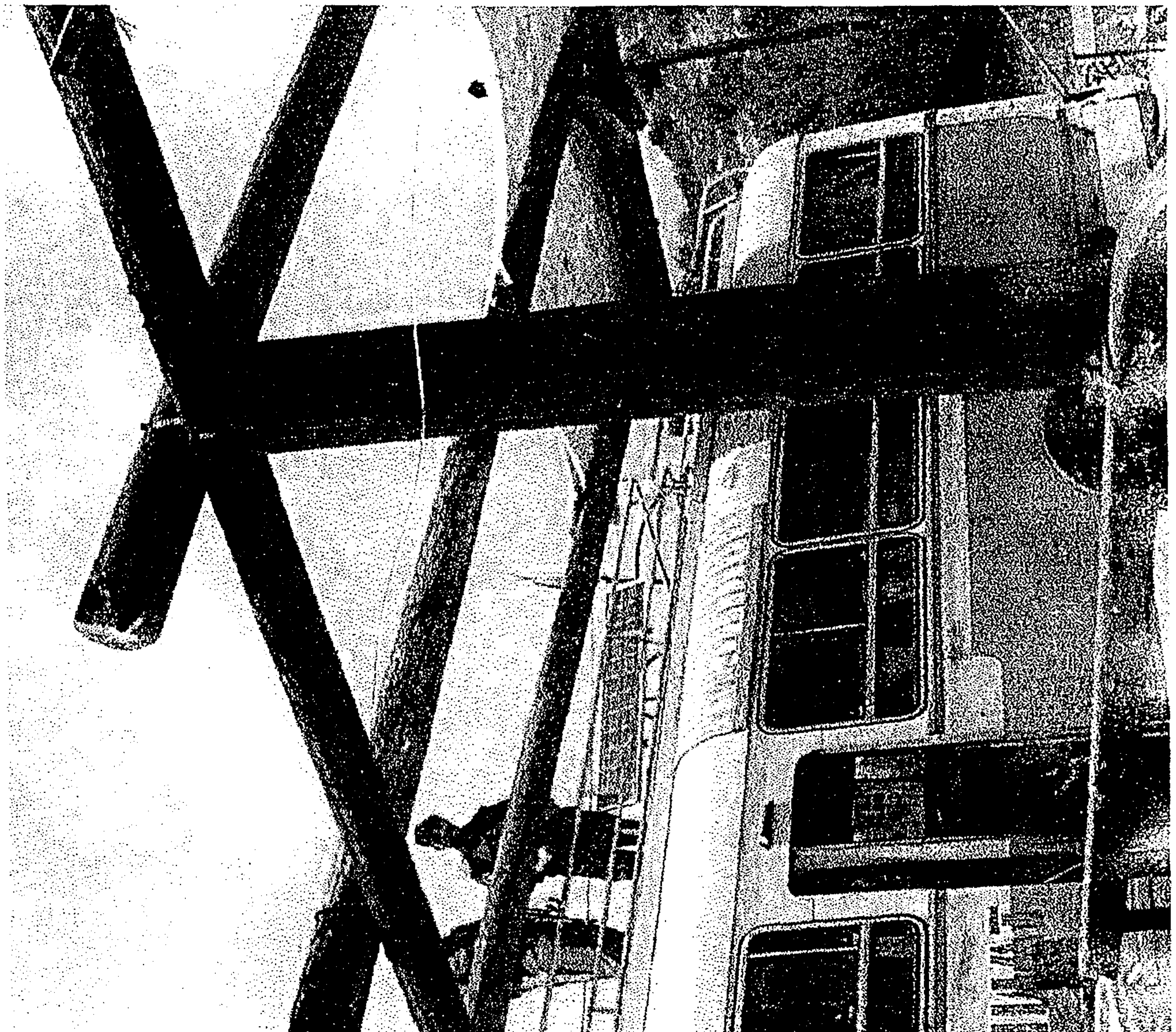


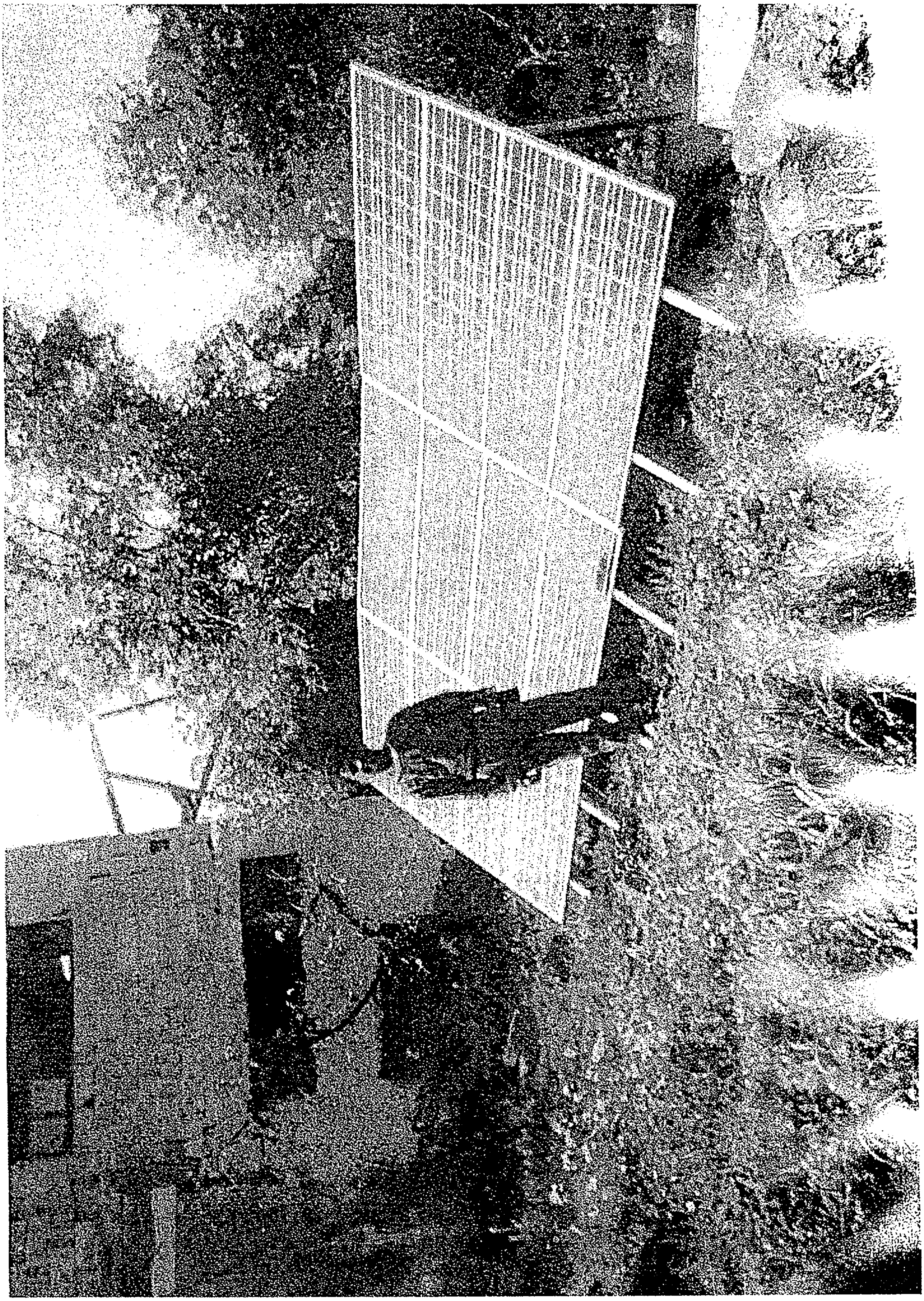


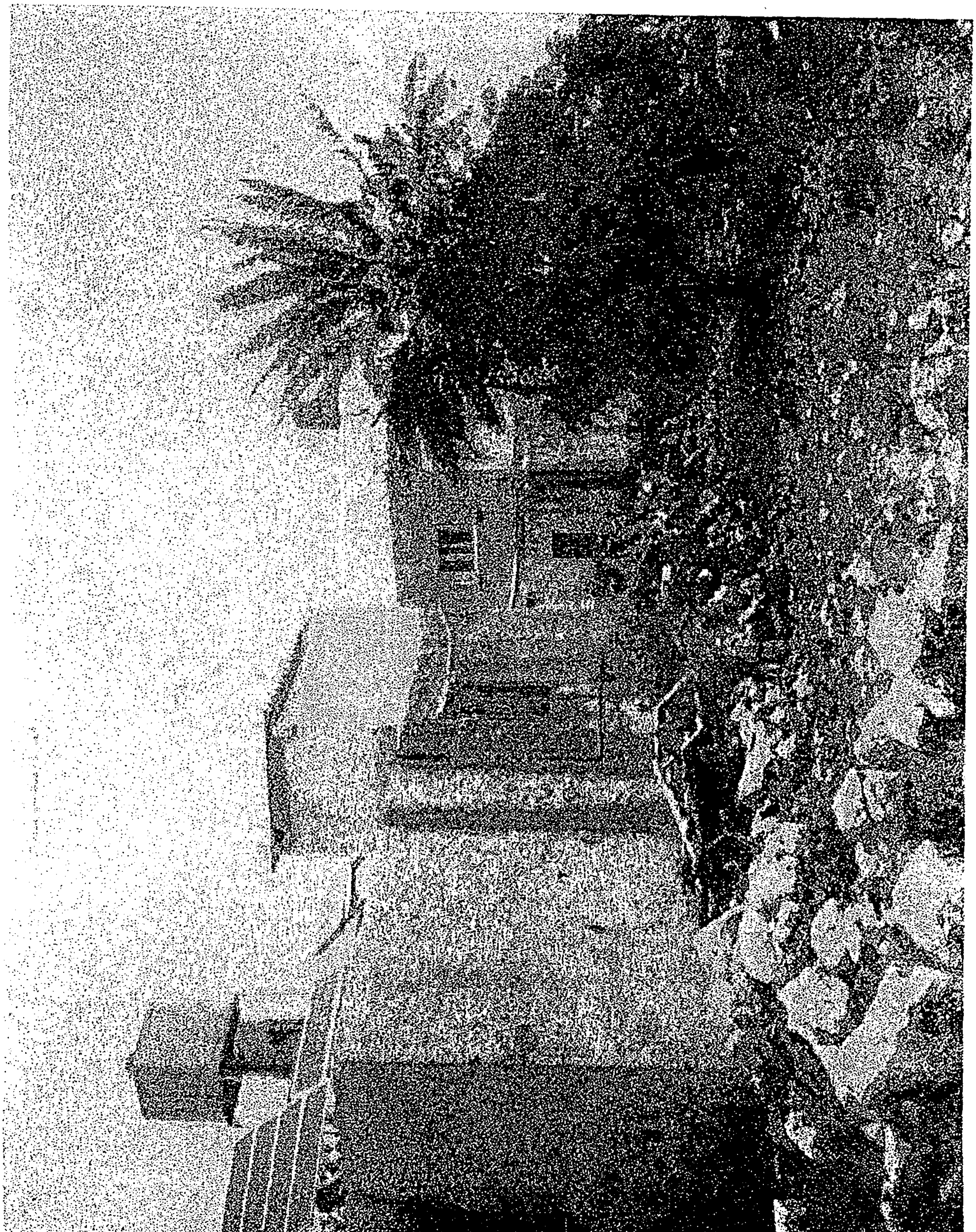
عيادة كفر ثلث/ قلقيلية

محمود سلامة الكعابنة/ العوجا









*Expert Group Meeting*
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*Cairo, 26-28 April 2000*

# *Saudi Arabia*

# Networking of PV Systems and Aplactions

## *(PV-Water Pumping & Desalination)*

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*ABSTRACT*

*Providing adequate portable drinking water is becoming a serious problem in remote areas. Saudi Arabia is a very suitable place to use renewable energy such as Solar Photovoltaic (PV) energy. For this reason, a PV system was designed and installed along with water pumping and desalination systems in the village of Sadous, about 72 km from Riyadh. The total number of panels is 158, and they give 11.06 kW. The average pumped water from the well is about 18 $m^3$/day with total dissolved solids (TDS) greater than 6000 PPM. The average product water is about 5$m^3$/day with TDS less than 300 PPM.*

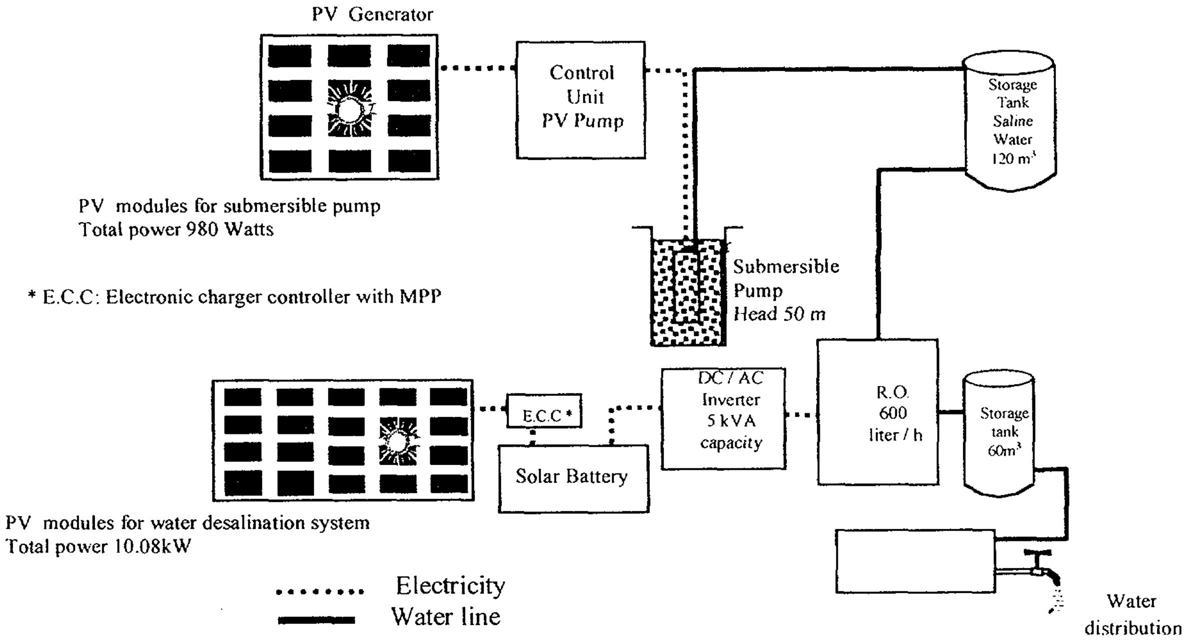


**Fig. 1: PV water pumping and desalination plant in Sadous (Riyadh).**

# Result and Discussion

The performance of the PV arrays in the plant is given in Table 2 and Figure 2. Including the losses due to module mismatches, wiring, and dust, the percentage deviation of measured to calculated PV array power is in the range of 1.9 to 11.9%. A thin layer of dust on the module can cause a derating factor on module power of about 4 to 8 %. The average ambient temperature during the time of measurement was 36°C and the PV arrays' operating temperatures range between 43.3 and 52.1°C. The measured PV arrays' efficiencies vary between 8.5 and 9.9%.

| Array | Rating (Wp) | Irradince (W/M2) | Array T (°C) | Measured (W) | Calculated (W) | Deviation % | Measured Array Effi. |
|---|---|---|---|---|---|---|---|
| Sda1 | 1680 | 966 | 49.6 | 1176 | 1320 | 10.9 | 8.6 |
| Sda2 | 1680 | 962 | 49.1 | 1158 | 1315 | 11.9 | 8.5 |
| Sda3 | 1680 | 926 | 50.6 | 1121 | 1267 | 11.5 | 8.5 |
| Sad4 | 1680 | 991 | 48.9 | 1192 | 1329 | 10.3 | 9.4 |
| Sda5 | 1680 | 995 | 46.2 | 1220 | 1370 | 10.9 | 9.7 |
| Sda6 | 1680 | 992 | 43.3 | 1246 | 1391 | 10.4 | 9.9 |
| sdwp | 980 | 995 | 52.1 | 662 | 675 | 1.9 | 9.5 |

**Table 2: performance of PV arrays in the plant, July 1998 at 10:00 am, Sda1-6(PV desalination), Sdwp(PV water pumping).**

The measured efficiency of the electronic charger controller (ECC) at different levels of irradiance varies between 93 to 96%. The inverter has protection for high and low voltage and current, and was tested for variable power factor with nominal low and high loads.

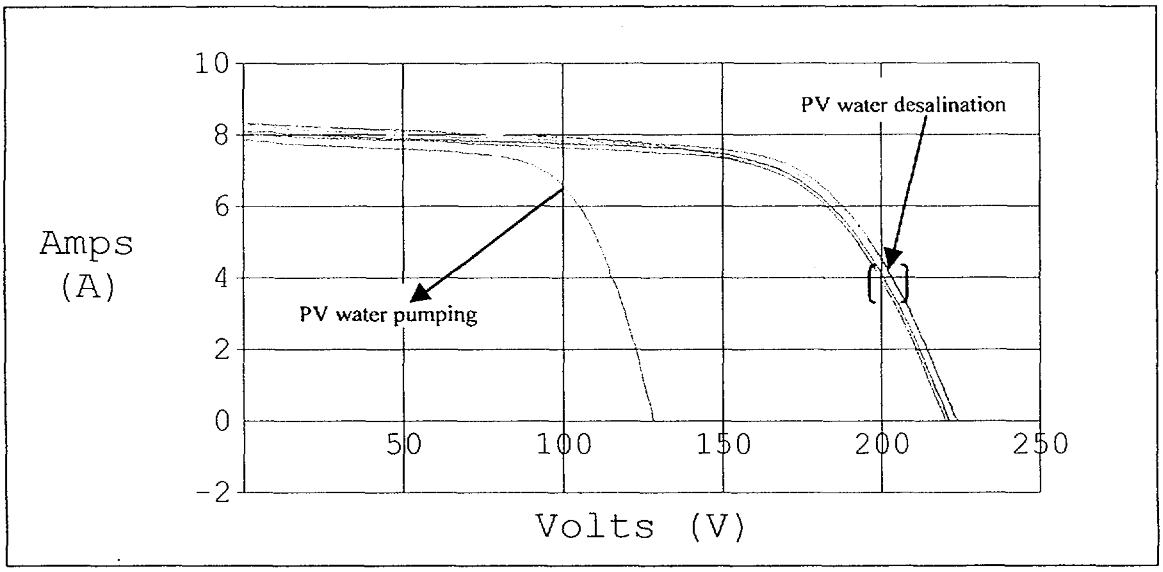


**Fig. 2: IV curves, PV water pumping system , and PV water desalination system, July 1998 at 10:45 am**

The daily water pumped from the well is about 18 $m^3$/day and this amount is affected by the amount of radiation per hour, as illustrated in Figures 3 and 4. The microprocessor control circuit of the inverter can start the submersible pump at the low radiation of 200W/$m^2$. For this reason, a correlation has been made for this system to find out the relation ship between the amount of pumped water in gallons per minute (GPM) and the insolation in W/$m^2$, this is illustrated in Equation 1. To maximize the overall system performance and minimize the total cost, there is no storage of electric energy in the PV water pumping system. The pumped water is stored in a storage tank with total capacity of 120 $m^3$ [3].

(X) GPM = 0.0303 GPM/(W/$m^2$) * IR (W/$m^2$) - 6.06 (GPM) ................... (1)

X = amount of pumped water from the well in gallon per minute.

IR= isolation in watt per square meter.

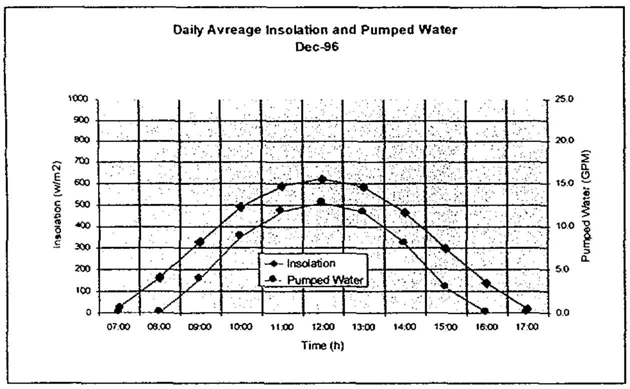


Fig. 3 Daily Insolation and Pumped water Dec.- 96

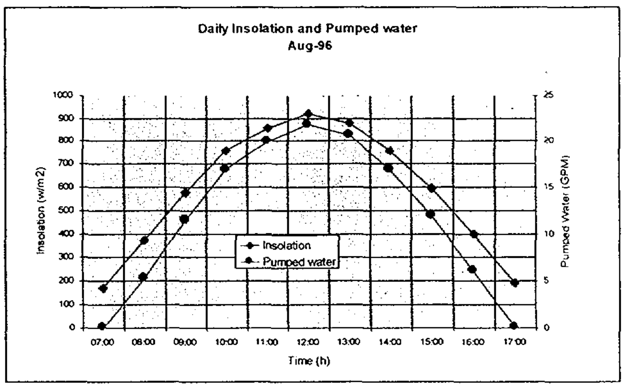


Fig. 4 Daily Insolation and Pumped water Aug.-96

The performance of the RO is affected by the feed water composition, feed pressure, temperature and recovery. For example, a feed temperature drop of 4 °C will cause a permeate flow decrease of about 10 %. The total amount of product water is about 5$m^3$ /day and this amount depends on the performance of the RO. Due to the high total dissolved solids (TDS) in the feed water, (greater than 6000 PPM), the efficiency of the RO is low, and it varies between 22 to 30 %. To increase the efficiency and life of a reverse osmosis system, effective pretreatment of the feed water is required. Selection of the proper pretreatment will maximize efficiency and membrane life by minimizing fouling, scaling, and membrane degradation. Also, selecting the proper pretreatment will optimize the product recovery, salt rejection, product flow, and operating costs [2,4]. In addition, by recycling part of the rejected water, or by adding another stage to the reverse osmosis system, the efficiency will be increase.

## Conclusion

The plant was designed and installed in Sadous village, about 72 km from Riyadh. In December 1994, construction of the plant was completed and operations started. In remote areas, PV water pumping systems are reliable since installation is straight forward, and the maintenance and operation costs for a PV water pumping system and desalination system are acceptable. In conclusion, the overall performance of a PV plant for water pumping and desalination is good.

## Acknowledgments

The authors wish to acknowledge the support of the Energy Research Institute at King Abdulaziz City for Science and Technology in the preparation and publication of this paper. Appreciation is also expressed to the Solar Village staff.

# TUNNEL LIGHTING - A REMOTE AREA APPLICATION FOR PHOTOVOLTAIC POWER SYSTEM

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## ABSTRACT

*Highway tunnels must be sufficiently illuminated to eliminate two phenomena that poses problems to drivers perception, thus, assuring public safety. Tunnels are remotely located where power is neither readily nor economically available for the national utility grid. Photovoltaic power system is a renewable energy technology that can be applied to satisfy the requirements for lighting tunnels that are located in the remote areas. This paper presents the composition of a PV lighted tunnel that is located in the higher grounds of Saudi Arabia. It also presents the performance of the system as well as the key lessons learned concerning its operation as well as from failures of the system.*

## 1. INTRODUCTION

During the last twenty years, Saudi Arabia has implemented its infrastructure programs. One of the project of the Ministry of Communications (MOC) was to link the major cities and towns by means of roads and highways. Many tunnels located in the mountainous areas were constructed. Tunnels must be provided with sufficient lighting to ensure safety and comfort for the commuters at all times of the day. Two issues are highly considered in lighting designs for tunnels located in remote areas: one is transitional adaptation, the phenomenon that concerns the changes in visibility resulting from an abrupt change (increase or decrease) in the prevailing luminance level of the visual field and the other is the source of electrical energy needed to power up the lighting system. MOC has consulted King Abdulaziz City for Science and Technology for a technical advice in using solar power for tunnel lighting. It was decided later on to design, construct and operate and maintain an experimental lighting system powered by photovoltaics. This project entailed the lighting of a 546 meter, two lane highway tunnel on a mountain highway through the Shaar Descent, about 25 kms north of Abha city. This project is identified as Project 9.

## 2. SYSTEM DESCRIPTION

Project 9 is basically comprised of 4 major systems: [illegible] Array, Battery, Load and Control subsystems. Figure 1 shows the Power/Data block diagram of the system.

### 2.1 PV Array Subsystem

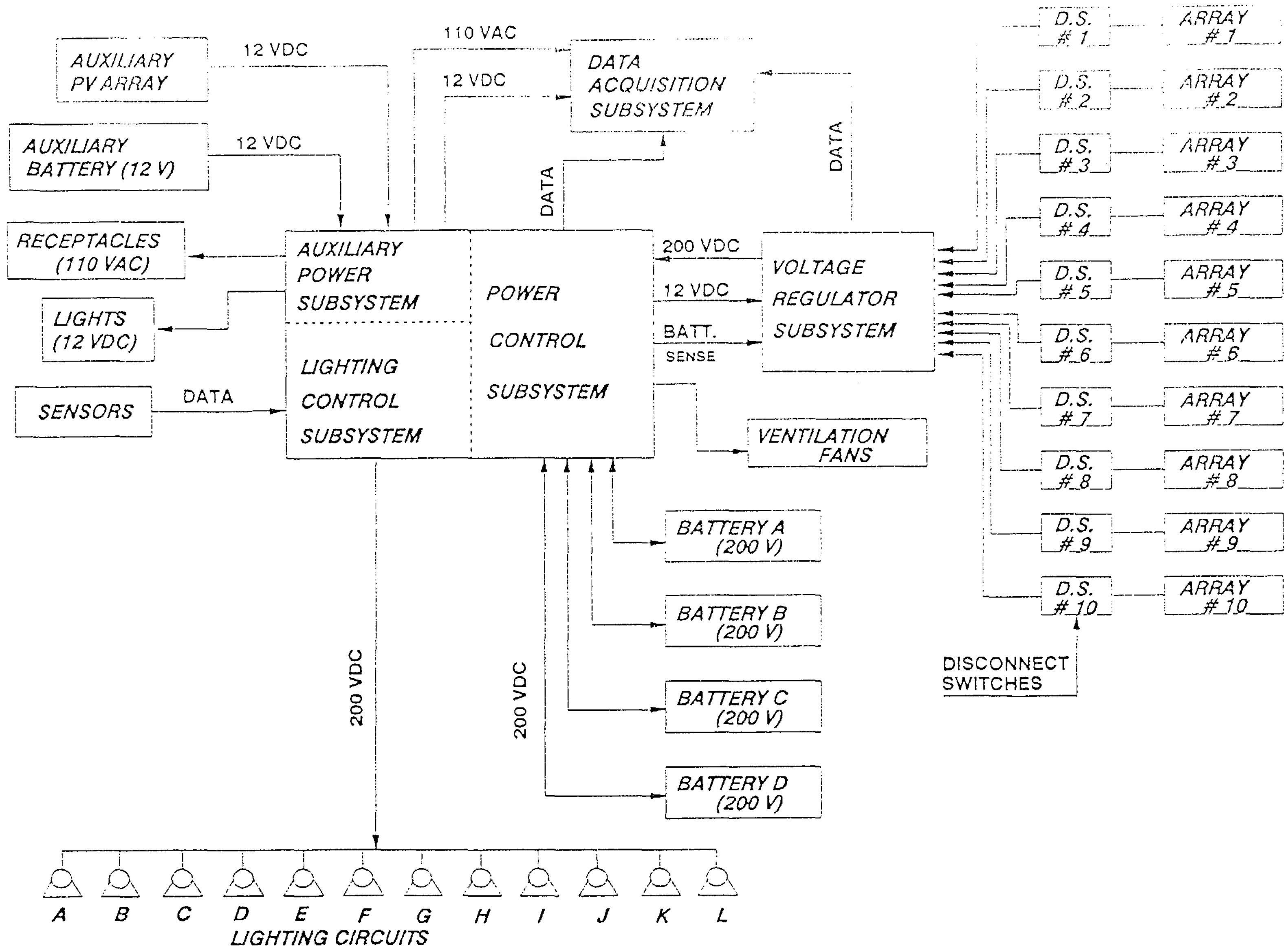
The Photovoltaic array is rated with a peak output of [illegible] kW at Standard Test Conditions. It consists of 1440 SC-LA40 40 watt solar modules configured in 160 panels of 9 series connected modules. These pre-assembled panels are variously grouped into 10 sub-arrays containing from 10 to 20 panels each. This varying size was made to make best use of the site. The PV array is tilted to the south at 20 degrees to achieve an optimum year round efficiency. Each module contains 40 cast polycrystalline silicon 100 mm square cells. The system voltage output is 204 vol[illegible]

### 2.2 Battery Subsystem

The system uses 4916 ampere-hour of battery capacity at 204 volts from four parallel strings of GNB Absolyte II 75A25 battery cells. Each battery string is composed [illegible] 102 series connected 2 volts cells. The batteries [illegible] completely sealed, maintenance free and has a long life and deep cycling characteristics.

### 2.3 Load Subsystem

The load is comprised of 83 dual lamp fixtures, 14 single lamp tunnel fixtures and 6 single lamp highway fixtures. The dual lamp fixture is an English Electric Corporation model Nightwatch Corrosion Commander fixture an[illegible] lamps used are the 66 watt Low Pressure Sodium [illegible] model SOX/E. LPS lamps uses AC power, thus, the lamp fixtures contain a high voltage DC inverter/ballast which converts the 204 VDC input to 115 VAC at 28 kHz to operate the light bulbs. The ballast can operate with an input voltage of up to 265 VDC. The system has a total [illegible] 188 lamps. During day time 168 lamps are switch[illegible]




Figur 1. Project 9 Power/Data Block Diagram

for a load of 9.94 kW while night time load is 4.32 kW being consumed by 74 lamps.

## 2.4 Control Subsystem

The power control subsystem contains the main system circuit breakers, volt-meters, ammeters and battery branch circuit breaker. A main system circuit breaker allows total system shutdown in an emergency by operating a single lever.

The lighting control subsystem is composed of a logic and control equipment that controls 12 light circuits and monitor day/night condition, a panel assembly housing 12 mercury contractors and 12 circuit breakers that are connected to the 12 separate tunnel lighting circuits and three ambient light sensors. These 3 light sensors enable the logic and control equipment to determine day and night condition. The lighting circuits are grouped into 9 light circuits operating at day time, 3 light circuits during night time and 1 light circuit for continuous operation. The system has a very special control feature in which in the event of a declining battery power (80% Depth-of-Discharge), the system initiates a reduced lighting scheme to reduce overall power consumption while providing adequate illumination within the tunnel. During day time, the number of operational lamps will drop from 162 to 92 while night time reduction is from 74 to 54.

## 2.5 Other Subsystem

Auxiliary power system provides a 12 volt power to operate all the controls, data acquisition, interior building lighting and a 100 VAC supply. This system is comprised of 16 separate 40 watt PV modules mounted on top of the control building, two 12V voltage regulators, two GNB 75A25 batteries, a 2200 watt inverter and AC convenience electrical wall outlets for operating hand tools. It is independent with the main power lighting system in order to provide reliable power to the main lighting control circuits and data acquisition system.

Voltage regulation is achieved by connecting the sub-arrays into individual voltage regulator. Each voltage regulator consists of a temperature compensated logic card that determines when a sub-array should be disconnected, blocking diode, mercury displacement contractor, transient protection devices, circuit breaker and ammeter.

Data Acquisition system is an industrial version of an IBM compatible personal computer for data collection and recording and for system monitoring. Hourly average of PV array string and battery voltages and currents, insolation and temperatures are saved in a 20 Mbyte hard disk. The data are retrieved from the computer on floppy disks for further system performance analysis and for system characterization. The data stored are in a format that is suitable for direct entry into a standard IBM spreadsheet software. The disk drive is capable of storing several months of data. The computer is also programmed to control and monitor systems operation and identify potential problems.

## 3. TUNNEL LIGHTING DESIGN

The tunnel has the following parameters:

| | |
|---|---|
| Tunnel width | 10.1 M |
| Tunnel length | 546.0 M |
| Tunnel height | 6.8 M |
| Required minimum clearance | 5.5 M |
| Road surface | Asphalt (R3 Classification) |
| Speed limit | 40 Km/h |
| Traffic Density | Light |

The requirement of Project 9 is to provide a safe and reliable lighting system designed according to applicable standards and recommended practices. Its goal is good visibility. The basic problems addressed in the design are the amount of time required for the eyes to adjust to changed light levels and the minimum lighting required for proper visibility. These requirements are reflected in the length of the various zones and the lighting levels in each zone. External luminance must also be considered because eyes are adapted to the external brightness prior to entering the tunnel. These are the prime considerations taken in Project 9 tunnel lighting design.

There are three types of zones in a tunnel lighting. The first zone is called the threshold zone. This reduces the "black hole" effect, that phenomenon which makes the tunnel appear like a black hole while the motorist is still in a bright open road approaching the tunnel. This phenomenon occurs by a kind of negative glare effect due to the extremely high contrast of luminance between the tunnel entrance and the open surrounding scenery. The threshold zone for this project is a 50 meter luminous gallery that consists of a structure over the road with windows to admit ambient brightness in a controlled pattern. The light level in this zone vary with ambient light, thus, the gallery provide an intermediate level that is proportional to the ambient light level. The luminous gallery is followed by a transition zone that is divided into subzones having decreasing light levels. These subzones reduces the "black out" effect, the phenomenon that causes the inside of the tunnel to appear almost black immediately after entry due to insufficient entrance illumination. This effect is the result of the sudden change in the luminance of its visual field. Project 9 transition zones are three 20 meters long subzones. The next zone is the central zone. This is a 326 meter length central section of the tunnel.

The lamp inverter/ballast component of the fixture provides two functions; one is to control the lamp power and the other is to transform the voltage into the necessary AC power at 28 kHz frequency. This design was selected to increase lamp efficiency and to decrease the cost of the inverter components. The inverter is most efficient when two lamps are operated as a pair from one inverter.

## 4. SYSTEM PERFORMANCE

Project 9 was put into operation in November, 1988. The system operated satisfactorily during the first stage. Valuable data about the project's operation were recorded and analyzed. Due to the difficulties in covering all the period of operation that was selected for analysis (November 1988 to November 1990) , a sample of data for three days of the same date of November in the years 1988-1990 were chosen to demonstrate the system performance. Figure 2 shows the 3 days of operation in November, 1988, 1989 and 1990. Eight PV string (sub-arrays) were automatically connected to the DC bus during day time that powers up the lamps and at the same time provides charging current to the batteries. There are 188 lamps that constitute Project 9 load subsystem. These lamps are wired in pairs such that an inverter/ballast powers up one of its lamp and another lamp in an adjacent fixture. This configuration was adapted to provide adequate spacing during low voltage condition.

The project, due to its distance, was turned over to a contractor for its operation and maintenance requirements. the project started operating satisfactorily, however, lighting fixtures were noticed failing after four months of operation. There are three components in the fixture that could fail, the inverter, the ballast or the lamp. Failure of one or more of these elements causes the lighting fixture failure. The O&M activity for failed fixture was to replace it completely due to the failure of one of its component even though the other components were good. Changing the whole fixture instead of the failed element makes the O&M of the project costly. The O&M contractor reasoned out, to give immediate solution to the problem as well as to facilitate resumption of traffic in one lane of the road. This lane which is disabled to park the special equipment (cherry picker truck) needed to reach the ceiling of the tunnel to replace the fixture.

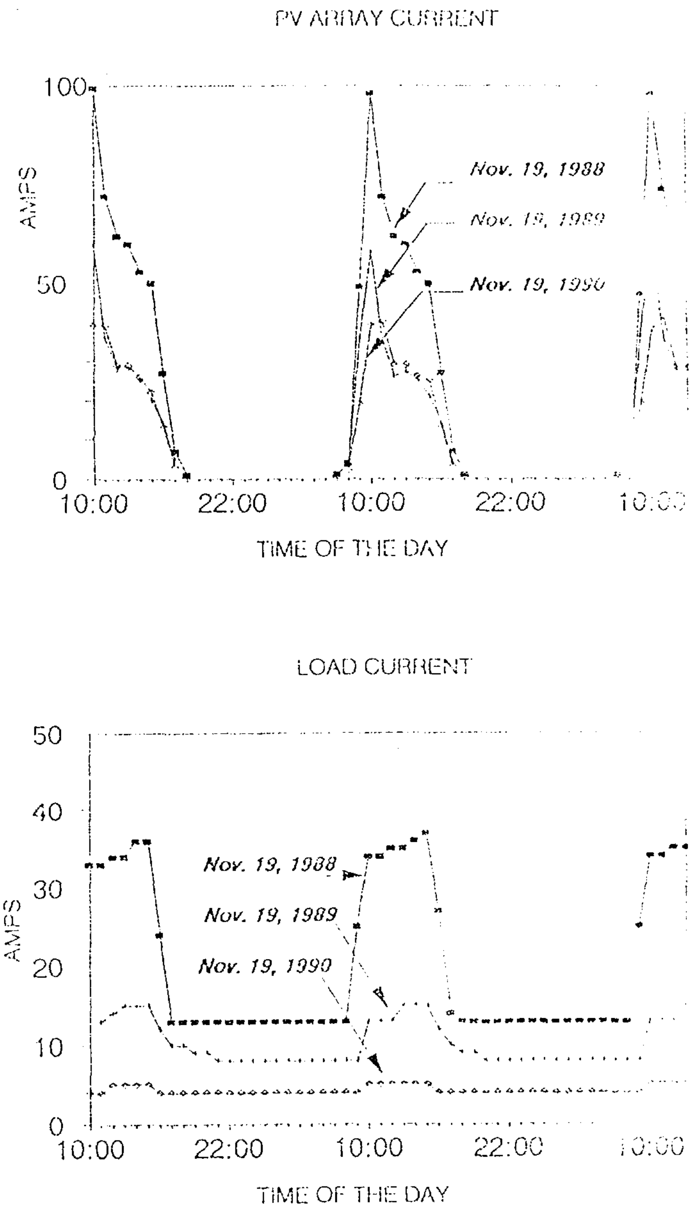



*Figure 2. The system output and input current...*

The November 18-20 hourly PV array and Battery current were plotted for three years, 1988-1990. Solar ins... during those days are almost identical. The PV array energy output and the load energy output (Figure 3) were also plotted for the same day in the three years. Figure 4 shows the monthly average day and night time load of the system. Frome the sample data, which are demonstrated in figure 2, its can be observed that the system current was remarkably declining from one yesr to the next. By the end of 1990, the number of light fixtures failed considerably that the day load has nearly equaled the night time load as illustrated in Figure 4.

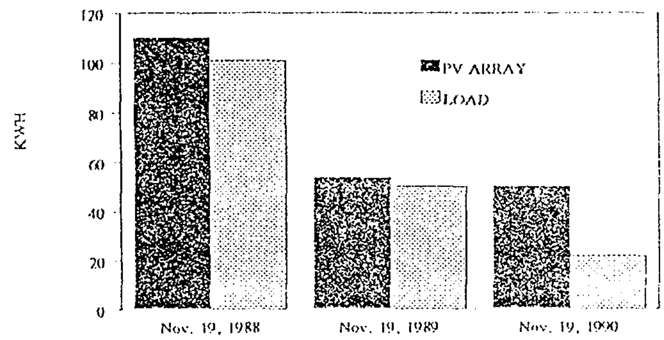



Figure 3. PV Array and Load Output Energy.

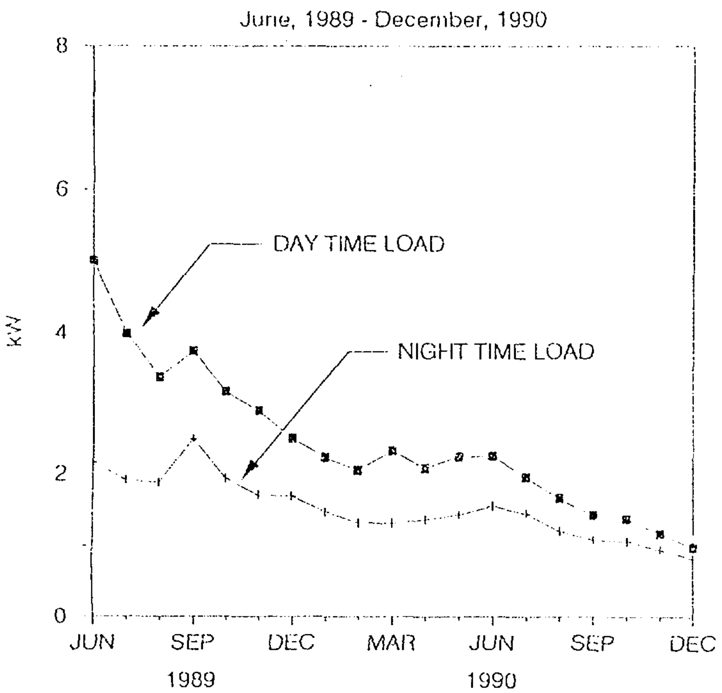



*Figure 4. Average day and night time load.*

## 5. CONCLUSION

A stand-alone 57.6 KWp (designed) phtovoltaic power system started operational satisfactory at its earlier stages. However, a significant degridation of the system out put has been experienced during the first three years of the system operation. It is expected that the main reason is the high rate failure of the lighting fixtures. This failure could be due to one or more of the following factors:

-Designe of system.
-Type or specifications of particular elements.
-Envoronmental or location.
-Maintenance activities.

Therfore, further investigations are necessary to find out the maijor influencing factors behide the failure problem, which if it is solved will cosiderably contribute in improving overall the system performance.

## 6. ACKNOWLEDGMENT


The authors would like to thank Mr. F. Huraib, the director of the institute for his continuos support. Thanks is also expressed to all staff of the renewable energy department for their cooperation.


## 7. REFERENCES


(1) Documents and Manuals of Project 9, KACST, Solar Programs Library.

(2) Operation & Maintenance Records of Proje KACST, Solar Programs.

# PV POWER - STUDY OF SYSTEM OPTIONS AND OPTIMIZATION

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ABSTRACT. A multipurpose photovoltaic (PV) test system was installed in April 1987 at the Solar Village near Riyadh, Saudi Arabia to study the effects of tracking and long term accumulation of dust and dirt on the PV array energy output. The system consists of four separate branches each with the same number and type of PV modules in series and its own peak power tracking unit. The energy generated by each branch is dumped into a common load. Performance results indicate an average monthly energy gain of about 18% due to single axis and 20% due to dual axis tracking as compared to a fixed array tilted at the site latitude. Seasonal tilt angle measurement of the passive thermohydraulic two axis tracker at solar noon and its comparison with the theoretical angle revealed discrepancy in the tracker performance. Energy loss due to dust on a fixed tilted array increased to 32% in eight months and was reduced to about 2% following occasional rain. System operation todate has produced valuable information on a number of parameters including the hardware performance.

## 1. INTRODUCTION

A photovoltaic (PV) test system (Figures 1,2) consisting of four identical monocrystalline PV arrays - one sun tracking in two axes, one in single axis, one fixed tilted and one fixed tilted that is kept uncleaned, has been installed. Array tracking in the system is accomplished by means of solar-energy-powered totally passive thermohydraulic devices. Each array contains twelve identical PV modules in series and feeds through a maximum power point tracker to a common resistive load (Figure 3). A microprocessor controlled control and data acquisition system monitors the PV system performance as it operates continuously unattended. The data logging system continuously integrates the solar power input and array electrical power output and records them in the form of energies on a cassette tape every 15 minutes. In addition to this, input, output voltages, currents and powers are also recorded. The system is unique in design that it has several parallel arrays of identical PV modules with different orientations, which operate independent of each other, however dumping their energies into a common load. This multipurpose system has been installed to evaluate 1) the effect on energy output of PV modules (array) orientation, 2) seasonal variation in the energy gain due to tracking, 3) long term effect of accumulation of dust on the fixed tilted modules, 4) long term performance of the PV modules outdoor, 5) PV module/array power/energy efficiencies and effect of temperature on efficiencies, 6) reliability, efficiency and accuracy of the maximum power trackers, 7) reliability and accuracy of the passive thermohydraulic trackers, and 8) measurement of incident solar energy. It is also the purpose of the system to develop and validate mathematical models based on the test data obtained from the system.

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## 2. SUMMARY OF TEST RESULTS

Results obtained from the analysis of the performance data collected for a period of one year are shown in Figures 4 through 11. Figures 4 and 5 show the total electrical energy generated during the month by each of the four branches. The gain in the energy output due to single-axis tracking as compared to the fixed tilted array (Figure 6) is about 18% per month. However, the energy gain realized due to dual-axis tracking as compared to the single-axis tracking is inaccurate except during the summer months (Figure 7). This inaccuracy was revealed by the tilt angle measurements performed on the 21st of each month at solar noon, on the dual-axis tracker (Figure 8). The array with dual-axis tracking generated on the average about 2% more energy per month as compared to the array with single-axis tracking. It would have been as high as 8% per month if the tracker had performed accurately.

Figures 9 and 10 show the effects of dust accumulation on a fixed tilted array. The monthly energy reduction in Figure 9 for the uncleaned array was obtained by comparing its performance with an identical array which was cleaned at the end of each month. The reduction in the energy output from the uncleaned array reached 32% at the end of eight months. However, the difference in the energy output improved to less than 2% in the next four months when the uncleaned array was washed by occasional rain. Figure 10 shows the adverse effect of dust accumulation on the array efficiency. The monthly solar energy input measured by the system is shown in Figure 11.

## 3. CONCLUSION

Major components of the PV test system which include PV modules from Dakhil-Spire, Jeddah; passive tracking systems/structures from Robbins Engineering, Ridgecrest, California; and maximum power point trackers and microprocessor controlled control/data logging system from Chronar-TriSolar, Princeton, New Jersey have performed well. The only problem encountered has been with the passive thermohydraulic tracking system on the dual-axis tracker which failed to track the sun accurately during winter months.

Test results as summarized above indicate that for increased PV energy output, single-axis tracking at the test site is definitely advantageous and sufficient. It can be optimized further by seasonal adjustment of array tilt angle due south or it can be operated at some other tilt angle to obtain a proper match between the array energy output and the load energy demand. Long term dust accumulation test on the fixed tilted array showed about 4% loss in the energy output per month. However, this loss was recovered in full following the rainy season. Based on this information and system maintenance frequency, a PV system can be sized adequately for this and similar sites.

System operation, data collection and analysis are continuing to further strengthen the above conclusions and obtain additional information. Tests are also in progress to determine the effect of array tilt angle on the accumulation of dust. Results from these tests and analyses will be reported in later publications.

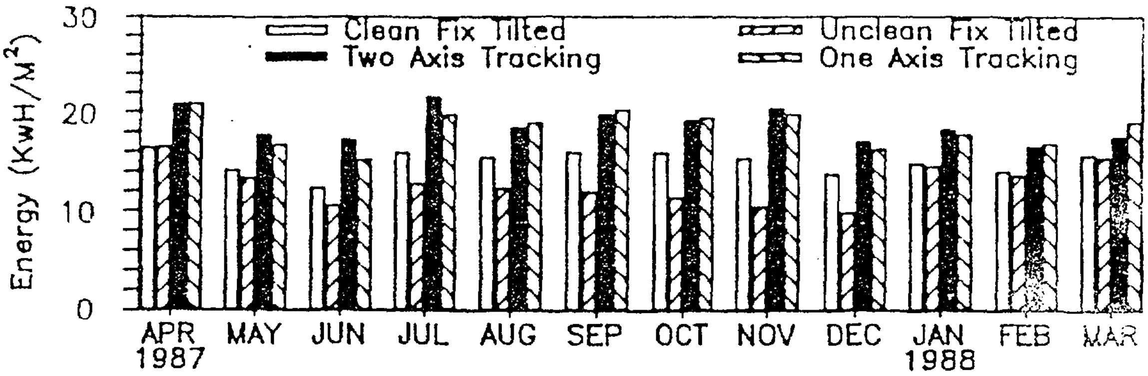



Figure 4. Energy Generated by Identical PV Arrays

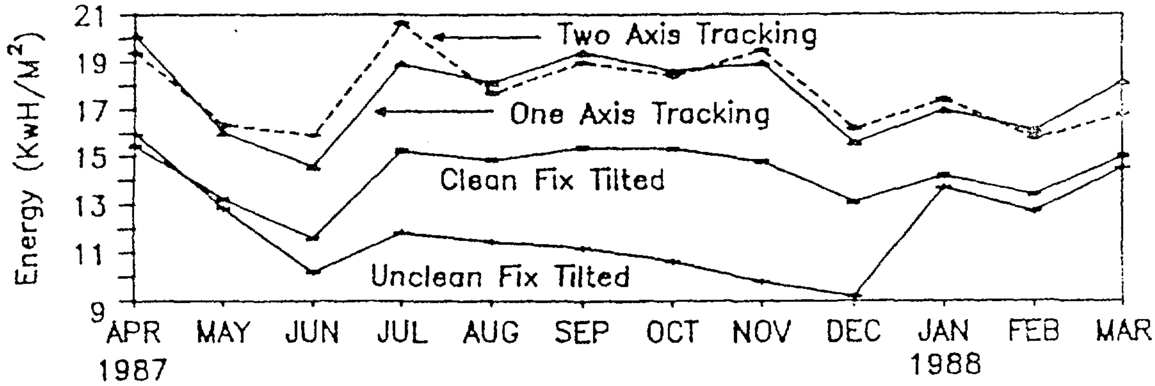



Figure 5. Output Energy Profile of Identical PV Arrays

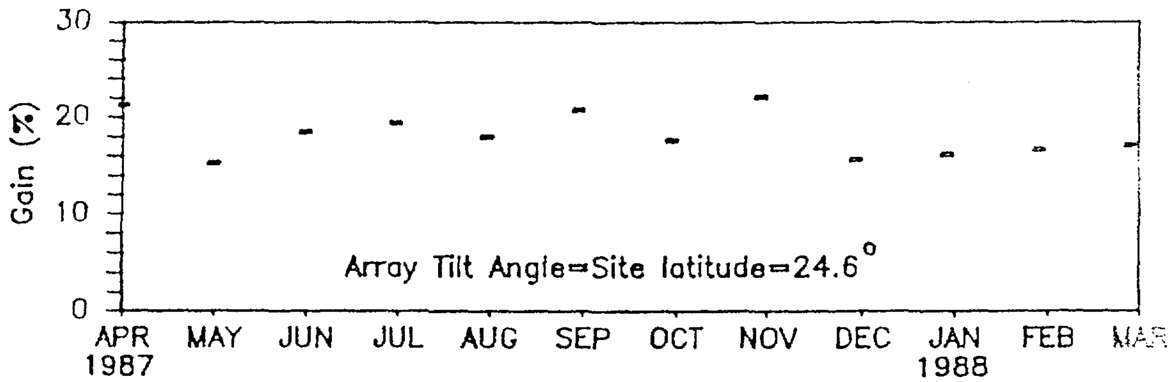



Figure 6. Energy Gain due to Single Axis Tracking as Compared to a Fixed Tilted Array

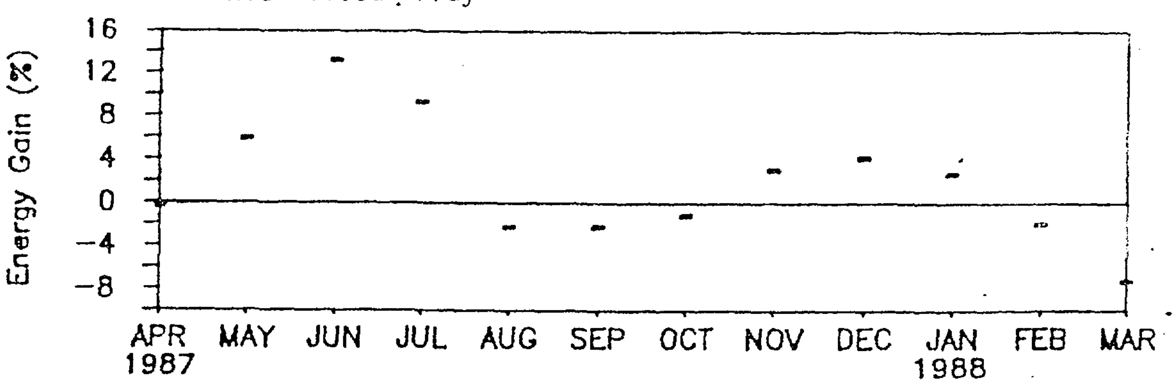



Figure 7. Energy Gain due to Dual Axis Tracking as Compared to a Single Axis Tracking Array

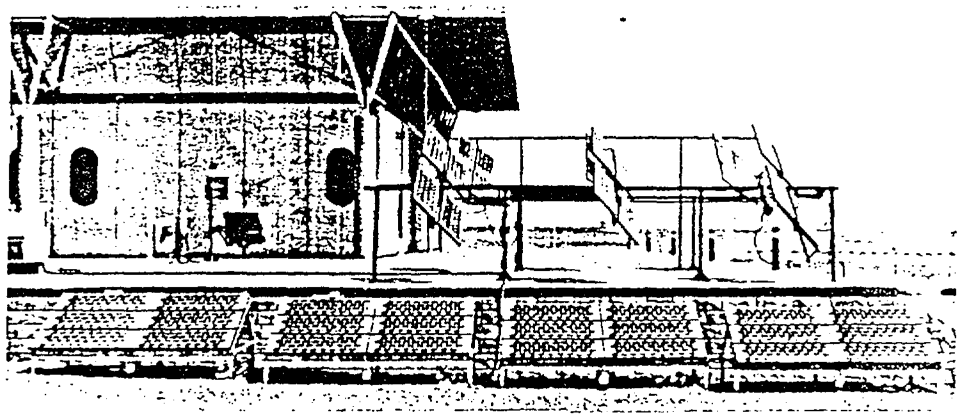


Figure 1. 3-kW PV Test System

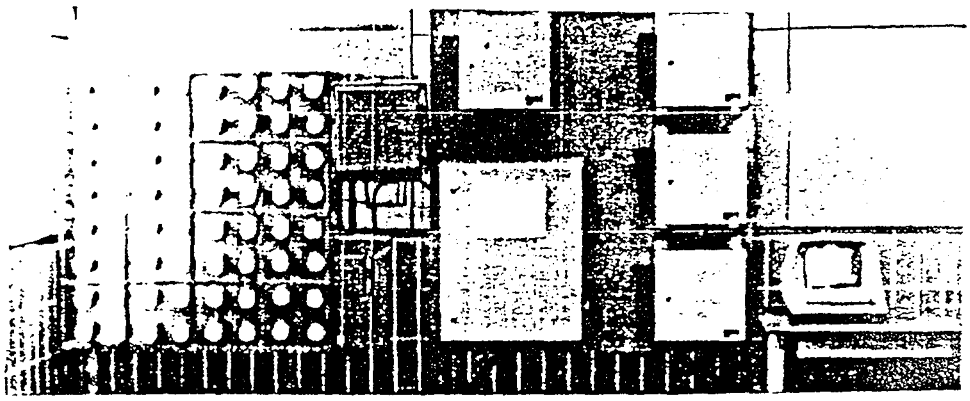
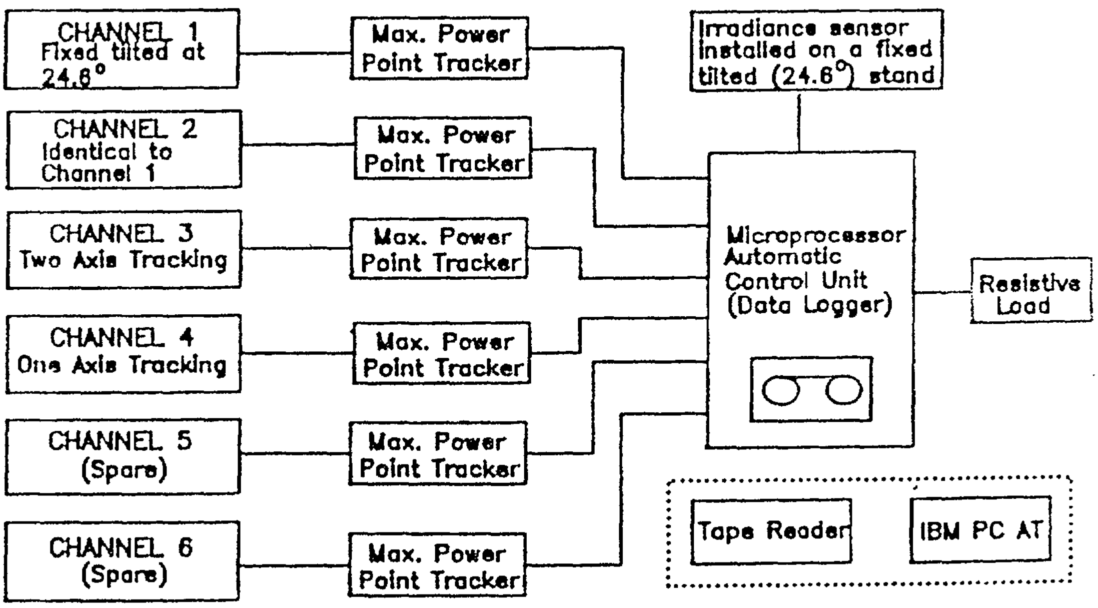


Figure 2. PV System Controls and Load




Notes: All channels contain twelve identical 40 — watt modules in series. Modules in channels 1, 3 and 4 are washed monthly. Modules in channel 2 are not washed.

Figure 3. Functional Block Diagram - PV Test System

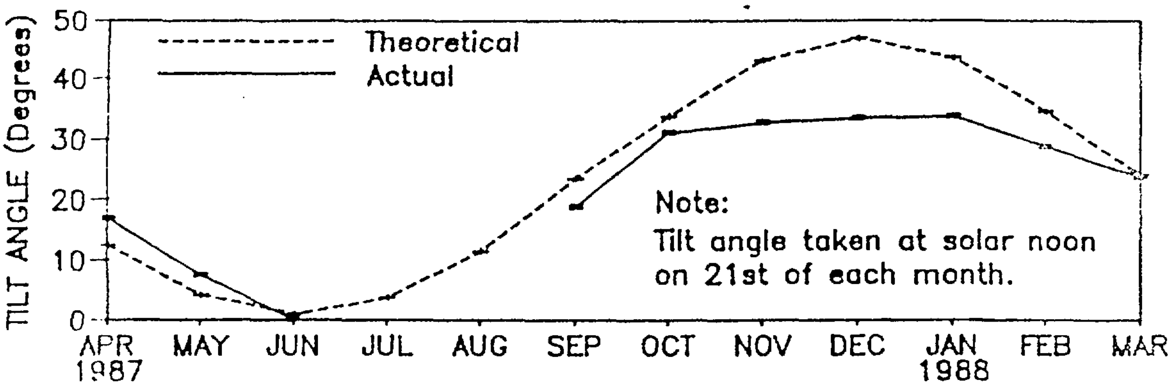



Figure 8. Performance of Thermohydraulic Tracker Installed for Elevation Tracking on a Dual Axis Tracker

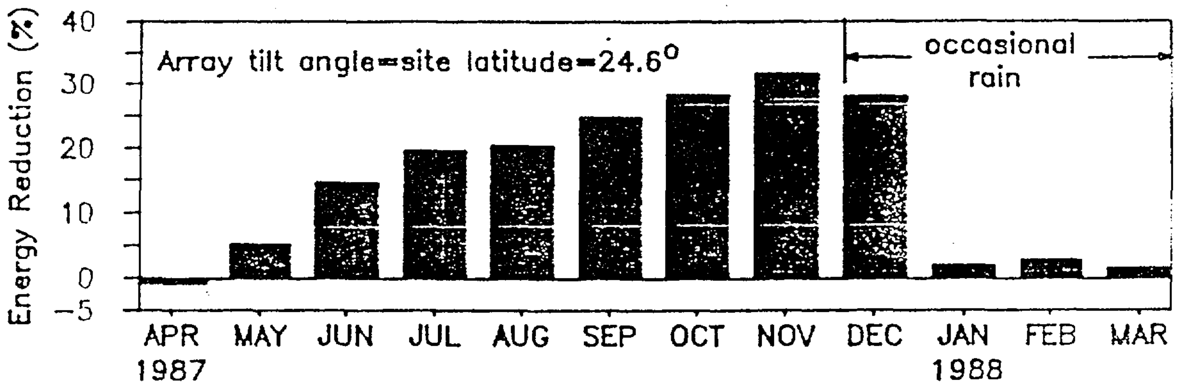



Figure 9. Effect on Energy Output of Long Term Accumulation of Dust and Dirt on a Fixed Tilted Array

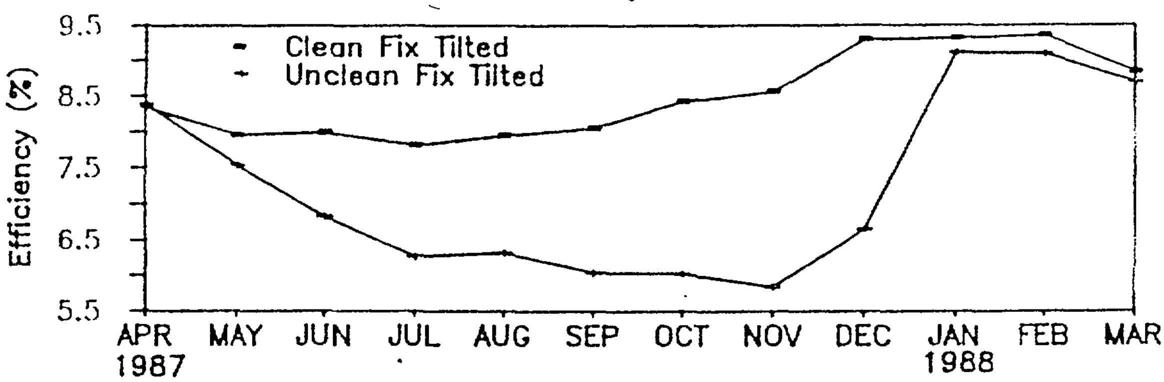



Figure 10. Effect of Dust on Array Energy Efficiency

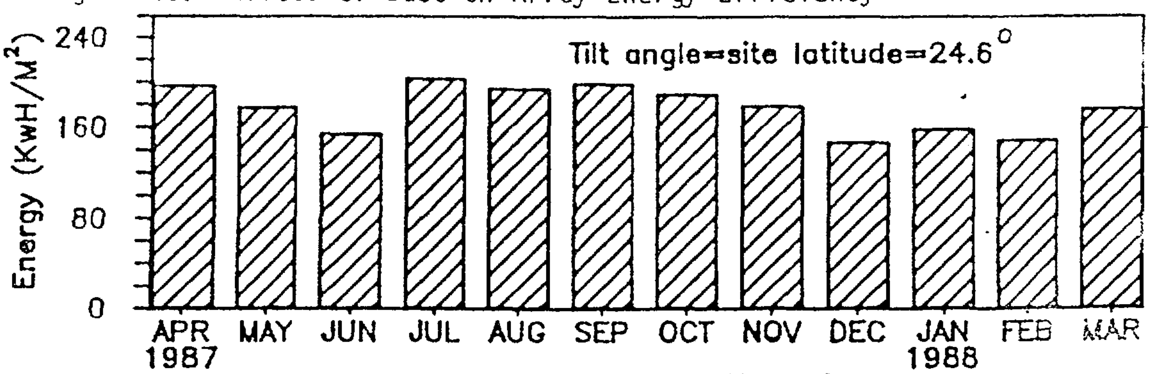



Figure 11. Solar Energy Input on a Fixed Tilted Array

# ARE LARGE PV SYSTEM
# RELIABLE POWER PRODUCERS

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Abstract:

The world's first and only operating Concentrator Photovoltaic Power System (PVPS) begun supplying power to three remote villages in Saudi Arabia in September, 1981. In late 1984, the PVPS was tied to the main utility grid. This paper describes in detail the composition of the system and its performance in different modes of operation. It also reviews the lessons learned in operating the system in 7 years. This operational period proves that large PV systems are reliable power sources with a minimal operation and maintenance effort.

## I. Introduction

In late 1977, Saudi Arabia and the United States signed a project agreement in the field of solar energy under the auspices of the Saudi Arabia/United States Joint Commision on Economic Cooperation. As a result of this agreement known as the SOLERAS (Solar Energy Research American-Saudi), a five year plan was established. One of the objectives of this plan was to enhance the quality of rural life in Saudi Arabia using solar energy systems for domestic, communal, agricultural and local industrial applications. It aimed to bring to remote areas, not served by an electrical utility grid, an energy source to provide for the amenities of life found only in the urban areas. This PVPS project covered one of the SOLERAS program area that included a solar-cooling system and a solar desalination system.

The SOLERAS Project was sponsored by the Saudi Arabian National Center for Science and Technology (SANCST) and the United States Department of Energy (DOE). Martin Marietta of Denver, Colorado was the prime contractor of this system carrying out overall systems design, fabrication, installation and training. The project started in January, 1980 and the PVPS was commissioned in September, 1981. In December, 1986, SOLERAS program ended and the PVPS was turned over to the Saudi Arabian government. King Abdulaziz City for Science and Technology (KACST) formerly SANCST is now operating and maintaining the project.

## II. System Description

The PVPS was constructed in a hilltop site near the villages of Al-Jubaylah, Al-Uyaynah and Al-Hejra, which are about 45 kms. northwest of Riyadh, the capital city of Saudi Arabia. These villages were inhabited initially by a population of 4000 and did not have any local electrical grid, relying only on small diesel generators for their energy needs. The PVPS is shown in a simplified block diagram in Figure 1-A. Its major subsystems are the photovoltaic array field, battery, power conditioning and distribution, instrumentation and data recording, automatic control and back up power (see Table 1). Since its installation in 1981 until the end of 1984, it has been a stand alone power source of the villages operating in cogeneration mode with four 250-kW and two 800-kW diesel generators. At the end of 1984, the national utility grid reached the three villages, thus, PVPS became a conventional utility connected power system and has been since operating in this mode.

Photovoltaic Array Subsystem

The Photovoltaic array field (Figure 2-A) is the most striking feature of the system. It consist of 160 pedestal mounted arrays of PV modules. One array, (Figure 2-B), contains 256 serially connected circular solar cells of 5.7 cm diameter each, and 64 lens modules; each half module having four fresnel lens. Each fresnel lens module consist of four 30.48 square centimeter point focusing pattern with circular grooves on the surface away from the sun. These lenses enhance sunlight 40 times making one cell generate as much electricity as 40 cells receiving unconcentrated sunlight. The 4 feet modules are mounted on an aluminum heat sink that provides passive cooling for the solar cell.

The PV field is divided into 8 identical subfields. A subfield is furtherly divided into eight branches. One electrical branch that provides the necessary system operating voltage is composed of two and a half arrays (640 cells in series). The eight branches of each of the subfield are diode isolated and are paralled in the subfield distribution boxes while the eight subfields are paralled at the PVPS array bus located at the array power distributor inside the PV building.

An array is 12.2 m x 2.74 m. It is mounted on a 1.5 m high pedestal. Each array has its own electronic control unit (ECU), sun sensor and a 2-axis drive mechanism. The ECU's provide manual or automatic control of the array. It interfaces with the PV field system controller called the field control system which provide individual control for an array or for a whole subfield for lens cleaning and other routinary maintenance. The tracking approach is based on active sun sensing. It uses four "coarse" sensors to acquire the sun and four "fine" sensors to track the sun which has a narrower angle of view of approximately 5 degrees.

Battery Subsystem

The battery subsystem is comprised of four lead acid batteries. One battery is composed of thirty modules, each containing 4 cells in series and is rated at 1600 Ah. The operating depth of discharge of 75% was selected to provide 1100 KWH of useful energy. These cells use dilute sulfuric acid as the electrolyte and lead antimony as the grids. The charge control mechanism provides long service life and low battery maintenance. The use of a two step temperature-compensated constant voltage charging technique permits the battery to recharge quickly when solar energy is available.

Power Conditioning and Distribution Subsystem

The principal equipment in the power conditioning and distribution subsystem are the 300-kVA inverter, uninterruptible power supply (UPS), auxiliary battery charger, analog shunt regulator, 750 kVA transformer and the necessary switchgear.

The inverter converts the 215 to 350 Vdc power to 277/480 Vac, 3-phase, 60 Hertz ac power. It is capable of operating in either stand alone or cogeneration mode. In the stand alone mode, the inverter supplies a voltage and frequency regulated power to dedicated load. In the cogeneration mode, the inverter provides power output in parallel with the diesel generators. Its output voltage and phase are controlled by the control computer's power dispatch command. In the peak power tracking mode, the inverter is synchronized with the utility grid. Its output voltage and phase are controlled to extract the maximum power from the Photovoltaic Arr for ac power conversion.

The UPS comprised of two 10 kW dc/ac rectifier and a 10 kW ac/dc rectifier that are powered by the main dc bus and the main ac bus.

The auxiliary battery charger is a 60 kW, 300 Vdc unit which was included only for battery maintenance purpose.

The shunt regulator is used to limit the voltage across the batte DC bus by connecting or disconnecting PV branches. This feature was taken out from the system when PV branch control through the automatic control computer was found to be sufficient to handle battery dc bus regulation.

Control and Instrumentation and Recording Subsystem

Automation and Data collection are implemented using an HP9845 desktop computer and are real time controlled. The control subsystem includes all hardware and software necessary for automatic and manual operation. It provides the following functions (1) PVPS state and sequence control, (2) array branch control, (3) inverter operating mode, (4) diagnostic and status monitoring, (5) shunt regulator control, (6) battery charge control, (7) command processing an verification, and (8) display control.

The instrumentation and data recording subsystem consists of the computer and its data acquisition peripherals, sensors, signal conditioning equipments and I/V tracers and loads. It provides the following functions (1) automatic data collection, (2) PVPS sta monitoring, (3) data logging, (4) system performance display, and Subfield/Branch/Array/Half array I/V test.

Back up power

Four 250 KVA diesel generators with its switch gear and control electronics provides power backup to the PV arrays. The control electronics features are automatic start and shutdown synchronization with external source and spinning reserve management. It also provides protection to both engine and generator.

## III. System Operating History

The PVPS was originally designed as a stand alone system to provide electrical power to three remote villages. The village electrical load consists of lighting, small appliances, air conditioning and heating units and agricultural water pumps. In November, 1981, PVPS provided power to both Bus # 1 and Bus # 2. Operation and maintenance personnel was provided by Electricity Corporation of the Ministry of Industry and Electricity. The initial mode of operation was cogeneration mode. During daytime, the array field produces power to recharge the batteries and feeds input power to the inverter for an ac power delivered to the utility grid. At night time, the stored energy on the batteries supplied the power. The stand alone mode was also tried and was successfully operating during the first several months. However, the process of urbanization in the villages was also taking place. Residential and commercial buildings were constructed thereby increasing the load demand. Two diesel generators (Figure 1-B) were added in 1982 to cope up with the rapid increase of power demand.

During this period, two additional mode of operation were incorporated into the system either under manual or automatic control. One is the peak power tracking mode. This mode enables the inverter to extract the maximum power available in the PV field and deliver it to the grid. Batteries are disconnected from the DC bus in this mode. The other is the reverse power mode wherein the PVPS receives power from the two 800-kW diesel generators. Additional manual switches at the control panel and incorporation of a few subroutines in the control software were all it takes to successfully implement these addendum.

In late 1984, the national utility grid, SCECO (Saudi Consolidated Electric Corporation) reached the three villages. As a result, the PVPS was also tied up to the utility grid (Figure 2-C). Since then, the normal operating mode is peak power tracking mode delivering electrical energy to the utility grid during daytime and reverse power mode (receiving power from the utility grid) during night time or during inclement weather. It then operated as a full research facility. By the start of 1989, a 350 kW electrolyzer will be added to the system for producing Hydrogen (Figure 2-D).

## IV. System Performance

The PVPS has operated very satisfactorily on the dry and hot desert climate of Saudi Arabia since it was installed in September, 1981 [1-4]. The significant results it yielded in its seven year operation are as follows:

* The PV array field generated a maximum power of 375 kW in 1982. Maximum power are always attained during the cool winter months of January and February.

* The PVPS array field is generating an average monthly energy of 46,000 kWH.

* The PV field energy efficiency has been consistently ranging in between 8 - 11%. The inverter efficiency exceeded 90%.

* Power output of the PV field has declined by 2.6% per year due to PV module related failures.

* The change from stand alone to peak power tracking mode of operation has increased PV field energy generation by as much as 20%.

* System downtime due to the inverter fault is negligible. Since the mode of operation was change to the peak power tracking mode, the following downtime was recorded:

| Year | Downtime |
|---|---|
| 1985 | 5 hours |
| 1986 | 11 hours |
| 1987 | 6 hours |
| 1988 | None |

* The PVPS automatic control subsystem performed remarkably well leaving the system to be operationally unmanned. The only human interface needed with the system is the command to peak power tracking mode after sunrise.

* Dust and dirt accumulation on the Fresnel lenses decreases the array power output by 2.5% monthly.

* The PV array sun tracking electronics and its drive mechanism that provide the 2-axis orientation have operated much better than originally expected with very minimal failures.

The overall system performance has been very remarkable. Figure 3 shows the PV field energy efficiency. It should be noted that this efficiency is higher than most of the PV systems in the world. The system inverter efficiency has consistently exceeded 90%. Figure 4 shows the monthly generated energy of the PV field. The average monthly energy production has been in excess of 46,000 kWh.

Direct normal insolation peaks during the cool winter months which has the effect of increasing the PV field power output. However, the PV field produces higher energy during summer season, though the direct normal insolation is low coupled with a very high ambient temperature, due to the long sunshine hours (Figure 5). System availability which is the ratio of the total operating hours of the system to that of the total sunshine hours has ranged in between 70 and 75%. Availability during December to March is low because of inclement weather (Figure 6).

Hardware Performance

The PV field hardware performance has been very satisfactory. There were no major failure experienced that stopped operation nor resulted to drastic reduction in the PV field power output. A relatively small min... problems occurred but were given immediate attention and solution. PV hardware performance can be divided into 4 major categories which are described in the preceding paragraph.

Solar Cells and Lens

The solar cells and lens have been performing very well without any degradation at all. This was revealed by a large number of solar cell, module and array I/V tests which are performed monthly for the past two years. One I/V test that was conducted on one of the arrays one year apart at nearly identical conditions revealed no array power output degradation. Similarly, the same results were obtained from I/V tests conducted from other selected arrays. An independent lens performance test conducted by the Sandia National Laboratories on one of the lenses revealed no appreciable degradation. However, 2% of the Fresnel lenses have discolored and turned yellowish. A preliminary result of the investigation performed by the Sandia National Laboratories tend to indicate that the discoloration is due to the deterioration of a solvent used to bond the superstrate to that of the compression molded lens. However, there are no other evidence to support this conjecture. Th... investigation is continuing.

PV Module

The PV field power output was reduced by 18% due to module open circuit problems. These problems are either due to detached cell to cell interconnect or due to the detachment of cell from their ceramic substrate. Failure analysis indicated solder bond failures at th... cell/ceramic substrate interface and interconnect/ceramic substrate interface. The rate of failure is nine half modules per month which is 6% of the 18% power output reduction. The remaining 12% is due to current limiting caused by cracked solar cells.

Sun Tracker

The electronic control unit which was thought to be the weakest link in the PV field subsystem has performed extremely well. The average failure is two out of 160 ECU's per month. Majority of ECU failures have been component level and are repairable problems. Average time to repair including the time to remove and install the said unit into the ECU box is two hours.

Other PV field component

The most common failure on other PV field component is shorted PV modules. PV modules are shorted to ground through the bypass diode which in turn shorts through the heat sink when rain water seeps inside the module either through the O-ring or through improperly tightened screws used to secure the module housing to the heat sink. To prevent seeping of rain water inside the housing module, the arrays are stowed at an angle during rainy days. There are some other mechanical and electrical failures but have occurred infrequently. These includes drive assembly failures, cable failures and branch blocking diode failures. These could have been eliminated if proper design analysis and sufficient testing were done during the project design stage.

## Array Washing

The PV field array lenses are washed every two months with a high pressure sprayer. A newly washed subfield results to an increase of power production by 5-8%. The average time to wash a subfield with an area of $475.91m^2$ and performed by 3 people is 2 hours. Thus, 48 manhours or 0.013 manhours/$m^2$ is required to wash the field every two months.

One subfield composed of 20 arrays was chosen as a test bed to determine the effect on power output due to dust and dirt accumulation on the array lens. The arrays were not washed for more than two years during this test. At the end of the month, subfield I/V tests were taken on this subfield as well as on another freshly washed and well maintained subfield. The test results were compared and revealed that the short circuit current and to a certain degree, the maximum power point, decreases linearly at the rate of 2.5% monthly. However, this rate is not for a complete 12 months since the arrays were washed by rain during the cold season.

V. Economics

The Photovoltaic Power System of Saudi Arabia is not a commerc... producing facility but was installed primarily for research and experimental purpose. As a result, it contains a large number of sophisticated equipments which increase the cost of the system. It should be noted that in 1981, it was the first and the largest photovoltaic power system in the world. It comprised of hardw... specifically the photovoltaic hardware, which had to be designed and developed from the drawing table and geared for mass production. Another area of expensive development is software engineering. The computer programs used for automatic control and for data collection and recording had to be developed from scratch. Thus, a large portion of the total systems cost was absorbed by non-recurring engineering and developmental cost. The total cost of the system exceeds US$ 32 million which equates to $92,000.00 per kilowatt or $92.00 per peak watt. This value is in terms of 1982 US dollar. The solar cell used with the system is made of silicon material. Its conversion efficiency is 13.5%. Since the time PVPS was installed in 1981, intensive research and development on concentrator solar cell was made by various organizations. Solar cells now which are similar to the ones with the PVPS have a conversion efficiency of 28%. Onl... recently, another type of concentrator solar cell called mechanically stacked multijunction (MSMJ) solar cell was developed at the Sandia National Laboratories. The solar-to-electric conversion efficiency attained is 31% [5].

Operations and maintenance cost has not been accurately estimated. The operating philosophy of the PVPS is to optimize energy production. To meet this requirement, full time personnel for both the electrical and mechanical aspects of the system were employe... The system is well maintained that any failures that occur in any of the sybsystem are given immediate attention and solution. Research activities has also, to a great extent, affected O & M cost. One test that never was tested with the PVPS is the effect of unmanned operations to that of O & M cost. However, an identical system (though smaller in size, 80 arrays, 225kW rating) installed ... Phoenix, Arizona, USA has adopted unattended operation. The test was implemented in 1985. The test revealed that at an optimized energy production, the O & M requirements is only 32 manhours per month [6].

## VI. Conclusion

The 350 kW concentrating photovoltaic power system is now in [illegible] eight year of operation. It has performed well with little or [illegible] down time and has met most of its design objectives. The 18% power reduction of the PV array field is still small. The causes of this reduction are mainly due to design and manufacturing deficiencies and are easily correctible on future designs of concentrator photovoltaic power systems. The contineous operation of the system for over seven years have clearly demonstrated the viability of photovoltaic power systems as reliable power sources. The system experienced several operational and a number of hardware problems but were all easily correctible.

With the invaluable experience gained and several lessons learned by operating the system and the degree of development of concentrator solar cells, it is reasonable to state that concentrating photovoltaic power systems installed in the future would be [illegible] reliable and cheaper.

## VII. REFERENCES


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Table 1. Major PV Plant Elements

| ITEM | FEATURES |
|---|---|
| PV System | |
| PV Array Field | 160 Concentrators Arrays, 12.1 m x 2.7 m, 64 Parallel strings of 640 cells in Series; 40,960 Circular Silicon (Cz) Cells (5.7 cm–dia); 160 Sun Tracking Electronics and Drive Mechanisms; 10,240 Fresnel Lenses (Quad) and Plastic Housing |
| Battery | 4 Lead–Acid Batteries, 120 Cells in Series Each; 1.6 MW–Hr Rated Capacity (each cell 1700 A–Hr) |
| Battery Auxiliary Charger | 60 kW, 300 Vdc, 200 A for Off–line Maintenance |
| Inverter | 300 kVA, 480 Vac, 3 Phase |
| Diesel Generators | 1 MW (Four 250 kW Units) |
| Transformers | 3 MVA (Two 1500 kVA Units, 480 to 13,800 Vac) |
| Switch Gear | 600 Vdc, 480 Vac, and 110 Vac |
| Control Equipment | Manual/Automatic Operation with HP9845 Computer |
| Uninterruptible Power Supply | 10 kVA, 110 Vac Inverters (2 Units) and 10 kW 300 Vdc Power Supply |
| Instrumentation and Data Recording Equipment | Magnetic Tape, HP9845 Computer, and HP3052 Data Acquisition System |
| Array Cleaning Equipment | Purified Water Spray (82°C at 1000psi); 7.5 liter/min; Truck mount |
| Facility | Building that houses PV system Hardware, Training, Maintenance and Storage Rooms, Diesel Fuel Storage Tanks |

Figure 1-A Simplified PVPS Block Diagram

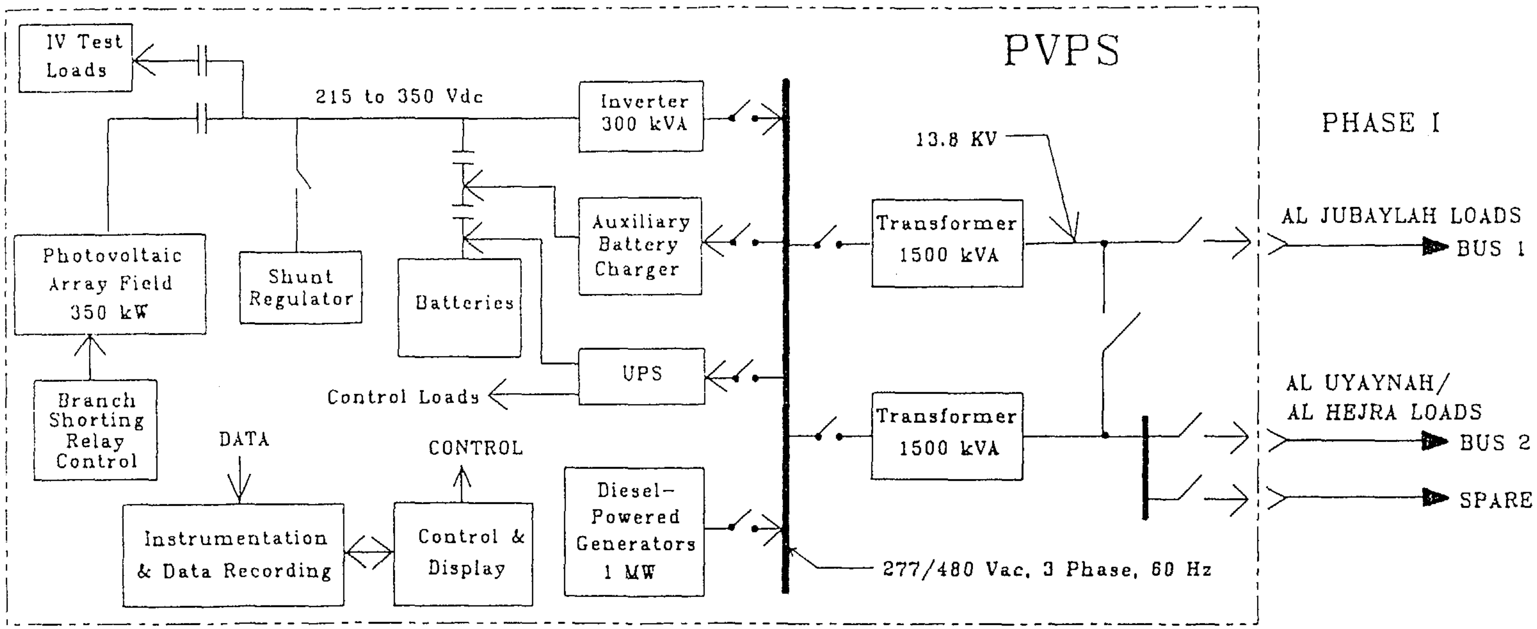



Figure 1-B

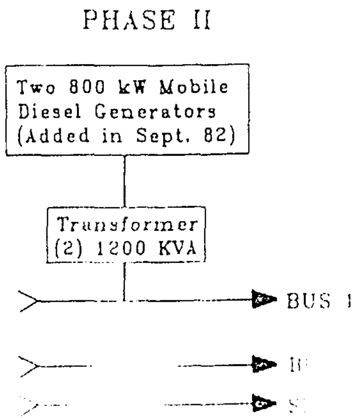



Figure 1-C

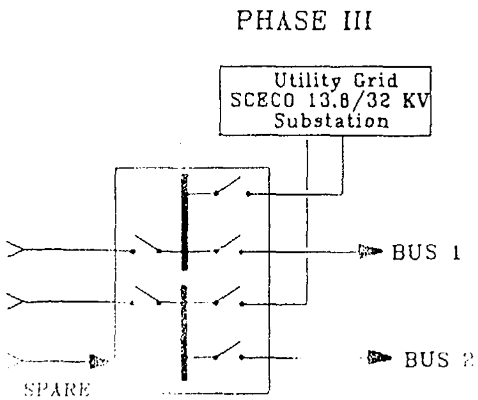



Figure 1-D

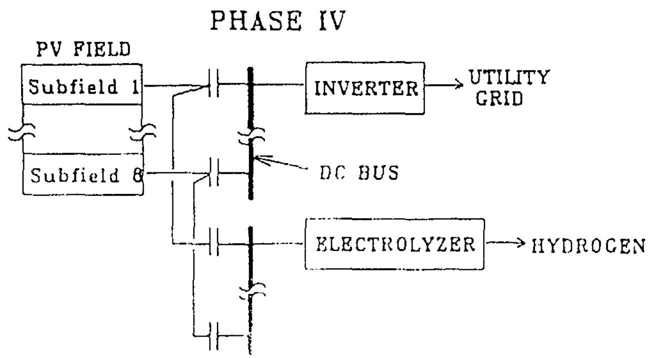


Figure 3. PV field and inverter energy efficiency

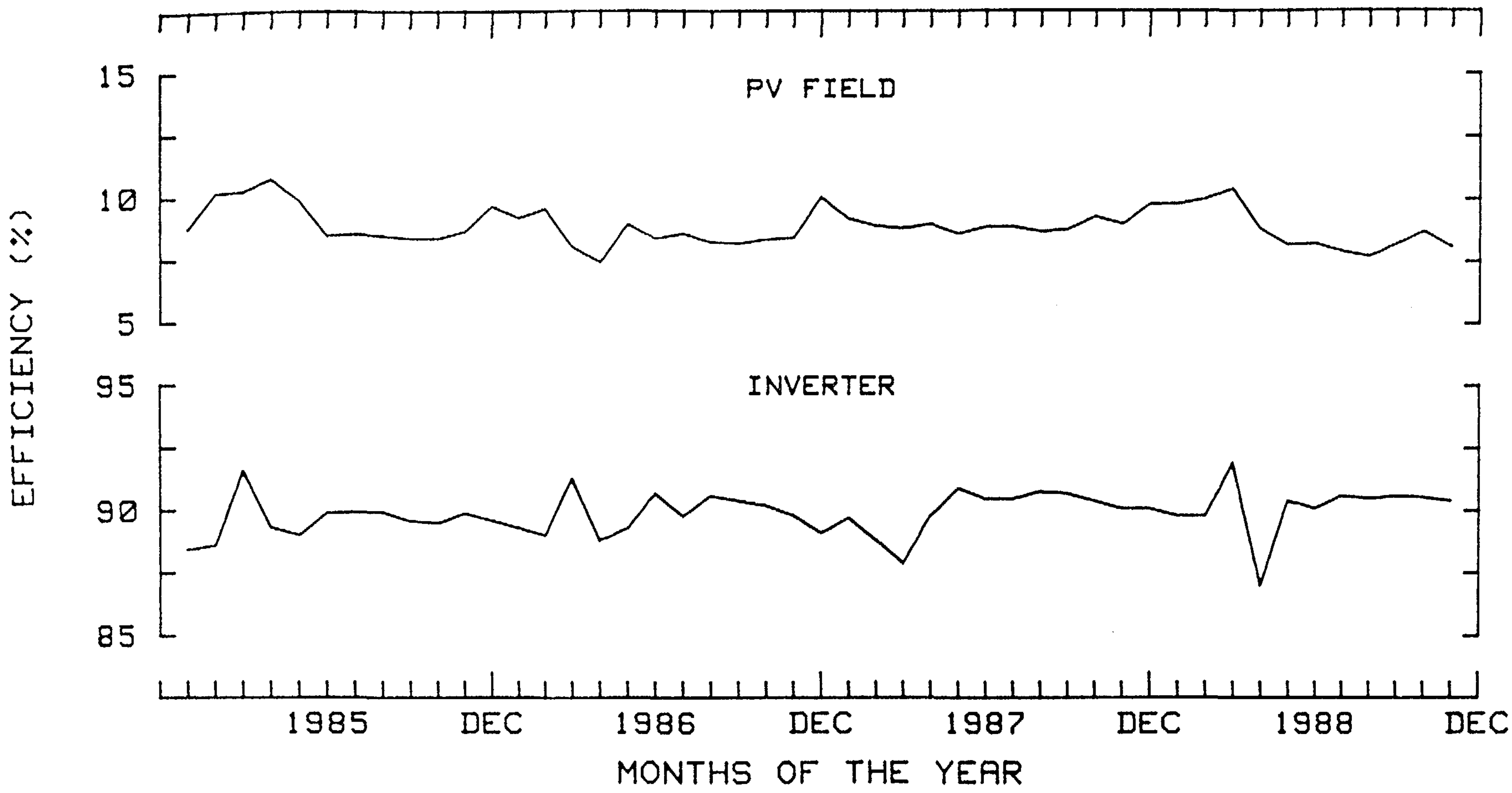


Figure 4. PV field monthly energy production

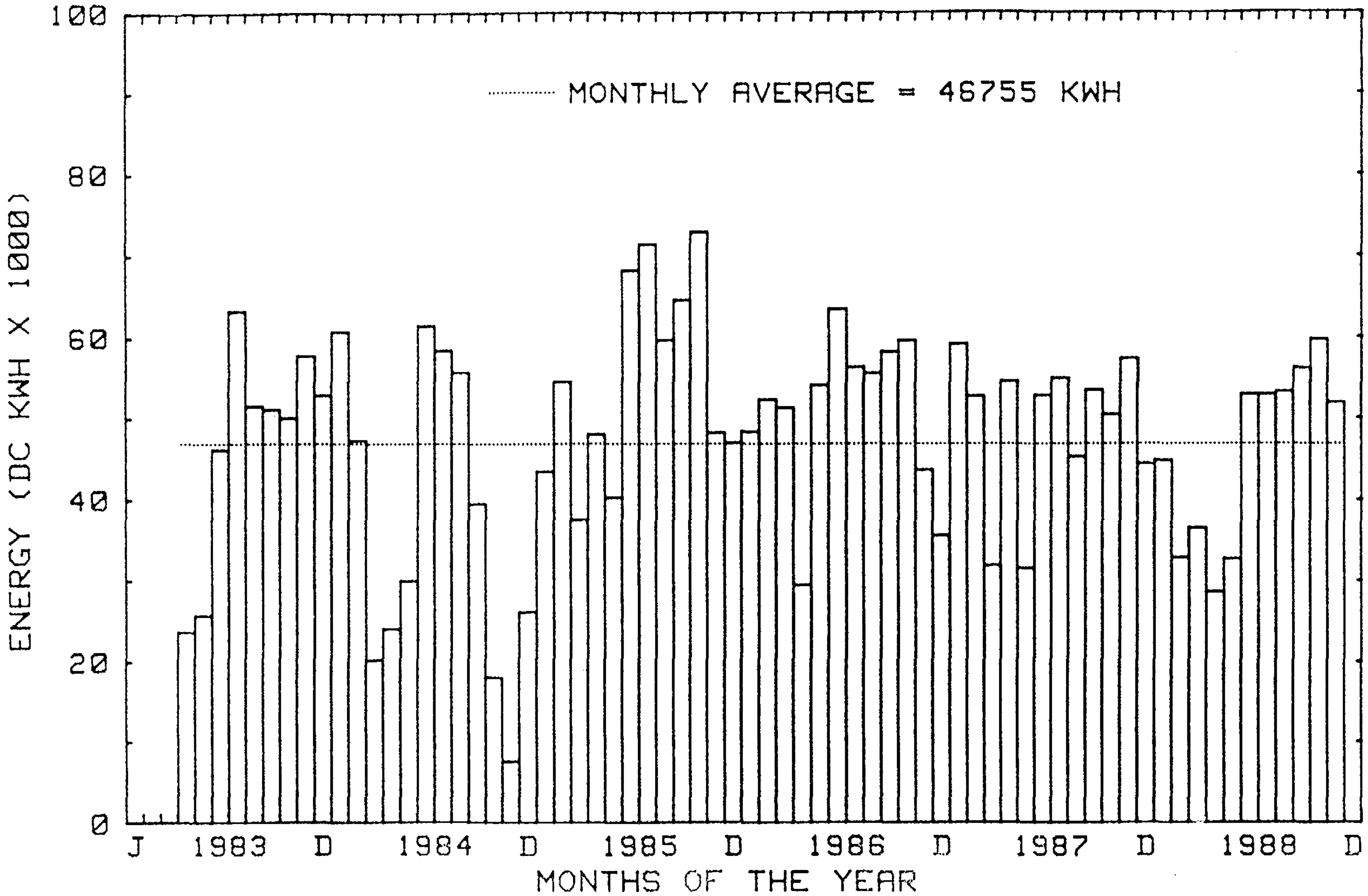
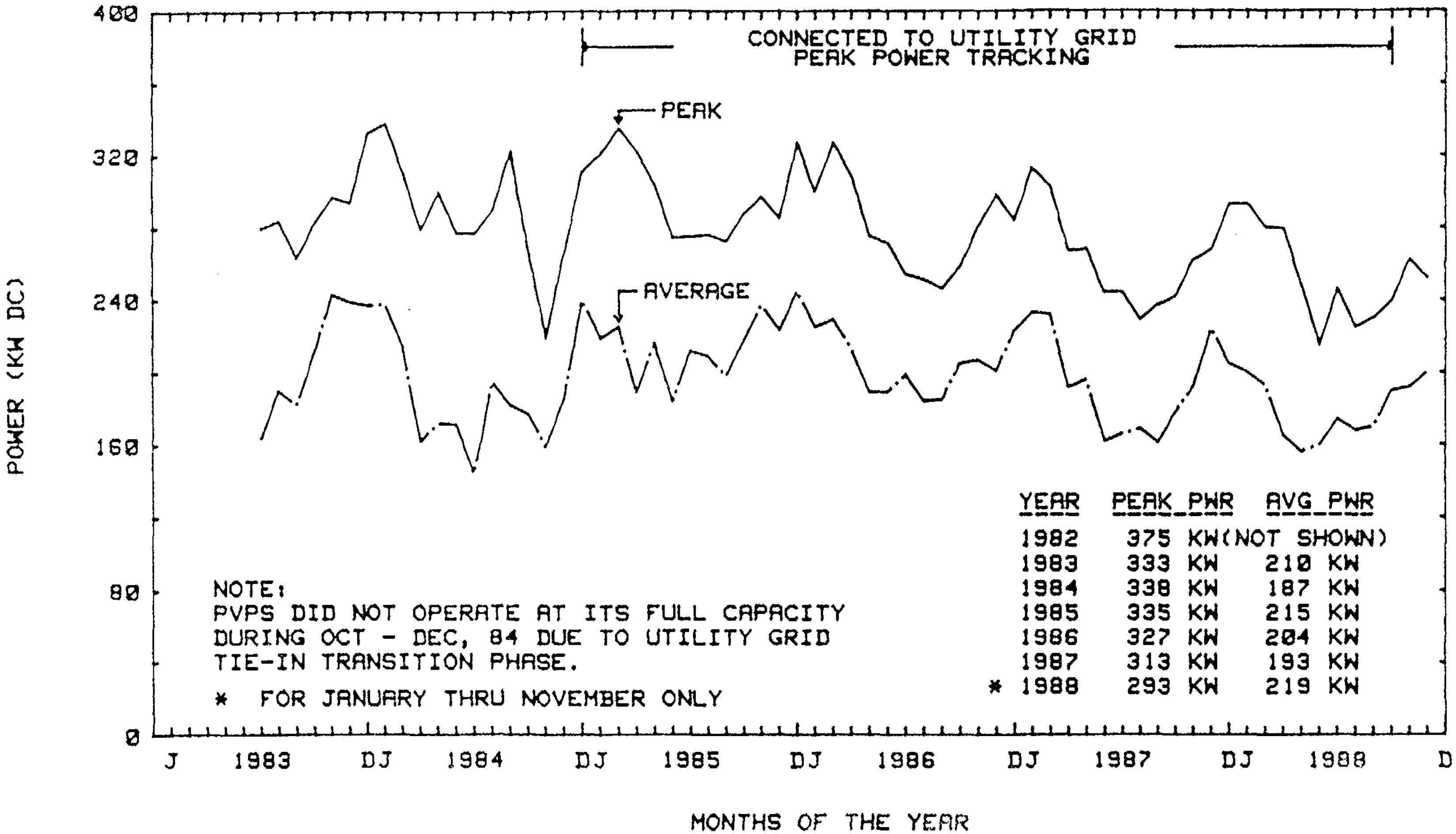


Figure 5. PV field monthly peak and average power



*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# *Syria*

# PHOTO-VOLTAIC (PV) APPLICATIONS IN SYRIA

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**Expert Group Meeting on" Networking of PV Systems and Applications"**

**ABSTRACT:**

**In this presentation, a detailed information about renewable energy resources in the country is given. More emphasis on the potentiality of solar radiation resources (thermal, light) will be considered. Possible and available applications of solar applications, for the daily life of the inhabitants especially in rural areas are analyzed. In addition, the expected growth of the renewable energy demand is summarized.**

**Introduction:**

Syrian Arab Republic is geographically situated in between 32° 3' and 37 latitude north of **Equator** line and in between the longitude lines 36 and 42° 5' east of Greenwich line. Therefor, as a Mediterranean country, Syria enjoys a large scope of renewable energy resources that include solar, bio-mass, wind and Geothermal. Syria is blessed with high level of solar radiation. The average rate of the solar radiation (insolation) is approximately in access of **5kWh/m$^2$** per day which is equivalent to **1825kWh/m$^2$** per year over the entire area of the Syrian land. The number of hours on which the solar radiation can actually be utilized varies from **2820-3270** hours/year. The number of cloudy days varies from **38-45** days/year.

The available climatic data are presented in a set of three tables [1], [2] and [3]. These tables represent the daily sunshine hours, daily solar irradiation on the horizontal plane and daily mean ambient temperature respectively. The reported measurements are for 15 meteorological stations in 15 different geographic locations.

## KEY FIGURES OF THE SYRIAN ARAB REPUBLIC:

- Population: **17 200000**(1999).
- Urban Population: **50.57%** (1994).
- Rural Population: **49.43%**(1994).
- Total Area: **185000** sq. Km.
- Number of houses: **2578564**(1994).
- Major Energy Sources: oil, gas and hydro-power.
- Oil Consumption: **12.5** Million Tons of Oil Equivalent(1996).
- Rate of Consumption: **4.7%** per year (before 1996).
- Expected Increase in Rate Consumption: **4%** per year up to 2015.
- Total Electricity Generation: **18328 G.W.h**(1996). This includes:

  1. Hydroulic Turbine: 3550 G.W.h(1996), Forms(19.48%) .
  2. Steam Turbine(N.G): 1608 G.W.h(1996), Forms(8.75%).
  3. Steam Turbine(F.O): 5347 G.W.h(1996), Forms(29,14%).
  4. Combined Cycle: 3555 G.W.h(1996), Forms(19.5%).
  5. Gas Turbine(N.G): 4230 G.W.h(1996), Forms(23%).
  6. Gas Turbine(D.O): 38 G.W.h(1996), Forms(0.21%).

- Average (Solar Radiation) Insolation: **5 kWh/ $m^2$** per day, equivalent to **1825 kWh/ $m^2$** per year.
- Average Sunny Hours: **2820-3270 Hours/year.**
- Average Wind Speed: **6-12 m/s for 53.7% for7 months per year, in Area A.**
  **5-10 m/s for 34.9% for 4 months per year, in Area B.**

- Expected potential of Bio-gas which can be generated from the available Bio-mass is approximately: **286 Million Cubic Meters/year.**

| Station | Period | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qarachoch | 60-79 | 4.5 | 5.2 | 6.1 | 6.8 | 9.5 | 12.1 | 12.3 | 11.4 | 9.5 | 7.9 | 6.1 | 4.2 | 8.0 |
| Jarablus | 58-77 | 4.1 | 5.4 | 6.6 | 8.0 | 10.2 | 11.7 | 12.3 | 11.7 | 11.8 | 8.5 | 6.3 | 3.8 | 8.4 |
| Hassakeh | 58-77 | 4.7 | 5.9 | 6.7 | 7.5 | 9.9 | 12.1 | 12.4 | 11.7 | 10.3 | 8.2 | 6.6 | 4.8 | 8.4 |
| Meeselmiyeh | 68-79 | 3.9 | 4.9 | 6.1 | 7.8 | 10.3 | 12.2 | 12.5 | 11.9 | 10.3 | 8.1 | 6.2 | 4.0 | 8.2 |
| Alleppo | 58-78 | 4.1 | 5.3 | 6.7 | 7.9 | 10.7 | 12.4 | 12.7 | 12.0 | 10.6 | 8.5 | 6.7 | 4.3 | 8.5 |
| Raqqa | 60-73 | 4.9 | 5.9 | 7.1 | 8.5 | 10.2 | 12.1 | 12.3 | 11.8 | 10.6 | 8.6 | 7.1 | 5.0 | 8.7 |
| El Jeed | 66-79 | 3.0 | 4.5 | 5.9 | 7.3 | 10.2 | 11.8 | 12.1 | 11.4 | 10.0 | 7.1 | 5.7 | 3.0 | 7.7 |
| EL Baida | 60-79 | 5.1 | 6.0 | 7.1 | 8.4 | 10.3 | 11.6 | 11.0 | 11.0 | 10.1 | 8.5 | 6.7 | 4.9 | 8.4 |
| Lattakia | 69-78 | 5.7 | 5.8 | 6.4 | 7.3 | 9.9 | 10.7 | 10.3 | 10.3 | 9.5 | 7.9 | 6.7 | 4.8 | 7.9 |
| Deir Ezzor | 58-82 | 5.1 | 6.5 | 7.3 | 8.2 | 10.1 | 12.0 | 12.2 | 11.8 | 10.4 | 8.5 | 7.1 | 5.2 | 8.7 |
| Hama | 60-77 | 4.2 | 5.5 | 7.1 | 8.4 | 10.7 | 12.5 | 12.7 | 12.0 | 10.5 | 8.5 | 6.9 | 4.5 | 8.6 |
| Palmyra | 58-82 | 5.3 | 6.9 | 7.7 | 8.5 | 10.4 | 12.2 | 12.5 | 11.8 | 10.5 | 8.7 | 7.3 | 5.6 | 8.9 |
| Kharabo | 68-79 | 5.1 | 6.7 | 7.7 | 8.6 | 10.5 | 12.3 | 13.3 | 11.8 | 10.5 | 9.3 | 7.3 | 5.3 | 8.9 |
| Damascus-Mezzeh | 58-77 | 5.5 | 6.7 | 8.1 | 9.0 | 10.9 | 12.5 | 12.7 | 12.0 | 10.8 | 9.2 | 7.5 | 5.7 | 9.2 |
| Damascus-Airport | 70-82 | 5.4 | 6.8 | 7.7 | 8.4 | 10.7 | 11.9 | 12.0 | 11.8 | 10.4 | 9.0 | 7.2 | 5.3 | 8.9 |

**Table 1: Daily Sunshine Hours**

| Station | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qarachoch | 2.2 | 3.0 | 4.0 | 4.9 | 6.3 | 7.3 | 7.3 | 6.6 | 5.3 | 4.0 | 2.8 | 2.0 | 4.7 |
| Jarablus | 2.1 | 3.1 | 4.2 | 5.3 | 6.5 | 7.2 | 7.3 | 6.7 | 6.0 | 4.2 | 2.9 | 1.9 | 4.8 |
| Hassakeh | 2.3 | 3.2 | 4.2 | 5.2 | 6.5 | 7.3 | 7.3 | 6.7 | 5.6 | 4.1 | 2.9 | 2.2 | 4.8 |
| Meeselmiyeh | 2.2 | 3.0 | 4.1 | 5.4 | 6.7 | 7.5 | 7.5 | 6.9 | 5.7 | 4.2 | 2.9 | 2.0 | 4.8 |
| Alleppo | 2.2 | 3.1 | 4.3 | 5.4 | 6.8 | 7.6 | 7.6 | 6.9 | 5.8 | 4.3 | 3.0 | 2.1 | 4.9 |
| Raqqa | 2.4 | 3.3 | 4.4 | 5.5 | 6.6 | 7.4 | 7.3 | 6.8 | 5.7 | 4.3 | 3.1 | 2.3 | 4.9 |
| El Jeed | 2.0 | 2.9 | 4.1 | 5.3 | 6.7 | 7.4 | 7.4 | 6.8 | 5.7 | 4.0 | 2.9 | 1.8 | 4.8 |
| EL Baida | 2.5 | 3.3 | 4.3 | 5.5 | 6.6 | 7.1 | 6.9 | 6.5 | 5.6 | 4.2 | 3.0 | 2.3 | 4.8 |
| Lattakia | 2.4 | 3.2 | 4.1 | 5.1 | 6.4 | 6.8 | 6.6 | 6.3 | 5.4 | 4.1 | 3.0 | 2.2 | 4.6 |
| Deir Ezzor | 2.5 | 3.5 | 4.5 | 5.5 | 6.6 | 7.3 | 7.3 | 6.8 | 5.7 | 4.3 | 3.2 | 2.4 | 5.0 |
| Hama | 2.3 | 3.3 | 4.5 | 5.7 | 6.9 | 7.7 | 7.6 | 7.0 | 5.9 | 4.4 | 3.2 | 2.3 | 5.1 |
| Palmyra | 2.6 | 3.7 | 4.7 | 5.7 | 6.7 | 7.5 | 7.5 | 6.9 | 5.8 | 4.4 | 3.3 | 2.6 | 5.1 |
| Kharabo | 2.7 | 3.8 | 4.8 | 5.8 | 6.9 | 7.6 | 7.6 | 7.1 | 6.0 | 4.8 | 3.5 | 2.6 | 5.3 |
| Damascus-Mezzeh | 2.8 | 3.8 | 5.0 | 6.0 | 7.0 | 7.7 | 7.7 | 7.1 | 6.1 | 4.7 | 3.5 | 2.7 | 5.3 |
| Damascus-Airport | 2.8 | 3.8 | 4.8 | 5.7 | 6.9 | 7.5 | 7.4 | 7.0 | 5.9 | 4.6 | 3.4 | 2.6 | 5.2 |

**Table 2: Daily Solar Irradiation on the Horizontal Plane(kWh $m^{-2}$ $d^{-1}$)**

| *Station* | Period | Jan. | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Qarachoch | 60-79 | 5.7 | 7.5 | 11.1 | 15.7 | 22.5 | 28.9 | 32.7 | 32.4 | 27.5 | 21.1 | 13.6 | 7.6 | 18.9 |
| Jarablus | 57-76 | 5.2 | 6.7 | 11.0 | 15.9 | 21.6 | 27.0 | 30.3 | 29.8 | 25.3 | 19.1 | 12.3 | 7.0 | 17.6 |
| Hassakeh | 57-76 | 5.3 | 7.2 | 11.5 | 16.5 | 22.5 | 28.2 | 31.3 | 30.5 | 25.7 | 19.3 | 12.0 | 6.8 | 18.1 |
| Meeselmiyeh | 57-79 | 4.9 | 6.6 | 10.8 | 15.2 | 20.4 | 25.2 | 26.1 | 27.7 | 24.6 | 18.0 | 11.9 | 6.7 | 16.4 |
| Alleppo | 51-78 | 5.6 | 7.4 | 10.7 | 15.5 | 20.9 | 25.7 | 28.1 | 28.1 | 24.9 | 19.5 | 12.3 | 7.3 | 17.2 |
| Raqqa | 58-79 | 6.4 | 8.2 | 12.3 | 17.5 | 23.2 | 28.0 | 29.9 | 29.4 | 25.5 | 19.8 | 12.9 | 7.7 | 18.4 |
| El Jeed | 66-79 | 6.9 | 8.9 | 12.4 | 16.4 | 21.1 | 26.1 | 28.5 | 27.9 | 24.5 | 19.7 | 12.8 | 8.1 | 17.8 |
| EL Baida | 60-79 | 11.5 | 12.5 | 14.5 | 17.4 | 20.4 | 24.1 | 26.4 | 27.0 | 25.3 | 22.1 | 17.7 | 13.2 | 19.3 |
| Lattakia | 66-78 | 11.6 | 12.6 | 15.1 | 17.9 | 20.9 | 24.0 | 26.4 | 26.9 | 25.6 | 22.6 | 17.8 | 13.2 | 19.6 |
| Deir Ezzor | 51-82 | 6.9 | 9.2 | 13.1 | 18.6 | 24.3 | 29.6 | 32.9 | 31.9 | 27.6 | 21.1 | 13.2 | 8.1 | 19.7 |
| Hama | 56-76 | 7.3 | 8.3 | 11.8 | 16.3 | 21.5 | 26.0 | 28.1 | 28.2 | 25.3 | 20.3 | 13.5 | 8.2 | 17.9 |
| Palmyra | 56-82 | 6.8 | 8.9 | 12.8 | 17.7 | 22.9 | 27.3 | 29.3 | 29.1 | 25.9 | 20.6 | 13.2 | 8.1 | 18.5 |
| Kharabo | 56-79 | 6.3 | 7.7 | 11.3 | 15.2 | 19.1 | 23.3 | 25.0 | 24.7 | 22.0 | 17.5 | 11.9 | 7.3 | 15.9 |
| Damascus-Mezzeh | 51-76 | 7.1 | 8.6 | 11.8 | 16.2 | 21.0 | 25.1 | 26.8 | 26.9 | 24.1 | 20.0 | 13.8 | 8.6 | 17.5 |
| Damascus-Airport | 56-82 | 6.1 | 8.1 | 11.3 | 15.7 | 20.2 | 24.5 | 26.2 | 25.9 | 22.9 | 18.2 | 11.8 | 7.4 | 16.5 |
| Bailaneh | 66-73 | 5.4 | 7.6 | 11.8 | 16.9 | 22.7 | 27.2 | 29.6 | 29.1 | 25.7 | 19.5 | 12.0 | 6.7 | 17.9 |
| El Shoghour | 57-71 | 8.3 | 9.5 | 13.1 | 16.8 | 21.8 | 26.2 | 28.5 | 28.9 | 25.7 | 20.0 | 13.3 | 9.1 | 18.4 |
| Joureen | 65-79 | 7.0 | 9.0 | 12.6 | 16.6 | 21.4 | 26.9 | 29.9 | 29.4 | 25.9 | 20.1 | 13.0 | 8.2 | 18.3 |
| Khafseh | 59-71 | 6.3 | 7.5 | 11.5 | 16.4 | 22.4 | 27.4 | 29.7 | 29.6 | 25.6 | 19.2 | 13.0 | 7.9 | 18.0 |
| Qattineh | 57-72 | 6.4 | 7.6 | 11.1 | 14.8 | 19.0 | 22.1 | 23.4 | 24.1 | 22.6 | 18.8 | 13.3 | 8.1 | 15.9 |
| Salkhad | 59-72 | 4.6 | 4.9 | 8.1 | 12.4 | 17.0 | 21.1 | 22.1 | 22.8 | 21.1 | 17.3 | 11.6 | 6.1 | 14.1 |
| Qamishli | 52-78 | 6.2 | 7.8 | 11.3 | 16.1 | 22.1 | 28.0 | 32.2 | 31.7 | 27.4 | 21.3 | 13.5 | 8.1 | 18.8 |

**Table 3:** Mean Temperature (C°)

## SOLAR ENERGY APPLICATIONS IN SYRIA:

Both the sun's heat and light can be utilized to generate energy, either by a thermodynamic process or by a direct conversion of light sunshine into electricity by means of photo-voltaic (PV) devices.

The most popular application, in Syria, is the households solar hot water (SHW) systems. The Syrian government had established a public company for manufacturing these systems and also encourages and facilitates the private sector to establish small companies and workshops for manufacturing such systems. At the present time, there are more than fifty private small firms and workshops officially licensed by the **Ministry of Industry**, and one state owned company.

**The full annual production capacity of the solar flat plate collectors produced by the private sector is approximately 15000m$^2$ and about 6000m$^2$ by the government company.** To cover the expected future demands for solar hot water systems, all factories need to double their production in the coming years.

In fact, there is no exact survey for the number of installed solar hot water systems in the count, however the estimated number is about 6000. The following table gives some of the major firms manufacturing solar hot water systems.

| Company Name | Location |
|---|---|
| L AVA | Damascus |
| JARRAR | Damascus |
| QOURDAB | Damascus |
| Deutsch Arabische Solar Technik | Damascus |
| Al-FAJER | Damascus |
| Kossabi and Souas | Homs |
| Kial Company | Lattakia |
| M.A. Younis | Tartous |

**-Feasibility study of SHW systems in Syria:**
At the present time, it is possible to produce high quality and high performances SHW systems with cost not exceeding similar systems in the neighboring countries. The total cost of SHW with two panels ($2x1m^2$) systems is approximately 400 $.

Let us consider a practical application:
**The cost analysis study of the SHW systems is as follows;**

The daily consumption of hot water is approximately 20 L/capita.
The average family consumption is 120 L/family/day.
The total energy needed to rise the water temperature about 40 C° is 120x40=4800 k.kalory.

**In case of Electric heater:**
The equivalent electricity is 4800/860=5.6 kWh.
The total energy needed is 365x5.6=2044kWh/year.
The real cost for one kWh is 2,5 S.P.(Syrian Pound).
The annual electricity cost is 2044x2.5=5110 S.P.
The heater cost with its connections is about 5000 S.P=100$..
Annual maintenance is approximately 300S.P.

**In case of Diesel heater:**
The diesel heater efficiency is about 45%, therefore, the required amount of diesel is **one liter/family/day (Approximately 10000 K.Kalory).**
The total energy needed is 365 Liter per year.
The real cost for one liter of diesel is 10S.P.
The annual diesel cost is 3650S.P.
The heater cost with its connections is 5000S.P.
Annual maintenance is approximately 300S.P.

**In case of SHW:**
The total cost (installation + connection) is about 25000S.P.
Annual maintenance is 300S.P.
Useful life is 20 years.
From the above figures, its clear that the pay back is approximately five years in case of electric heater and about six years in case of diesel heater if real prices for electricity and distillate oil are considered.

## *-OTHER SOLAR ACTIVITIES:

- **Airport employees' buildings project:**
  The project involves more than 2000 flats in two-story building located near Damascus international airport. The project started in 1984 adopting **solar passive heating techniques** using Trombe walls and direct gain. This project is considered as a pilot project in the middle east area. Until now about 529 units were completed . In addition, all units are provided with solar hot water systems ($3\times1.4=4.2m^2$ collector area) connected to a 280 liter storage tank.
- **Student's housing building at Tishreen University (Lattakia):**
  This project supplies about 13750 liters of hot water at 50C°. The system has 750 sq. meters flat plate collectors.
- **Solar passivation heating systems for elementary school:**
  The school is situated in Jaramana near Damascus. The school consists of thirteen classrooms in two story building.

## PHOTO-VOLTAIC APPLICATIONS:

**The photo-voltaic programs, in Syria, are still not widely exploited. Except the recent electrification of few villages in the rural areas, the overall applications of (PV) technologies are very modest and very limited.**

### Existing PV applications:

* -The first demonstration project using photo-voltaic technology was started in 1992. The **UNDP** and under the technical cooperation contract (SYR/88/007) has provided financial support to the Higher Institute of Applied Science and Technology (**HIAST**) to implement the electrification of **Abou-sorra and Al-Mesherfe villages**.

* -Another electrification project using (PV) technology of four villages in the north of Syria was also executed with cooperation between the Japanese International cooperation Agency (**JICA**) and (**HIAST**).

Table [4] shows number of inhabitants, number of households and the installed capacity of PV panels in **Abou-sorra and Al-Mesherfe, Zarzeta, Fadra, Katora and Rasm Al-Shake Kalaf (water pumping) villages north of Aleppo [4].**

| Village | No. of inhabitants | No. houses | Install. Capt.kW |
|---|---|---|---|
| Abou-sorra | 275 | 13 | 2.1 |
| Al-mesherfe | 110 | 6 | 0.3 |
| Zarzeta | 300 | 40 | 35 |
| Fadra + Katora | 250 | 37 | 9.8 |
| Rasm Alshake | 150 | 15 | 0.8 |

**Table [4].**

*** -PHOTO-VOLTAIC TEST STATION IN ADDRA:**
The system has been installed since 1978. The output is 2kW peak (**Cipel France**) with twenty 48Ah batteries with an autonomy up to 10 days. The load consists of four 24V, 100W lamps and 24V radio transmitters. There is also 200W solar force water pump.

* -PHOTO -VOLTAIC PUMPING INSTALLATION:

This installation is used to lift water for irrigation in Dummar near Damascus. It adopts, AEG modules supplying 3.25 kW and 24 batteries, each 2V, 400 A.h.

## Size of the PV market:

The government of Syria executed many ambitious programs to electrify most of the Syrian cities and villages. As a result of these programs, about 96% of houses were electrified. However, still a considerable number of small villages and isolated houses are not connected to the main national grid. That is mainly because these villages are either far from the national electricity grid or very costly and not feasible to be connected to the grid. Therefor, using a PV technology for electrification purposes is a good and sensible solution. In fact, the number of the off-grid small villages is approximately eight thousand. But there is no exact survey available about the number of isolated houses. To conduct a detailed survey about the market size and the places in need, a huge work by experts is still to be carried out.

## PV programs, centers of expertise and organization structure:

The PV program in Syria is still very modest, and as mentioned before the program, in general, includes electrification of six small villages and few PV panels used for testing facilities.
**Of course there are several reasons behind the unpopularity of PV systems will be explained later.**

## active centers and institutions:

In Syria there are several governmental institutions conduct researches and development on renewable energy applications. Also, in recent years, courses on renewable energy resources ( solar, wind and bio-mass...) are introduced at several universities. These are:
1- University of Damascus, Aleppo, Al-Baath and Tishreen.
2-Higher Institute of Applied Science and Technology.
3-Atomic Energy Commission.
4- Ministry of Electricity.

**It is useful to mention here that my commission has a good group of researchers working on the development of solar cells and its related materials.** There are also, in the above mentioned centers, few groups carrying small research activities on PV.

## Areas of need and existing training programs:

**Since the technology of PV is still not fully established in Syria, a technology transfer and intensive training programs are urgently needed. Most of the research laboratories need to up date their old testing equipment, sample preparation systems and measuring equipment to cope with the fast development, in surrounding world, in this field. Also intensive training programs, courses and workshops for the technical staff in many areas of PVs technology (i.e. characterization, sizing, solar PV systems implementation, solar effects, .....) are needed. At the present time the activities in these areas are very limited. In conclusion:**
**instrumentation and intensive technical training are urgently needed to promote the PV activities in Syria.**

## Collaboration links:

In the past few years there was some cooperation with international organizations such as (**UNDP**) and with friendly countries through (**JICA**). The government received some experts and trained few engineers working in different sectors of government ministries.

- Training project on bio-gas technology (pilot plant) with cooperation of **ESCWA**.
- Scientific cooperation with **India** to construct two bio-gas plants 90 $m^3$ and family size plants.
- Electrification of two villages south of Damascus with cooperation of **UNDP.**
- Electrification of four villages north of Aleppo with cooperation of **JICA.**

**At the present time, the ministry of Electricity with the cooperation of UNDP are conducting a national survey on renewable energy resources in the country.**

## Expected Renewable Energy Demand:

There are many reasons (i.e. expected increase in energy consumption, limitation of conventional resources, expected increase in oil prices and damage to the environment....) to justify a policy by the government to support the use of alternative energy resources. In this regard, solar energy is an excellent option to reduce the fuel oil consumption for hot water production and for electricity generation. Also, the use of available bio-mass and wind resources will help in saving oil consumption and compensating the expected future shortages. Moreover, the total emission of $CO_2$ and other gases to the atmosphere, as a results of conventional energy consumption, will be reduced and consequently reducing the damage to our environment.

Taking into account all these parameters, there are strong incentives to put plan and policies to develop the applications of renewable energy resources and to have their shares in the future energy balance. **It is expected to contribute, by renewable sources, more than 700 Thousand Tons of Oil Equivalent in year 2010. This is equivalent to 3.5-4% of the total energy balance.**

## Conclusions:

In spite of the abundance of solar (insolation) in Syria and the efforts by the government to promote the applications of SHW systems for public use, the results of such efforts are still disappointed and very modest. The main reasons behind that are:

1-Availability and cheapness of the conventional energy resources. That is because the Syrian government subsidizes all forms of energies (electricity, oil fuel, and gas....).
2-High cost of the solar systems in comparison with the people income.
3- National electricity grid covers more than 96% of the Syrian inhabitants.
4-Limited space available, on top roofs, since more than 50% of the Syrian population live in cities and more than 90% of them are living in multi-story building.
5- The benefit of the renewable energy technology is still not fully recognized by the public.

At the end, to promote the applications of renewable in general and with more emphasis on the application of PV, vigorous work is urgently needed.

*Expert Group Meeting*
*on*
*"Networking of PV systems and applications"*

*Cairo, 26-28 April 2000*

# ***Tunisia***

# Photovoltaïcs in Tunisia

## *In nine questions...*

Pr. Dr. Bahri REZIG
Photovoltaïcs and semiconductor Materials Laboratory
Ecole Nationale d'Ingénieurs de Tunis - Tunisia

UNIDO / EGM Meeting,
CAIRO, April 26-28 - 2000

# 0. Birth of PV activities in Tunisia

- 1976 : First research activity in passive solar energy applications, followed in 1978 by the PV- ENIT Group ( today: PSM Lab.).
- 1981: First PV Workshop. Recommendation to launch national R&D activities dedicated to PV module production.
- 1985: Birth of Energy Save National Agency (Ministry of Industry).
- 1986: First experimental 10 kWp PV plant (Hammam Biadha) connected to the STEG Grid.
- 1992 : First PV 14.3% cr-Si 4" solar Cell and encapsulated 10%- (30, 50 Wp) prototype modules by INRST process.
- 1999 : Renewable Energy Agency (Ministry of Environment)

# 1. Existing Applications

- 1.1 : Solar resources:
  - Winter: 4 kWh/m$^2$/day
  - Summer 7.5 kWh/ m$^2$/day
  - 2800 hours / year ( near 234 days)

  - Solargis technique applied to Mahdia, Kairaoun and Monastir

- **1.2 : Rural Electrification:**
  - Targets:
    - Off-Grid regions (remote areas and scattered households).
    - Rural integrated communication, social and health services
    - Primary and adult education (alphabetization)
  - Rural household first needs: Official Scenarios
    - 96/S1: 400 Wh/day few lamps, radio and B&W small TV
    - 96/S2: 1200 Wh/day S1 + Color TV and refrigerator
    - 2010 forecasting are S2-based, with expected tendencies favorable to Renewable Energies.
  - PV Installed Power by ANER (former AME):
    - 93/96: 3250 PVS ( # 300 KWp)
    - 97/99: 3750 PVS ( # 400 KWp) ISOPHOTON - Spain
    - ANER's Goal: 10 000 PVS is not reached: Logistics problems

## 1.3 : PV Water Pumping Systems:

- TN-Germany cooperation Program
- R&D involved (testing, modeling, sizing)
- On-site reliability tests: 14 PVPS (1.2 to 2.8 kWp) installed in 93-96 period.

- 1.2 to 1.6 kWp for submersible pumps
  2.1 to 2.8 kWp for deep wells pumps

Unit output: 7 to 25 $m^3$/day depending on the total delivery height
Efficiency of PV system: 10%
Total PVPS efficiency : 3%

- Lack of Financial support to implement new programs

- **1.4 : Stand Alone Communication Systems**
  - Rural, Emergency and Mobile telephony are the coming exploding areas of application for PV small and medium systems.
  - 50 Installed systems in the south for scattered and off-grid stand alone communication systems.

---

- Ksar El Ghilene: a solar Village in the desert.
  - 40 households connected
  - 1 primary school
  - 1 mosque
  - 1 refrigerator for a primary health center
  - 3 public baths with solar thermal systems
  - 1 PVPS for 300m well - 25 $m^3$/day for 200 inhabitants.
  - Public lighting and
  - rural telephony stands.

# 2. Size of the PV market

- 2.1 : Characteristics
  - Widely accepted application as low cost clean energy
  - Mainly governmental supported programs and projects
  - Still exclusively a ‘social market’
  - Basically a bridging market towards wider one
- 2.2 : Size
  - 100000 to 300000 out of grid households
  - expanding market: water pumping and communication relays
  - Handcraft based rural micro-projects (21 21 funds)
- 2.3 : Barriers
  - Scaling problem
  - Weak marketing strategy
  - Weak After Sale Service

# 3. PV Programs

- 3.1 : Rural Electrification & Water Pumping
  - 2000- 01 : 2500 PVS ( #200 kWp) in bilateral negotiation with Spain to achieve 10 000 foreseen systems.
  - 2010 : ANER is planning to connect 70 000 hh among which only 10% are implemented. An exploding 550% growth rate of PV activity in Tunisia is expected.

- 3.2 : R&D
  - INRST Process could be transferred to an innovative joint venture ( start up company)
  - Thin film based laboratory processes are strengthened and new equipment are being installed. New National Research Programs have priority.

# 4. Centres of expertise: Capacity and Capability

- 4.1 : University
  - Mainly alternative materials and solar cells. New thin film compounds and low cost processes.
  - Work is, also,carried out on PV systems: 1KWp in ENIT
  - Main tasks: characterisation, electronic blocks, (conversion, storage, sizing, lifetime studies…).
  - ENIT work focused on lighting, pumping and freezing.
- 4.2 : Research Centres
  - INRST: cr-Si based Pilot Plant sized for 90KWp/year.
  - Innovative process and 14.3% efficiency on 4” cells
  - From diffusion to system encapsulation and indoor test
  - 5KWp plant is installed for outdoor tests and training

## 4.3 : Governmental Organisations:

- CRDR: Rural development with some interest in renewable energies and especially PV dissemination. Partner supporting on-site test and sizing studies.
- ANER: National Agency for Renewable Energies. Shifted recently from ministry of industry to ministry of environment.
  - 15 years old experience in PV planning and implementation.
  - The main governmental policy tool in the area.
  - All national and international dissemination programs are managed through ANER.
- STEG: Up today, the main national electric power supplier. An unavoidable partner in on-grid PV electricity market.
  Privatisation of power production sector will not decrease the involvement of STEG in innovative markets (ex: PV).

## 4.4 : Non Governmental Organisations:

Weak but growing contribution and capability

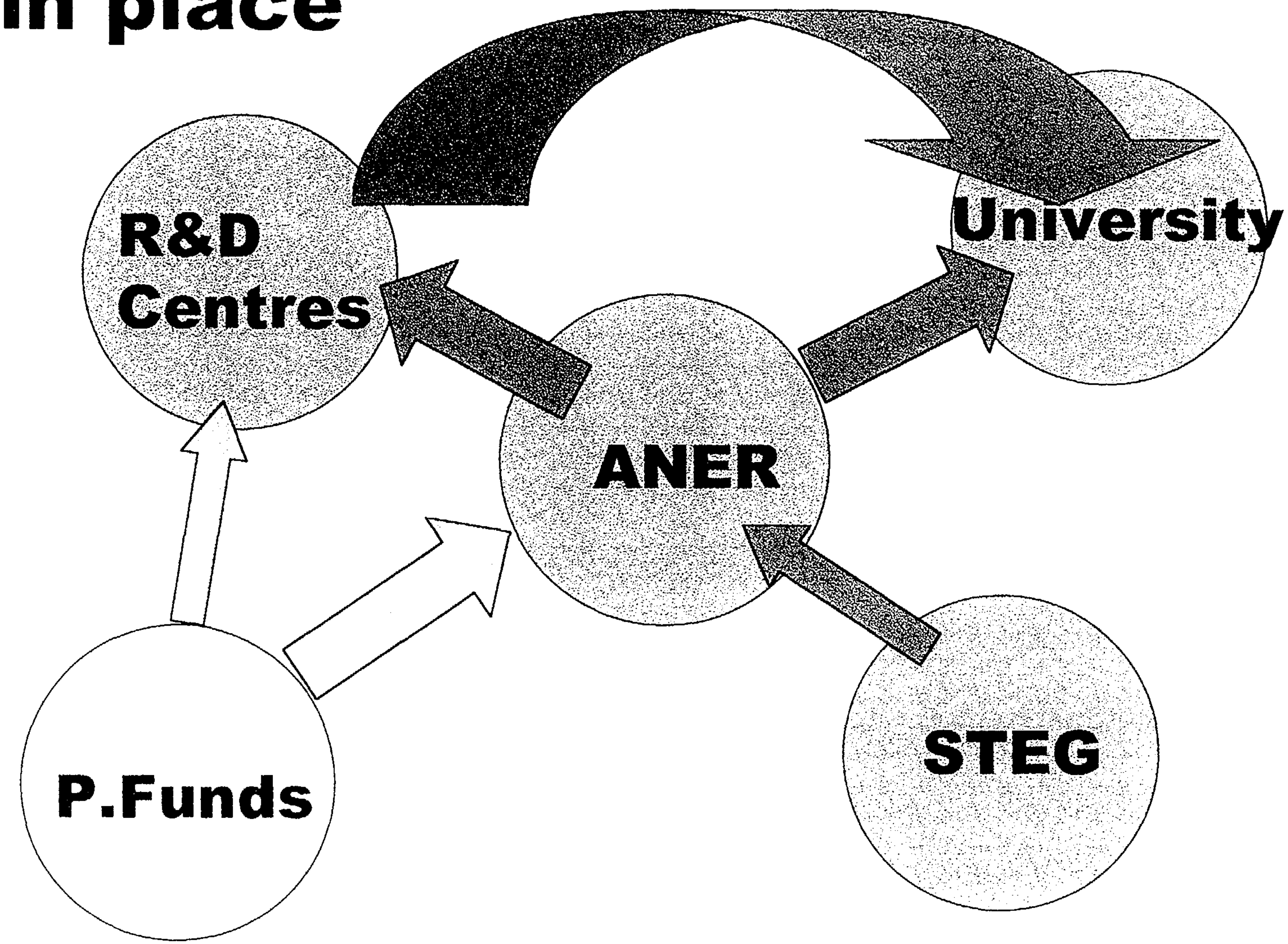
# 5. Industry Capacity

- 5.1 : PV module production
- 5.2 : Competitiveness
- 5.3 : IME supporting industries
- 5.4 : Joint-Venture industries
- 5.5 : Commercialisation

# 6. Areas of needs

- 6.1 : Technology
  - Technology Transfer Process.
  - Research networking with DC labs
  - Industrial and commercialisation strategy
  - Related Electronics:  micro and mid power devices
  - Outdoors Test & qualification implementation.
- 6.2 : Training
  - Short training for Technicians: (Few weeks) sizing individual needs, installation, electronics, storage, maintenance of pumping systems...
  - Post graduate PV specialisation: PV Project & Program implementation, Decision making in PV Technology management, Clean energy: environmental return to investment

# 7. Collaborative links already in place



# 8. Education & Training Programs

- 8.1 : Thermie Project
- 8.2 : Seminars & Workshops
- 8.3 : Education and Engineering projects

# 9. Organisation Structure for PV activities

- 9.1 : Ministry of Environment and Land Layout
  ANER
- 9.2 : Ministry of Agriculture: CGDR
- 9.3 : Ministry of Economy: STEG
- 9.4 : Ministry of Higher Education: University and Research Centres
- 9.5 : Secretary of State for Research and Technology: Research Centres: INRST, CGDR

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# *UNIDO*

# What is ICS ?

## ICS:

- operates under the aegis of UNIDO
- forms part of UNIDO's industrial promotion network
- promotes science and technology transfer to developing and transition-economy countries

# ICS in numbers

| | |
|---|---|
| 1988 | established |
| US$4million | annually, through UNIDO Trust Fund |
| 20 | permanent staff |
| 20 | consultants |
| 20 | fellows from target countries |
| 10 | new projects |
| 50 | courses and meetings |
| 1000 | experts and technologists trained |

# Achievement of goals

Benefit target countries through:

- development of human resources
- creation of sound base for professional advancement
- institutional capacity-building

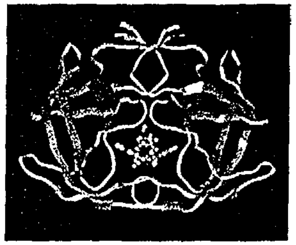
# Overall strategy

- Close interaction with UNIDO programmes
- Tailored technology services as guide activity
- Promotion of environmental technologies
- Development and utilization of in-house capacity
- Chemistry, environment, high-tech, infosystems activities, technology services

# General framework

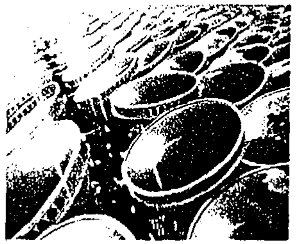
- partnered projects
- donor fund-raising
- training courses, workshops and seminars
- fellowships
- publications and training packages

# The three technical areas



Pure and Applied Chemistry

Earth, Environmental and Marine Sciences and Technologies



High Technology & New Materials

# High technology & new materials

### *high technology*

- laser applications and optical technologies for industry and medicine

### *new materials*

- composite materials for low-cost housing

### *photovoltaic solar energy*

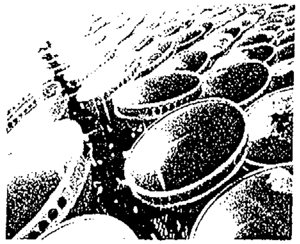
- diffusion of pv systems and applications

### *telecommunication technologies*

- radio communications, fixed, mobile, satellite and rural networks

## KEY ISSUES

- train technologists and scientists for up-to-date PV systems and applications
- feasibility studies for project proposals to be submitted to potential donors

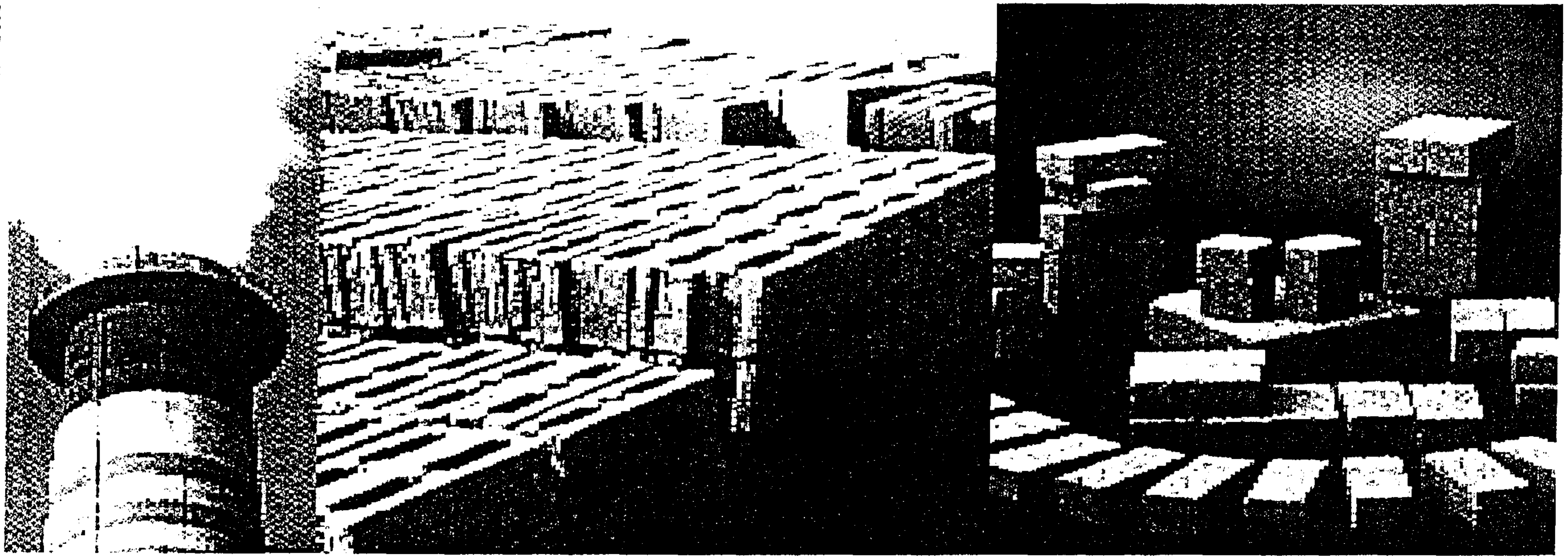


## ACTIVITIES FOR YEAR 2000

- EGM "Networking of PV Systems and Applications", Cairo, 26-28 April 2000
- TC "Computer Simulation of PV Systems", Trieste (Italy)
- TC "Production and Use of PV Systems", Malaysia

# Case study: new materials

Indian Government



*turning power-station ash into bricks*

**ICS is helping developing countries to produce useful products from "waste"**

# Project proposals and sponsorship

ICS involves other international partners and donors in its activities.

These are found by identifying, developing and promoting demand-oriented programmes and projects.

Project proposals are assessed and submitted for donor funding.

Some ten proposals are selected each year.

ICS also seeks involvement in international events and programmes.

# International co-operation

## Example of co-operations with international organizations:

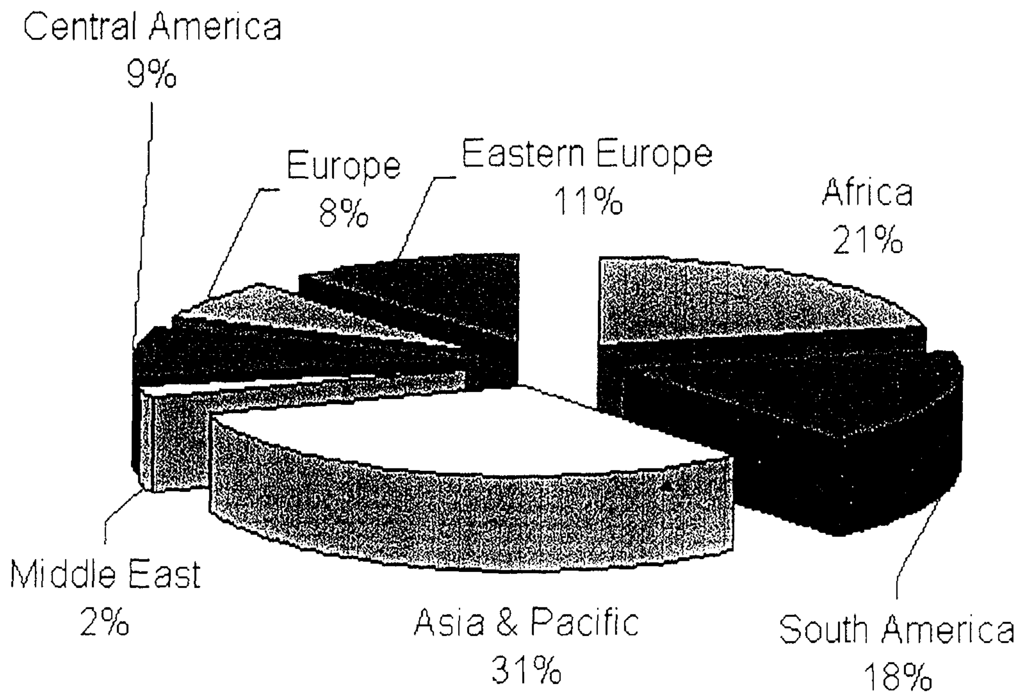
→**UNIDO** (United Nations Industrial Development Organization)

→**UNEP/MAP** (United Nations Environment Programme / Mediterranean Action Plan)

→**MCSD** (Mediterranean Commission for Sustainable Development)

→**CEI** (Central European Initiative)

# Training for developing countries (1999)



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# ***Republic of Yemen***

# *PV Technologies in Yemen: Potentials, Applications, Marketing and Promotion*

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## Abstract

This work concerns PV Technologies in Yemen. At the beginning a brief description of the country background is introduced describing the developments which took place during the last decay hence the reasons behind the present economical depression. Further the energy status of the country is described. In this context the energy sources are outlined both conventional and renewables. A special emphasis is given to the availability and high potentials of renewable energy sources (RES). In addition the energy balance is demonstrated.
The institutional arrangement of energy sector is also introduced showing that PV technologies do not have an adequate room in this arrangement.
The existing electrical energy services for rural areas are examined in order to show the market potentials for PV technologies. It will be seen that a small percentage of rural house holds are using electricity for lighting. As the vast majority are still using kerosene or gas for lighting.
In order to show the reliability and remarkable success of PV technologies in Yemen the existing applications are investigated in different areas (telecommunication, TV, water pumping, rural electrification, . . . etc.). As a result of the investigations one can see that these applications can be assumed quantitatively negligible but qualitatively successful.
Although Yemen has great solar energy potentials and there is a real need to use PV Technologies in remote rural areas as a source for electrical energy the number of installed PV capacity is very low. In this work the barriers for diffusion of PV Technologies are briefly discussed. In addition the existing commercialization problem is also discussed and practical solutions to promote commercialization are proposed.
Most of International Agencies and Organizations (IAO) have shown a great interest in renewable energy technology development in general and PV Technologies in particular. An example of these agencies and organizations are: UNIDO, UNDP, WB, GTZ, EU, . . . etc. Most of IAO have contributed in some projects in this field in Yemen. However one can notice the absence of coordination among IOA. This work proposes a mechanism enabling the necessary coordination of all national and international efforts.
Finally this work withdrew some recommendations and conclusions which would possibly lead to promotion of wider PV Technology applications in Yemen.

# 1. Introduction

On one hand three quarters of population are considered rural. On the other hand the energy used in rural areas is quantitatively very low. According to 1994 census only 20% of house hold (H.H) are using electricity for lighting (see table 1). The electricity consumption of rural areas does not exceed 3% of generated electricity by Public Electricity Corporation (PEC). This picture shows clearly the status of the electrical energy services in rural areas. Actually, most of rural houses are shuttered in remote areas and substitute more than seventy percent of total house holds of the country. Therefore the problem of rural electrification can be economically solved using PV technologies. This paper is a contribution to demonstrate the potentials, existing applications and importance of PV technologies in this issue.
At the beginning energy status of the country is looked at. A number of aspects are studied, namely conventional energy sources, energy balance of the country, renewable energy sources (RES) and their potentials and applications. A special emphasis is given for PV technologies due to mentioned above reasons.
Further the existing situation of electrical energy services in rural areas are investigated. The investigations cover also the conducted policies, institutional arrangement, commercialization and areas of needs.
Finally the necessary conclusions are worked out.

# 2. Country Background

22 May, 1990 Yemen Arab Republic (YAR) and People's Democratic Republic of Yemen (PDRY) merged to create the Republic of Yemen (ROY). This unification has led to dramatic political and economical reforms in Yemen. YAR till 1962 was isolated kingdom with theocracy regime. 1962 Revolution opened the country to greater contact with the rest of the world. YAR had generally market economy with some influence of Arab countries like Egypt and Syria in that time. PDRY formal British colony since 1967 took socialist principles of economy.
During 70's & 80's in YAR a significant economical and social development were achieved due to the following:

- ♦ A great number of workers were working in Gulf States (around 1 million).
- ♦ Arab and International financial aids and soft loans.
- ♦ Discovery of oil.

Virtually in PDRY one can say that just slight economical development took place, since the independence till the unification.

However, since 1990 a number of occasions have led to a serious set back of the national economy, namely:

- Process of unification and the merge of two completely different systems have resulted in high costs necessary for governmental and social restructuring.
- Gulf war and ROY political position from this war has led to :
    - ☆ Return of Yemeni workers from Gulf States.

- ✯ Termination of around 80% of the foreign aid.
- ✯ Suspension of Soft loans from Gulf States.

- Civil War broke out March, 1994.

All these factors have caused great economical difficulties, e.g. the exchange rates of USD were at 1990: \$ 1 = YR 12.5. Since then Yemeni Rial value was going down and it reached some times YR 165 for \$ 1. For the last year due to some economical reforms the exchange rate is nearly stable as : \$ 1 ≈ YR 157 ± 2%

This figure shows clearly the inflation level reached during the past ten years. The Government of ROY has committed economical reforms, which hopefully would lead to economical stability and further economical recovery. Energy sector is one of the key elements of mentioned reforms because great subsidies are spent in the energy sector, e.g. oil products, gas and electricity. For a certain period of time these subsidies must be eliminated. Therefore one can expect significant development in this sector.

Geographically, Yemen is situated between 13° - 16° latitude and 43.2 - 53.2 longitude. The country consists of three major zones. A coastal plain extends inland 30 to 60 km. The rugged foothills of the central mountain range rise from the plain, eventually forming the mountains and plateaus of the central highlands. Mountains in the central highlands often exceed elevation of 3000 m. Most of the rural population inhabits this region. The central highlands give way to the rolling countryside of the arid eastern plateau, which drops to an elevation of approximately 1000 m.

Other than petroleum and gas reserves, Yemen is not well-endowed with natural resources. Soil and climatic conditions, as well as the mountainous topography found in much of the country, are not conducive to agriculture. Although effective terrace and irrigation systems have been developed over the past two millenniums, some of this infrastructure has deteriorated due to a lack of maintenance. This resulted from rural labor shortages which occurred during the 1970's, when more than one third of the total male workforce was abroad. Furthermore, a significant portion of arable land and agricultural labor is used to grow qat, which is chewed by most Yemenis for enjoyment and constitutes an important social activity. Although this cash crop brings money to the countryside, it consumes resources that would otherwise be available for food production or export crops such as coffee. Another reason has led to deterioration of agricultural product was the subsidy of imported wheat. It is worth to mention here that the food of Yemeni household is based on grains and mainly on wheat.

## 3. Energy Status

### 3.1 Oil

Oil was discovered in the Alif and Azal fields of eastern YAR in 1984 and 1986 respectively. Production began in 1986 to supply a 10,000 barrel per day (bpd) hydroskimming refinery in Mareb. The refinery previously met 38 percent of domestic needs for gasoline, diesel and fuel oil in the former YAR. At the end of 1987, the pipeline from Mareb to the coast was opened and crude oil production was eventually increased to a level of around 190,000 bpd, most of which is exported to the Red Sea through a pipeline with a capacity of 240,000 bpd. Total reserves are estimated to be 1.8 billion bbl. Estimated recoverable oil reserves are about 900 million bbl at present.

This oil from what is termed the Mareb Production Sharing Area, is being developed by the Yemen Hunt Oil Company (YHOC).
After unification other oil fields were developed, e.g. Al-Masila by Canadian Oxy and in Shabwah by other oil companies.
The total production of Yemen now has reached 380,000 bpd. 177,000 bpd is produced in Al-Masila and 203,000 bpd is produced in the rest fields

### 3.2 Natural Gas

Natural gas finds have been made at Raydan, Lam, Meem and Ma'een in addition to the important associated gas at Assad Al Kamil, Alif, and Azal and the smaller fields at Nacum, reinjection and flaring to improve long-term oil recovery and conserve the resource for consumption.

These gas resources are also managed by YHOC; they are significant but insufficient to justify gas export. The Gas Utilization Study has recommended the domestic use of gas for power generation for the grid and to supply cement factories, but has advised against manufacture of methanol or fertilizers.

LPG is currently produced internally due to the availability of rich gases in the Production Sharing Area. LPG is recovered from three sources:

(1) solution gas from the Alif, Azal and Assad Al Kamil fields;
(2) the Alif, Azal and Assad Al Kamil gas caps; and
(3) non-associated gas fields such as Raydan, etc.

From the current estimates of gas reserves are approximately 16 million tons, or over 300,000t per annum for the next 50 years without any new discoveries.

Now 24000 t per month of LPG are currently produced. This amount of production was reached due to participation of private sector in building bottling plants in different locations of the country. Actually LPG bottles are available now every where in the country. More than 80% of national market is covered.

### 3.3 Biomass

Fuelwood production can be measured by annual consumption since there are not fuelwood imports and changes in storage are insignificant. Households are the primary consumers of wood in the form of firewood and/or charcoal. The most charcoal production takes place in the Tihama, by artisans using semi-pit kilns.

The availability of LPG with reasonable low price has led many households especially in urban areas to use LPG instead of firewood. However in rural areas the use of firewood is still very popular due to high unemployment and low income.

### 3.4 Renewable Sources of Energy

Yemen has high potentials of renewable energy sources, namely: solar, wind and geothermal. A brief description of each type will be introduced here:

#### 3.4.1 Solar Energy

The average solar radiation in Yemen is 450-550 cal/cm$^2$/day see Figure 1. The annual average of daily sunshine hours is between 7.3 and 9.1 hours/day Table 2.

Looking at these Figures one can realize the great potential of solar application in Yemen. For instance to produce an average of 1kWh of electrical energy per day using PV panel will cost much less than to produce this energy in an other middle east country like Syria, Lebanon or Jordan. This is due to long time of sunshine hours all the year and high average of solar insulation. This means that PV systems in Yemen will have better use in producing greater electrical energy. Consequently faster pay back time, i.e. the cost of electrical energy produced by PV will obviously be lower hence higher economic performance.
This argument is applicable also to solar heating for the same reason. Conclusively electrical energy produced in one year by, let say, 50 Wp in Sana'a region will produce much greater electrical energy than that produced in Beirut region, for example. Also the thermal energy produced in one year by solar collector of 1 $m^2$ will be greater than that produced in Amman, for example. An important factor, concerning solar heating application, is the perfect match of demand and production. From table 2 one can see that daily average of sunshine hours during coldest months (October to February) is more than 8 hours per day. Generally in Yemen the energy produced by any solar device will be higher than that produced in another Middle East country, e.g. Syria.

3.4.2 <u>Wind Energy:</u>
Unfortunately the available meteorological data does not contain enough information about the wind in various locations in the country.
Geographic Nature of Yemen has helped to generate daily wind with reasonable duration and speed. The well known phenomena of local wind patterns are clearly realized in Yemen. These are:

- Sea breezes:

  Sea Breezes are generated in coastal areas as a result of the different heat capacities of different rates of heating and cooling. The land has a lower heat capacity than the sea and heats up quickly during the day, but at night it cools more quickly than the sea. During the day, the sea is therefore cooler than the land and this causes the cooler air to flow shoreward to replace the rising warm air on the land. During the night the direction of air flow is reversed. In Yemen a great number of villages, small towns and cities is located in coastal areas.

- Mountain-Valley wind

  Mountain-valley winds are created when cool mountain air warms up in the morning and, as it becomes lighter, begins to rise: cool air from the valley below then moves up to slope to replace it. During the night the flow reverses, with cool mountain air sinking into the valley.

The most populated areas of Yemen are Mountain-Valley areas. There are a great number of small villages shuttered on the top of mountains where the electricity supply could be provided most economically by installing wind-turbine generators.

The wind is available almost whole year which permits to use wind turbines in decentralized fusion to produce electrical energy for house-hold use in rural areas. In some areas the availability of sun and wind is in contrast. This situation can encourage to propose Wind-PV hybrid systems.
The coastal areas high speed wind continues for more than six months that September to March. This condition is a good indicator to propose wind farms combined with Diesel generation, with PV system or connected to the grid.

Further study for wind availability and daily wind speed is required to precisely assesst wind generation economics.

3.4.3 Geothermal Energy

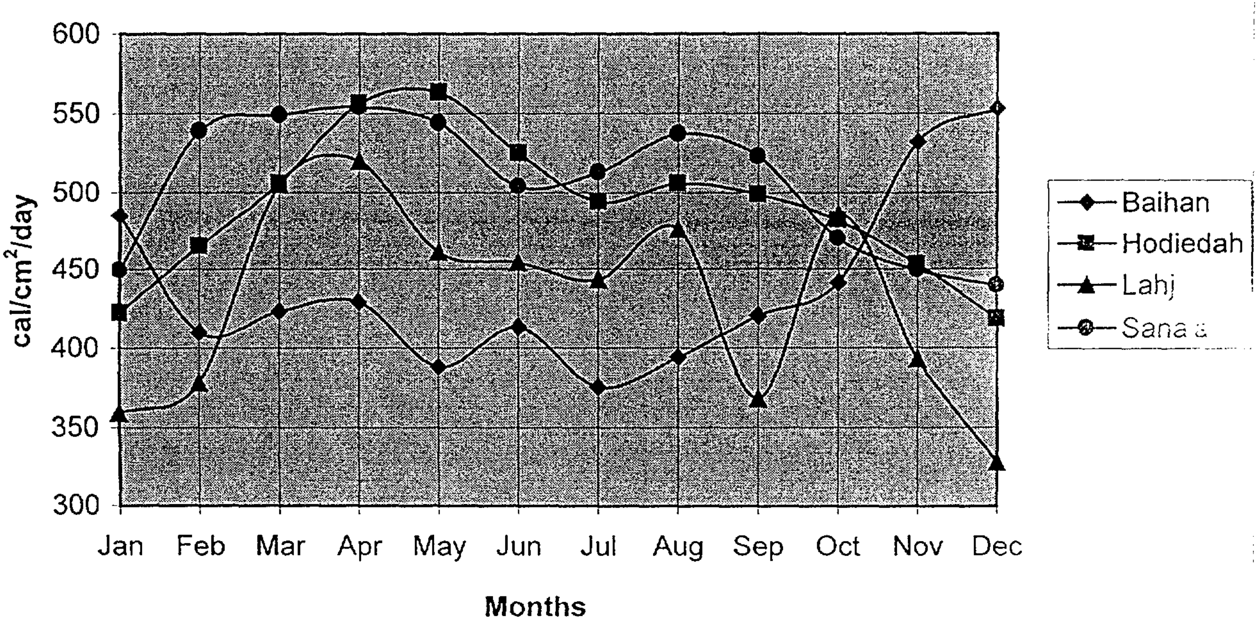
Yemen is characterized by volcanic nature. There is more than seven areas of natural hot springs of water. In addition Yemen is specified as one of the countries having high heat flow. The heat flow reflects the potential of geothermal energy. The world map of heat flow shows the Yemen and Italy have equal potential of heat flow (60 $mW/cm^2$). The total capacity of geothermal power installed in Italy is more than 500 MW which clearly demonstrates the high potential of geothermal energy in Yemen.

In 1984 a study financed by World Bank was performed by Geothermex Inc. The study was directed to investigate the availability of geothermal energy in Dhamar area. The study concluded that it is possible to build a geothermal power station with a capacity of 125-250 MW. Such a power for Yemen is considerably high in relation to the total installed power.

Further study may be carried out in two directions :

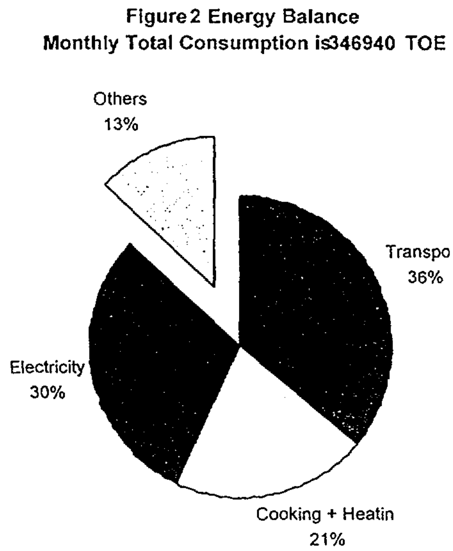
- Further implementation of Geothermex study.
- Assessment of geothermal energy in other areas in the country.

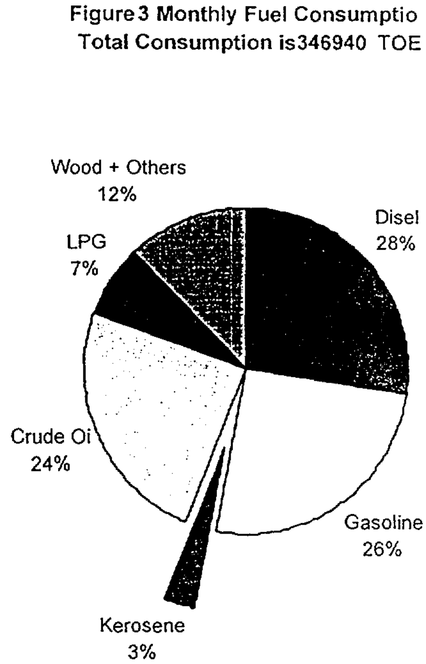
**Fig. 1 Average Solar Radiation in Different Areas in Yeme**



## 3.5 Energy Balance

Energy consumption by sector and fuel type for the Yemen and energy balance is depicted in




Figures 2 and 3. A brief analysis of the data highlights the relative importance of energy services for rural areas in the national energy regime.

Apparently the fuel used in rural areas are kerosene for lighting as the wood, gas and others are used for cooking Figures 2 and 3 demonstrate qualitatively and quantitatively the low level of energy service in rural areas. Also these figures show the great gab of energy services between urban and rural areas.

# 4. Institutional Arrangement of Energy Sector

Flow chart in Figure 4 shows the institutions responsible for energy sector in ROY. One may realize that mainly two ministries are involved in energy sector, namely: Ministry of Oil and Mineral Resources (MOMR), and Ministry of Electricity and Water (MEW). This situation has led to a number of problems e.g.:

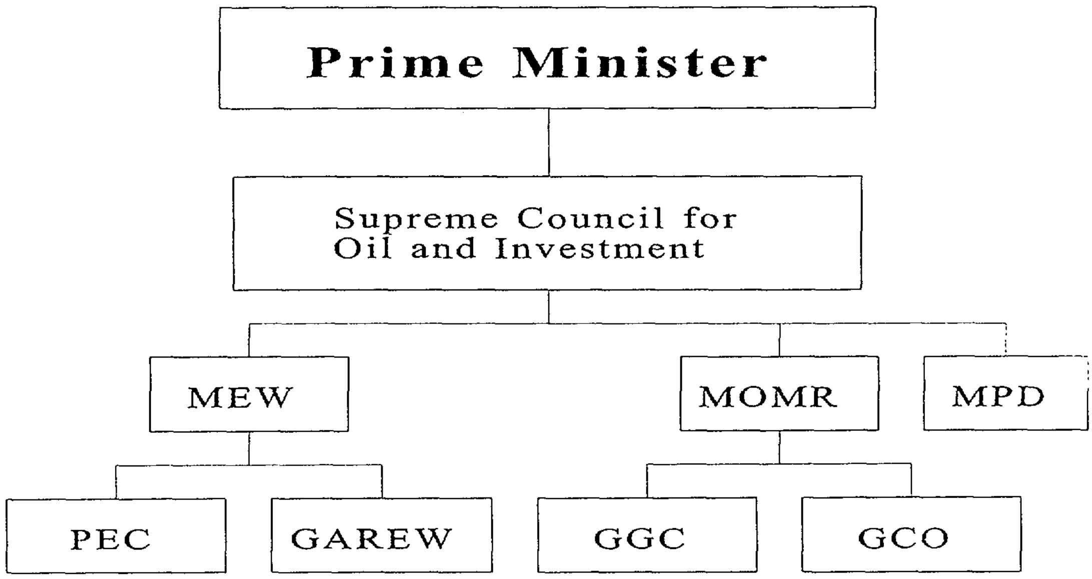
- A national strategy has not been established.
- A lack of coordination and sometimes conflicts between the two ministries
- Low efficiency

The actual day-by activities are performed by various corporations of the ministries. These corporations are semi-autonomy. However, heavy interference from the ministries is a usual practice in ROY.

*Rural Electrical Energy Services are provided by:*

- The General Authority for Rural Electricity and Water (GAREW) is responsible for electricity generation and distribution in rural areas. GAREW was established 1994. The main activity of GAREW consists in:

- Importing Diesel-Generating (D-G) units with different capacities of 50 kW up to 1000 kW from different manufacturers in the world.
- Import electrical equipment and materials for distribution networks of 11 kV and 400 V voltages from different manufacturers in the world.
- Build complete / incomplete power projects for secondary towns and some villages. A complete project would include: Diesel Power Station and Distribution Network.
- These projects are taken over by local authority or cooperatives. Further GAREW is not involved in operation or maintenance of these projects.




MEW: Ministry of Electricity and Water
PEC: Public Electricity Corporation
GGC: General Gas Companyy
GAREW: General Authority for Rural Electricity and Water
MPD: Ministry of Planing and Development
MOMR: Ministry of Oil and Mineral Resources
GCO: General Corporation of Oil

## Fig. 4 Energy Sector Institution

GAREW has executed around 100 projects with a total capacity of 65 MW. If GAREW continues to import D-G sets at the existing rates the number of D-G sets can reach a huge number in several years, which will lead to a serous financial and economical problem to perform the required maintenance and provide necessary spare parts, . . . etc.

- PEC runs a national Grid with 132 kV transmission line of 1500 km length and a total capacity connect to the grid is 572 MW. The power availability is around 60%.

In addition PEC runs separate isolated system in various city which are far from the Grid with a total installed power capacity equal to 142 MW. Some of Diesel power stations are run by PEC in rural areas. Total yearly generated energy by PEC is 1,450 GWh/year.

Figures 5 and 6 show electrical energy profile in Yemen. These figures demonstrate clearly that rural consumption does not exceed 3% which is very little.

- Private Rural Electricity Companies

  In early 80's private companies in northern part of the country were established in rural areas. These companies operated successfully due to good economical conditions at that time.

  Since the economical set back the electricity companies are facing difficulties in operation, maintenance and sales. The operation and maintenance problems are due to high exchange rate of Yemeni Rial against hard currency. The sales problem is due to the lack of cash and high unemployment in rural areas.

Further more the policy of GAREW, mentioned above, has discouraged establishing new private electricity companies.

- Institutional Arrangement for RES

Unfortunately the institutional arrangement for RES is almost absent. In the MEW there is a department called Directory of RES. This department is lacking everything, with zero budget, and no staff except the manager.

It is worth to mention there is a number of university staff who are interested in RES, including the author of this work. In additions there is an intention to establish a Society for RES (The Author is the Chairman of Organizing Committee for this Purpose).

## 5. Existing Electrical Energy Services and Policies in Rural Areas

### 5.1 Electrical Energy Services:

Actually only 10% of rural houses are connected to the national grid. Generally around 20% of household are using electricity for light but more than 68% are using kerosene. The rest are using gas, which means that around 70% of the country do not use electricity in lighting, i.e., 10 million person do not enjoy the use of electricity in Yemen (see Table 1). Apparently the absence of electricity means also electrical appliances can not be used, e.g., TV, refrigerator, air conditioning, electrical heaters . . . etc.

The small percentage of rural house holds using electricity reflects the low level of electrical energy services provided for rural area.

Figure 5 Electricity Consumption Profile Total Consumption is 1,450 GWh/Year

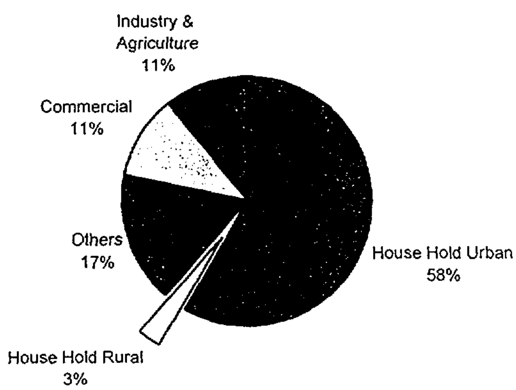
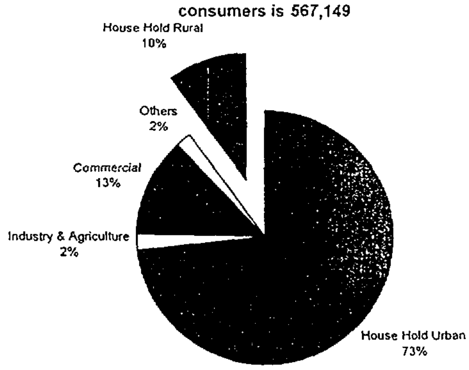



Figure 6 Profile of Electricity Consumers Total number of consumers is 567,149



As shown by Figures 5 and 6 the consumed electrical energy by rural consumers of PEC does not exceed 3% while their number is 10% which demonstrates again the low level of services in rural areas.

For the last 5 years since GAREW was established a number of power projects were executed in various rural areas. The total installed capacity is around 65MW. The estimated number of households benefiting from these projects can reach 150 thousand. Most of these projects consist of 1 or 2 DG sets with distribution networks, 11 kV and 400 V. These stations are isolated from the national grid. For current year the number of such projects is 72 projects with a fund equal to US$ 13.122 M. The expected number of household benefiting from these projects can reach 33,000.

### 5.2 Existing policies:

Rural Electrification is mostly carried out by building diesel power station of different capacities reaching 2 MW. According to GAREW these projects are completely financed by the government. Usually GAREW hands over the completed projects to local cooperatives or authorities, who are proposed to run them. The tariff adapted in such projects may reach a level near to commercial tariff used by PEC YR 11/kWh.

After handling over, GAREW does not have any obligations regarding operation and maintenance. In addition it is worth to mention that a good number of GAREW projects are not complete, e.g. the distribution system is not built and sometimes the projects are very near to the National Grid. Knowing that rural areas usually lack of technical expertise necessary for proper operation and maintenance, one can expect that existing policy is not capable of creating sustainability. More over the continuous increase of the number of diesel power stations can lead to huge running costs which the customers will not be able to meet. Consequently this policy is a complete waste of time and resources of the country.

In spite of:

- ✯ high potentials of renewable energy sources in Yemen
- ✯ shattered village and houses in different regions of the country
- ✯ great pressure on GAREW from some households who are located very far from villages and the small town where rural electrification projects are executed to be attached to the main projects causing very high cost .
- ✯ availability of funds located for rural electrification.

Until now there is no serious intention to use renewable energy source for rural electrification. This situation may be explained by a number of facts:

- ♦ Renewable energy technologies are not well-experienced in Yemen.
- ♦ There is no feasibility studies addressed to renewable energy sources applications showing their economics compared with conventional sources.
- ♦ Poor marketing.
- ♦ High Capital Costs.
- ♦ High Prices.
- ♦ No strong emphasis from IAO to direct their aid and loans to this aspect

## 6. Existing Applications of PV Technology

In Yemen PV systems are used as a power source for different purposes: Telecom, TV transmission, water pumping, electrification of rural houses and other purposes, e.g. clinics, boarding house, . . . . etc. in rural areas.

- Telecommunication Transmission uses more than1060 panels in different parts of the country. The total installed peak power has reached an amount of 42,400 W. Table 3 includes the details. This area of application is the most significant one.
  First installation started late 80's. Due to the successful performance and low rate of failure Telecom has expanded the use of PV as a power source to supply telecom microwave stations in the tops of the mountains where ever needed.

- Television Transmission also uses in many of transmission stations located at the tops of mountains PV systems as a power source. The total power is 1280 Wp installed in 19 stations. Table 4 includes the details.
  Regarding these applications one can realize that PV application is most reliable and economical solution as a power source in remote areas. A further study may justify a combination of wind and PV leading to higher reliability and lower cost.

  The satisfactory performance of PV station installed at remote mountains is a sufficient justification to go ahead with PV application for rural electrification in remote areas.

Water Pumping:

1. Al-Mahweet Project:

| | |
|---|---|
| Finance | GTZ Germany |
| Capacity | PV: 600 Wp |
| | Pump: 70 to 100 $m^3$/day dependant on ambient temperature |
| Performance | very good |
| Operation Condition: | Out of order due to controller fault |

PV for Domestic Application in Rural areas

This area of application is the most promising and important one. However the installed power is not very high. Table 5 shows a number of PV systems installed in different places. Given feedback information about the performance of these systems states that most of them are functioning well.
The total installed peak power could not exceed 10 kWp which is too little looking at number of house hold using kerosene or gas. Assuming that at least 20% of these houses are located in remote areas where it is economically justified to use PV rather than other source of electricity one can see from table 1 that the number of these houses is 300,000. This figure shows also the high potential of PV demand (future market) for rural electrification which can reach tens of MW.

A simple economical calculation can prove superiority of PV application over conventional power sources. PEC records state that for remote areas the network cost has reached US$1200 per household if the electrical energy cost will be added with Present Value Approach and taking in account that the electricity subsidy will be taken off soon the total costs can reach 2200$. As PV system cost for house hold can not reach this amount.

## 7. Barriers for Diffusion of PV Technologies

Looking at the high potentials of RES in Yemen and at existing applications one can realize that a great gap exists. Apparently there are some reasons behind this phenomenon. Having examined the energy policies and the economical conditions one may conclude that there should be institutional and financial barriers which cause Renewable Energy Technologies and PV in particular not to be diffused comparing with some regional countries like Jordan. The causes of this phenomenon can be:

- Institutional

  As mentioned elsewhere of this study in the past all energy products were subsidized by the Government. 2 years ago the price of 1 kWh of electrical energy was ¢0.7 to ¢1 which is very low even when this price is compared with electricity price in neighbor gulf states. This situation discouraged the use of other form of energy sources including renewable energy technologies, e.g. PV, wind and solar heaters.

  The electric power projects financed and executed by the Government, represented by GAREW in rural areas are based on diesel power stations. Rather than PV technologies because the initial cost of diesel power stations is much less than power stations based on PV technologies for the same capacities. In addition the operation and maintenance is not responsibility of GAREW.

- Financial

  For the last two years the electrical energy tariffs were increased. This action will continue until the price of electricity is virtually free from the subsidies.

  Such a policy will lead to the economical possibility to use other forms of energy. However, the financial situation of the household in rural areas is quite hard. Therefore, majority of households cannot afford the investment to use PV technologies, especially in rural areas. To promote wider use of PV technologies it is necessary to proceed in the economical reform program which aims to completely get rid of subsidies including energy products. In addition there should be some financial arrangement to help house hold to obtain PV technology with soft loans.

  In addition to the above reasons there is an external one, i.e. the international aid in aspect is very little and is not coordinated.

## 8. Commercialization

In Yemen there are only two agencies for solar PV panels and wind generators. These are:

- Technical Support Centre who is an agent for Solarex
- Tehamah Tract. Co. who is an agent for Seimens PV.

Table 6 shows total sales of Solarix one can see that the household sales are negligible.
The low level of commerce can be explained by:

- Lack of cash in rural areas
- High prices of PV
- Government subsidies for conventional power but not for PV systems.

In order to promote commercialization the following measures have to be taken:

- Establish a special credit funds with low interest rates (soft loan principle). This fund should provide finance for PV application. The establishment of the fund should involve:
  - Yemen Government

- International Agencies
- Private Sector
- NGO's

The fund can function similar to industrial Bank of Yemen, Credit Bank of Agriculture or the Social Development Fund.

- Promote Private Sector to be involved in commercial, industrial installation and maintenance of PV technologies using the above mentioned funds.
- Promote customers to obtain PV systems using also these funds.
- Divert Government investment plans in rural electrification from Diesel technologies to PV technologies.

## 9. Role of International Agencies and Organizations (IAO) in PV Technologies Applications

As a matter of fact there is a considerable interest from International Agencies and Organizations in renewables in general and in PV applications in particular. Time and space would not allow to list here all intentions and attempts to initiate the use of renewables in Yemen. However, one can mention WB, UNIDO, UNDP, GTZ, EU, . . . as an example of (IAO) who have shown readiness to help Yemen in this area. Nevertheless, the success of these attempts is limited and inconsistent due to some reasons, e.g.:

- Absence of institutional arrangement necessary and capable to represent the recipient in this aspect.
- Lack of coordination between IAO
- Absence of national energy strategy and in particular rural electrification strategy.

Therefore it is recommended to establish a national focal point for this purpose and request all (IAO) to coordinate their efforts through the focal point.

## 10. Conclusions and Recommendations

Having observed the situation of the Country which can be characterized by:

- Economical depression
- High potential of solar energy
- High potential of PV technology market
- Lack of electricity services in rural areas
- Governmental funds for rural electrification is directed to diesel generation
- Absence of PV applications in rural electrification
- Lack of coordination between (IAO)
- Lack of data.
- Absence of institutional arrangement for renewable energy technologies in general and in particular, PV applications

One can accordingly derive the areas of needs covering above mentioned aspects. However, there should be priorities. The priorities should be based on two factors: low cost & high importance to the development of PV applications. Then one can realize that most necessary and vital supports can be focused in:

- Establishing a technical secretariat under inter-ministerial steering committee to function as a focal point for RES technologies and PV in particular.
- Such a secretariat should perform the following:
  - Act as the National Focal and coordination of national and international efforts in renewable energy aspect.
  - Planing and supervision to achieve:
    - a) Development of national strategy for renewable energy technologies.
    - b) Establishment of institutional framework.
    - c) Establishment of special funds to promote diffusion of PV technologies.

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*Table 1 Percentage Distribution of Dwelling Units and Households by Kind of Lighting*

| Lighting | Total | | Urban | | Rural | |
|---|---|---|---|---|---|---|
| | HH | DU | HH | DU | HH | DU |
| Public E. project | 26.65 | 27.20 | 80.41 | 80.12 | 10.43 | 10.30 |
| Coop. E. project | 3.78 | 3.80 | 4.33 | 4.35 | 3.62 | 3.63 |
| Priv. E. project | 4.36 | 4.34 | 1.70 | 1.60 | 5.17 | 5.22 |
| Priv. Generator | 2.69 | 2.62 | 1.29 | 1.22 | 3.12 | 3.07 |
| Kerosene | 55.01 | 54.50 | 10.40 | 10.50 | 68.47 | 68.55 |
| Gas | 6.29 | 6.15 | 1.01 | 0.99 | 7.89 | 7.80 |
| Other | 1.20 | 1.36 | 0.86 | 1.22 | 1.31 | 1.41 |
| Not Stated | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.02 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | 2162847 | 2198442 | 501252 | 532102 | 1661595 | 1666340 |

## *Table 2: The Average of Daily Sunshine Hours In Different Locations*

| Station | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Yearly Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al-Cood | 7.6 | 8.4 | 8.3 | 8.5 | 9.9 | 7.9 | 7.8 | 8.2 | 8.3 | 9.7 | 10.1 | 8.3 | 8.6 |
| Al-Abus | 8.8 | 7.3 | 8.2 | 7.8 | 9.2 | 7.8 | 7.2 | 7.5 | 6.9 | 8.3 | 8 | 7.9 | 7.8 |
| Hodiedah | 8.9 | 9.1 | 7.2 | 9.1 | 8.8 | 7.6 | 7.1 | 6.6 | 8 | 9.9 | 10 | 9.1 | 8.4 |
| Lahj | 7.1 | 6.9 | 8 | 8.6 | 9.1 | 7.6 | 7.2 | 7.8 | 8.3 | 9 | 9.3 | 8.1 | 8 |
| Sana'a | 8.5 | 7 | 9 | 6.9 | 9 | 7.5 | 5.9 | 6.5 | 7.4 | 9.3 | 9.2 | 7.1 | 7.7 |
| Saiun | 7.5 | 8.7 | 9.2 | 8.7 | 10 | 8.8 | 7.8 | 7.9 | 9.2 | 9.5 | 9.2 | 8.7 | 8.7 |
| Sadarah | 5.1 | 5.4 | 7.2 | 9 | 8.6 | 8.4 | 8.8 | 8.2 | 8 | 7.2 | 6.5 | 5.4 | 7.3 |
| Soqatrah | 8.7 | 9.9 | 10.3 | 10.8 | 9 | 7.8 | 9.2 | 7.2 | 9.7 | 9.6 | 8.9 | 8.7 | 9.1 |
| Taiz | 7.7 | 8.7 | 9.1 | 9.3 | 9 | 7.8 | 6.4 | 7.2 | 7.5 | 9.3 | 9.1 | 8.8 | 8.3 |

## *Table 3: Installed PV Stations in Yemen Telecom System*

| No. | System Location | No. of Panels | Total Power (W) |
|---|---|---|---|
| 1 | Hajjah | 102 | 4080 |
| 2 | Sana'a | 210 | 8400 |
| 3 | Rada | 54 | 2160 |
| 4 | Zabid | 126 | 5040 |
| 5 | Hodeidah | 92 | 3680 |
| 6 | Mukairas | 28 | 1120 |
| 7 | Marib | 16 | 640 |
| 8 | Taiz | 120 | 4800 |
| 9 | Dhamar | 104 | 4160 |
| 10 | Saada | 150 | 6000 |
| 11 | Ibb | 58 | 2320 |
| TOTAL | | 1060 | 42400 |

## *Table 4: Installed PV Stations in Yemen TV Stations*

| Station | PV Power |
|---|---|
| Wadi Bana | 600 |
| Hewah (Damt) | 600 |
| Shairaz (Al-Rakamah) | 600 |
| Dhabrah (Aaness) | 600 |
| Rashidah (Aaaness) | 600 |
| Al-Balasenah (Al-Turbah) | 600 |
| Horaib (Marib) | 600 |
| Al-Fordah (Naham) | 2000 |
| Hooth (Sana'a) | 600 |
| Harf Sofian (Saadah) | 600 |
| Haroom (Saadah) | 600 |
| Al-Naw'ah (Saadah) | 600 |

| | |
|---|---|
| Saqain (Saadah) | 600 |
| Baihan (Shabwah) | 600 |
| Jarawat (Al-Maharah) | 600 |
| Saimoot (Al-Maharah) | 600 |
| Qash (Al-Maharah) | 600 |
| Hoof (Al-Maharah) | 600 |
| Soqatrah | 600 |
| TOTAL | 12800 |

## Table 5: PV Stations for Domestic Use

| Name of area | No. of Panels | Condition and brief information |
|---|---|---|
| Govt. Clinic, Ibb | 4 | Installed with monitoring meter |
| Bani Saif, Ibb | 40 | Not installed due to missing items |
| Military camp, Sana'a | 2 | Installed |
| Farm, Dhamar | 2 | Installed |
| Radhaei Village, Ibb | 44 | Installed, no information reported |
| Kheraishah Village, Taiz | 66 | Installed with some modification due to some burned out devices, they are benefiting |
| GTZ, Mahweet | 2 | Installed |
| Climatogical center, Sana'a | 3 | Installed |
| Faculty of Agriculture, Sana'a | - | Installed, working well |
| Faculty of Engineering, Aden | 3 | Installed by Author, monitoring started |
| Faculty of Engineering, Sana'a | 2 | Installed |
| PEC Training center, Aden | 4 | Installed, monitoring started |
| Maleh Village, Sana'a | 20 | Installed |
| Mukholiah Village, Lahj | 44 | Partially installed, lack of funds for Acessores and batteries |
| TOTAL | 236 | |

***Table 6:PV System Projects in Yemen Executed by Technical Supplies Center(Solarex)***

| Customer | Location | Application | Array (Wp) | Total Power |
|---|---|---|---|---|
| Public Telecom. Corp. | Raida, Mukalla | Telecommunication | 128x64 | 8192 |
| | Taiz | Telecommunication | 36 x 60 | 2160 |
| | Taiz | Telecommunication | 88 x 60 | 5280 |
| | Sana'a - Taiz | Telecommunication | 64 x 77 | 4928 |
| | Various | Telecommunication | 500 x 53 | 26500 |
| Ministry of Defense | | Telecommunication | 30 x 53 | 1590 |
| | | Telecommunication | 22 x 60 | 1320 |
| Yemen Radio & TV Corp. | Various | Transmission | 34 x 53 | 1802 |
| Ministry of Public Health | Various | Refregiration | 12 x 53 | 636 |
| Individuals | Hajjah | Remote Home Light | 5 x 60 | 300 |
| | Sana'a | Home Power | 4 x 60 | 240 |
| | | | 6 x 53 | 318 |
| | | | 4 x 60 | 240 |
| TOTAL | | | | 53506 |