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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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STATE-OF-THE-ART OF SOLAR ENERGY R & D AND AND APPLICATIONS IN SINGAPORE, THAILAND AND INDIA : UNIDO MISSION REPORT

by

Prof. TK Moulik

Indian Institute of Management, Ahmedabad

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SINGAPORE

In spite of the fact that Singapore is a small island-city country and research in the field of solar energy started fairly recently (1980's), the present R & D status in terms of expertise and knowledge in Singapore, particularly, in the National University Singapore (NUS) is quite impressive and commendable.

R & D Status in Singapore

The R & D activities on solar energy systems in NUS is mainly housed in the Mechanical and Production Engineering Department of which Thermodynamics and Heat Transfer area is the principal unit or the group. There are 9 faculty members in the Thermodynamics area having interest and experience in solar energy R & D. However, at any point of time at least four of the nine faculty members remain full-time involved in Solar energy R & D.

The main sources of funding for solar energy R & D in NUS have been the Science Council RDAS scheme, the University itself, and the ASEAN Australian Economic Cooperation programme. In addition GTZ of Germany has also funded some research projects (See Table 1 below).

Table 1: SOLAR ENERGY RELATED PROJECTS IN NUS

Project Title	Grant Amount	Commenced/ Year	Status	Funding Agency
1 Solar Air-conditioning	$ 20,000 $ 36,000 $ 29,000 $ 15,000	1979/80	On-going	NUS
2 An experimental and analytical study of heat and mass transfer processes in solar ponds	$ 20,000	1983	On-going	NUS
3 Performance of a 1.14kW solar cell array	14,500	1983	On-going	NUS
4 Study of solar cell design parameters	35,000	1985	On-going	NUS
5 Solar Energy Research and Application				
A. Equipment				
1 Solar Air-Conditioning	DM [illegible]	1980	Completed	
2 Solar Photovoltaic Systems	DM [illegible]			
B. Others				
8 man-mths of German expert 4.5 man-mths of training Fellowships in Germany			GTZ Germany	

NUS started R & D on solar energy system as early as in 1975 with its own fund obtained from the Ministry of Science and Technology, Singapore. To begin with the R & D work was mainly concentrated on flat-plate collector and hot water system. In early 1980's the GTZ, Germany funded research on solar absorption cooling system and photovoltaic system. At about the same time, NUS itself funded R & D activities in the same direction (see table 1 above).

While the well-equipped laboratory facilities and highly professional researcher manpower thus evolved in NUS, the Energy Project developed by the ASEAN-Australian Economic Cooperation Programme developed in mid-1985, selected Singapore to undertake research development and demonstration work on Energy Conservation Technology. Funded by the Australian Development Assistance Bureau with a total budget of A $ 540,000 over the first three years, the Science Council Singapore is the executing authority of the project. NUS is expected to be the obvious major recipient of this research grant and responsibilities. The Singapore sub-projects as formulated by (AAECP) is basically to meet the needs of the building and industrial sectors in the ASEAN region. Research activities cover the following areas:

i) Energy analysis and modelling of buildings;
ii) Industrial energy management;
iii) Optimisation of insulation materials; and
iv) Heat pumps.

Presently, the work on this AAECP project is being carried out at the Thermodynamics department of NUS, with the collaboration of or in consultation with the Nanyang Technological Institute, the Development and Building Control Division, PWD, and the Public Utilities Board. Although these R&D work is basically on energy conservation technologies in buildings and industries, the NUS scientists expect some spill-over relevant solar R & D and applications in the course of their work.

<u>Government Interest and Current Programme</u>

However, there are presently no government incentive or planned commitment and programme for the promotion of solar energy technologies in Singapore, except in the field of energy conservation in buildings and industries. The scientists of NUS are of the view that the government incentive in energy conservation technologies can be taken advantage of in promoting solar energy technologies in Singapore.

Given the lack of government incentive and definite commitment, there is hardly any field applications and demonstrations of solar energy technologies in Singapore. Except some solar hot water systems in a few hotels and in NUS itself, there are reported to be only two major solar energy application-demonstration projects: 1) a 25-tonnes solar energy refrigeration system in Bedok Library; 2) a 600 square meter solar hot water system for the kitchen in the newly constructed Changi airport complex. The second project is presently under planning and implementation.

It is interesting to note that in Singapore most of the field application projects are planned and implemented by PWD, often with some help and consultation with NUS scientists. However, right from project planning, fabrication of the systems and implementation are the sole responsibilities of PWD, which is benefitted with having engineering staff trained in NUS. The supply of solar energy trained manpower to PWD and other related government departments is certainly a significant direct contribution of R & D facilities in solar energy systems in NUS, which in the event of committed government programme can be of great help. For the present, however, except PWD there are no other commercial industrial enterprise in Singapore operating actively in the field of solar energy programme.

Perhaps the continuing government support and NUS scientists interest in solar energy R & D may be not so much keeping an eye with the domestic market in Singapore but mainly to create expertise and knowledge in this technology to serve or sell in the bigger regional markets. Added to it is, of course, the academic interest in this emerging field of technologies. The interest in the regional market is clearly and openly voiced by the NUS scientists in order to be able to do research and training students in solar energy systems on a continuing basis with appropriate level manpower and financial investments.

In order to enter into the regional market, over the years NUS have organised several regional workshops on energy analysis, thermal system, heat transfer insulation and other solar energy applications. In addition, in both its undergraduate and Masters degree programme, NUS offers special project courses on solar energy. NUS scientists are presently negotiating with Thailand for implementing a solar pond project in that country.

<u>Possible Areas for Funding According to UNIDO Workshop Guidelines</u>

Based on the foregoing observations, it is clear that there is an immediate necessity to sensitize the government and the industry about the potential use of solar energy systems in Singapore itself. Meanwhile, NUS expertise and facilities, which are of high order, can be utilized for the regional market. Based on this two-pronged approach the following projects from NUS are worth-considering for financial support:

1) Development of teaching materials and documentation on solar energy applications among the school and college students of Singapore.

2) Solar energy demonstration projects (i.e. hot water system in dormitories and solar air-conditioning of computer centres and libraries) in schools and colleges of Singapore.

3) Regional training programme on solar energy technologies - both research and applications, - through regular engineering student-exchange programme and by organising short term training courses.

4) Given the excellent infrastructural facilities, both in terms of physical and scientists, the NUS could be used as one of the regional optimization and evaluation centre for solar system equipments and appliances. NUS has particular experience in optimization of system studies, which can be harnessed on a sustained and coordinated basis for solar systems.

THAILAND

Over the last one decade, Thailand seems to have developed quite an impressive infrastructural and institutional facilities in solar energy R & D and applications. The process started with the energy-crisis in 1970's when Thailand imported 70% of her energy requirements amounting annually to 40% of export earnings. Hence the initial objective for solar energy R&D was to diversify Thailand's energy supply and sources indigenously in order to "making ourselves be quite prepared" for the day when the supply of conventional fossil fuel is running down. One of the most interesting and perhaps unique in many ways in the region is to develop a close organisational and programatic interface with the Electricity Generating Authority of Thailand (EGAT) - a state-owned enterprise responsible solely for the generation and transmission of bulk electrical power in Thailand.

R & D Status in Thailand

A brief account of solar energy R & D activities of the three important institutions in Thailand visited during the mission should give a fairly comprehensive idea of the State-of-the-art in this field.

1) EGAT

As mentioned earlier, EGAT, created in 1969, is the state-owned utility enterprise in Thailand solely responsible for generating and transmitting electricity in the country. Hence, EGAT's role in popularizing and commercializing solar energy applications in Thailand is crucially important. Direct involvement of an utility enterprise like EGAT, almost like a nodal agency makes this institution a prime mover in the field.

EGAT became involved in the field of solar energy applications and research starting from 1977. About 20-25 scientists of EGAT have been exclusively working on thermal and photovoltaic systems. During the last 10 years or so EGAT has spent a total sum of 47 million bahts on demonstrations, tests and evaluation of solar energy systems.

The main focus of EGAT's R & D is a system approach through field demonstrations and applications. For example, starting from around 1977, approximately 45 kWP of pv modules were procured from twenty manufacturers or so, about 10 kWP. have been evaluated, another 10 kWP. are scheduled with their applications in radio communications, lightings, navigation aids, etc. as the byproducts. By means of evaluation, performance data are recorded. This includes simple strip chart recording ampere-hour charge/discharge, insulation level, panels and ambient temperature, individual string voltage and current etc. by multi-channel digital data loggers. EGAT also tested and evaluated the hybrid system of PV & diesel, PV + wind Turbine Generator etc.

EGAT is also studying low temperature thermodynamic conversion system. Solar hot water heaters were installed at EGAT's remote sites in order to collect data of boiling systems for further developments and to make use of them at the same time.

Also, in order to demonstrate, test and evaluate solar energy systems and equipments, an energy laboratory is established at the roof-top of EGAT's headquarters. The laboratory is equipped for collecting data on wind and solar energy. However, EGAT's recent policy is to contract out R & D and testing as much as possible to other expert institutions in Thailand. But since EGAT is the pioneer in PV technology in Thailand, it continues with all R & D activities in this field.

EGAT's strength, therefore, lies in its pioneering role in solar energy field in Thailand both as a promoter of R & D, support to other expert institutions and practical demonstrations and evaluation. Being an utility enterprise, EGAT is probably one of the few organizations keenly interested in working out the comparative economics of various solar energy systems (See Appendix 1).

2) KMIT Thonburi

The energy activities have been spearheaded by the School of Energy and Materials and strongly consolidated through supports and cooperation of the Faculty of Engineering and the Faculty of Industrial Education and Sciences. Presently, about 25 staff members are engaged in solar energy research and they are being supported by roughly equal number of graduate and undergraduate students.

KMIT is one of the important institutes in Thailand in providing technically trained indigenous manpower in the field of solar energy technologies. There is, for example, a regular Master Degree Programme in Energy Technology, first offered by KMIT by the School of Energy and Materials in 1977. System approach to energy technology is integrated through courses in energy analysis and energy system optimization. In 1984 a one-year Graduate Diploma Programme was launched. There are presently about 50 graduate students in these two energy technology programmes. In addition, a graduate programme is developed in 1985 on energy management technology focussing on optimal utilization of energy from an appropriate supply mix. By 1988, this graduate programme is planned to be followed by a Master programme.

In R & D activities KMIT seems to be focussing principally on solar energy among all other renewable energy sources. Topics on thermal solar system under study are:

- Solar distillation using different construction materials and geometry, microscopic behaviour of solar stills and field testing. A very important development in this field is vertical surface solar distillation.

- Solar drying and solar-assisted drying of cash crops, meat, fish, rice, tobacco etc. Simulation study and field performance are being evaluated.

- Low temperature solar collectors such as flat-plate collectors incorporating different materials as receiving surfaces and casings, construction techniques, reverse flate plate collectors and compound parabolic collectors.

- Refrigeration and air-conditioning based on NH_3 and LiBr and LiCl Systems respectively.

- Pilot study on a 10 kWh solar electric power system using parabolic collectors.

- Experimental study on a 78 m^3 solar pond.

In order to support the above energy R & D activities KMIT has established a solar measurement facilities. Compilation and statistical interpretation of data are regularly undertaken. Another major supporting facilities is solar selective surfaces preparation and evaluation. A pilot-scale electroplating unit for the preparation of blackchrome has been constructed and a study on techno-economic feasibility is completed. Black nickel and copper oxide surfaces are also under study. In addition, construction of a solar simulator having a test area of upto 4 m^2 is nearly completed.

KMIT also has a regular R&D programme on PV systems in the areas of:

- design and construction of power conditioning equipment associated with PV systems;
- field monitoring of direct coupling PV water pumping systems;
- modelling of PV systems; and
- construction of PV water pumping system test facilities.

3) SEMICONDUCTOR DEVICE RESEARCH LABORATORY (SDRL)

Although not originally scheduled in my mission programme, EGAT was interested in my visiting this important research facilities in Chulalongkin University in Bangkok, Thailand. This research laboratory was housed in the Electrical Engineering Department of the University in 1975 with originally French collaboration and donations of equipments necessary for initial research on silicon technology. Over a period SDRL has grown to a well-equipped laboratory with a staff of five researchers, three technicians, and one research assistant.

It is interesting to note that the original research goal for SDRL was set for power semiconductor devices and solar cell fabrication and application. Since its establishment, SDRL has been receiving a research grant from various government agencies including EGAT and external agencies as well. Till the 1985 year end, the total financial support was 6,363,935 bahts. Quite a substantial part of this fund are being reportedly spent on solar energy research, particularly, on PV systems.

The following are some of the interesting and important research results so far obtained in SDRL:

- By 1981, SDRL had successfully developed its own technique which was believed to be appropriate for solar cell fabrication in a developing country like Thailand. The technique was also cheaper than the conventional one while the cost performance was comparable to those produced elsewhere. Cells with 10% efficiency were routinely fabricated using SDRL developed technique.

- SDRL staff members, upon request from National Energy Administration (NEA) of Thailand, conducted an equipment and provided consultancy on a testing procedure of PV pumping system to NEA which was to install PV pumping systems to the north-eastern part of Thailand. A prototype of foldable PV panel was also developed for the Military Research and Development Centre for use with portable telecommunication equipment.

- In 1983, SDRL, with financial grant from its University, designed and installed a 1 kW PV system at the Marine Science Research Center, at Si Chang Island, Chonburi.

- A Small PV system was installed by SDRL at Yang Hom village, Chiangrai where there was no electricity to provide lighting for social activities at night. Subsequently, the villagers of Yang Hom developed with the same PV system many innovative productive end uses e.g. light-trapping for insects for frog cultivation, honey production etc.

- SDRL designed and developed a tracking system for PV panels which was funded by the Faculty of Engineering of the University.

- In the device technology, SDRL, funded by the National Research Council of Thailand (NCRT) conducted research on poly-silicon solar cells. Cells were later fabricated and effects of grain boundary on the cell characteristics were studied.

In fact, over the years, SDRL had become not only Thailand's leader in solar cell fabrication and design, but also a recognized semiconductor R & D community in Asia and Pacific region for its contribution to solar cell fabrication technique and design.

[illegible]

Although there is still no definite committed government plan and programme for solar energy development and applications, the amount of infrastructural and institutional facilities created in Thailand as discussed above clearly shows government's implicit interest and concern in the subject. The very recent policy announcement on import-duty reduction on solar cell clearly shows government's intention to promote this technology in Thailand.

Similarly creation of 11 working groups under the Ministry of Science of Technology and Energy, in which the groups on Solar Thermal and Solar PV are two important elements. In fact among all other working groups, the groups on PV and solar thermal are reported to be most active (see the structure of PV working group in Appendix II).

However, inspite of the above mentioned signs of government's implicit interest, the lack of explicit plan commitment both in terms of physical targets and positive incentive scheme, coupled with recent drop in fossil fuel price, seem to have created some doubts both among the R & D infra-structure and in the potential commercial markets. This seems to be clearly reflected in the rapidly diminishing interest among the fabricators/industries/enterprises in solar energy R & D and product developments. In contrast, there came to existence quite a large number of PV and solar thermal panel manufacturers in earlier years (there are many solar hot water system installed mainly in hotels in Thailand). In fact, without even government financial assistance in the form of subsidy or other incentive, these manufacturers were able to be commercial viable. In recent times, many of them are reportedly gone out of business or remaining as a sleeping [illegible] enterprise.

There is also some organizational problem in the sense that the National Energy Administration created 30 years back with the responsibility of planning, monitoring and promotion in the field of energy technologies, are reported to have failed in its task. Instead of doing its essential task it became almost a parallel implementing and operating organization. As a result, there has been no coherent energy plan developed. On the other hand, the macroplanners in Thailand appear to be not yet convinced about the effectiveness and usefulness of solar energy, both perhaps due to its relative cost disadvantage and small-scale applications.

Economics of solar energy systems in Thailand is particularly not favourable because of a very large raw materials import component for its manufacture in Thailand. Added to this is the relatively small size of the market which inhibits mass production and thereby cost reduction. A serious effort, therefore, should be made for import-substitution of raw materials. On the other hand, perhaps the government should try to create market through large scale demonstration projects throughout the country. EGAT, for example, found that simple electromechanical charge/discharge controller and conventional antimonial lead acid battery (which are locally available as automobile spare parts) is quite practicable for applications in a climatic condition and demand/supply situation in Thailand. A government initiative in this regard could interest many entrepreneurs.

The most encouraging aspect of solar energy development and application in Thailand is EGAT's continuing efforts in various demonstration and evaluation projects. EGAT's existing plan for solar energy projects may be seen in Figure 1 (Appendix III) and Table 2 below. Most of these projects as shown in Figure 1 are already under implementation or completed. As a future programme on PV, EGAT plans to evaluate the existing PV-system with emphasis on the grid connection and adding more PV systems of larger capacity to meaningfully evaluate PV grid connected system.

Similarly KMIT and SDRL are involved in field applications of solar thermal and PV system for various end-uses such as solar drying, lighting, pumping, hot water etc. in remote rural areas. But obviously, with the lack of financial support, such involvement would remain marginal.

Table 2: PV STATUS IN THAILAND (MAY 1987)

APPLICATIONS \ CUSTOMERS	PEAK KILOWATT (KWP) INSTALLED: CU	EGAT	MH	ME	MI	MD	NEA	PEA	TOT	VH	MIS
REMOTE VILLAGES (AC 240V 50 HZ)								50+50+30 (JICA)			2
TELECOMM. (MICRO WAVE REPEATERS)						10			90-100		30
WATER PUMPING (W/O BATTERY)							1+4*				5
REMOTE AREA PRIMARY SCHOOL											
REMOTE AREA				10							2
HEALTH CARE			1-2							5-7	3
RADIO COMM. (VHF TRANSCEIVERS)											
MISCELLANEOUS IE.SMALL VILLAGE LIGHTING/TV	1-2	10		3-10	5-10						
NAV.AID		10*									10
VHF. COMM.											
SCIENTIFIC EQUIPMENT											
HYBRID/GRID INTERFACE DEMON.PROJECTS (IE.PV+WTG.GRID)		5*+20*									
TOTAL	1-2	45	1-2	13-20	5-10	10	5	130	90-100	5-7	52
GRAND TOTAL					357-383						

CU = CHULALONGKORN UNIVERSITY
EGAT = ELECTRICITY GENERATING AUTHORITY OF THAILAND
JICA = JAPAN INTERNATIONAL COOPERATION AGENCY
NEA = NATIONAL ENERGY ADMINISTRATION
PEA = PROVINCIAL ELECTRICITY AUTHORITY
TOT = TELEPHONE ORGANISATION OF THAILAND
MIS = MISCELLANEOUS

MH = MINISTRY OF HEALTH
ME = MINISTRY OF EDUCATION
MI = MINISTRY OF INDUSTRY
MD = MINISTRY OF DEFENCE
VH = VOLUNTEER HEALTH CARE MISSION UNDER THE PATRONAGE OF THE KING'S MOTHER
PV = PHOTOVOLTAIC
WTG = WIND TURBINE GENERATOR

( ) = DONATION AGENCY
* = DONATED TO HM THE KING'S RURAL DEVELOPMENT PROGRAM
• = DURING 1986-87

Areas of R&D worth-considering for Financial Support

It seems that R & D status of solar energy technology in Thailand have reached a stage where a large scale demonstrations would lead to develop viable market. In order to help in this process the following R&D areas may be prioritised for assistance:

1) Multiplication of demonstrations of PV-lighting system in remote villages as done by SDRL in Yang Hoon village, Chiengmai.

2) Multiplication of demonstrations of PV system for various productive end-uses (e.g. PV system for oxidizing water to grow shrimp for the Shrimp farmer near Bangkok where no electricity could be used due to loose in the rural area).

3) Multiplication of demonstrations of PV-system for decentralized electricity generation and grid connections.

4) Large-scale field demonstrations in solar drying of high-value-added cash crops, fish etc. solar pumping.

5) KMIT offers an excellent laboratory facility to develop itself into a testing/standardization/optimization Centre for Thailand and the region for solar energy system. It may be useful to associate EGAT and SDRL in developing such facility.

<u>**INDIA**</u>

Although the R & D efforts in the areas of solar energy were initiated in India in early 1970's, these efforts were concentrated on creation of certain facilities only in a few R & D laboratories. This area got a clear boost after the creation of the Commission on Additional Sources of Energy in early 1981 coupled with government of India's firm plan and budgetary commitment for promotion of this energy technology. During the past about six-seven years not only enormous amount of R&D work has been done in India to harness solar energy technologies, but also a large scale field demonstrations of these technologies are being carried out. As a result, many of these solar technologies have now become mature and popular and some of them have become commercially viable. India is probably one of the few countries which have actively pursued solar energy R&D and application programme in a scale which has not only generated a large body of knowledge and experience in this field but also a vigorous infrastructural facilities.

<u>R & D Status in India</u>

In order to harness various solar energy applications efficiently, India has initiated three-pronged attack namely, intensification and acceleration of R & D efforts, large scale demonstrations; and extension.

With the financial support from the government (both federal and state governments) as well as from some international agencies various national and regional laboratories, universities, technology and engineering institutes and polytechniques are presently involved in R & D efforts in solar energy field. The major thrust areas of R & D on solar thermal and PV systems are briefly described below:

Solar Thermal

R & D efforts in the solar thermal area are mainly being pursued for development of medium and high temperature solar thermal devices in addition to system engineering for improving the existing systems in terms of both performance and cost. The objective of these R & D efforts are to develop systems for generation of power through solar thermal route, solar refrigeration and air-conditioning engineering, advanced collectors for medium and high temperature output, including process steam, materials for efficient collector system, solar passive houses and huts and green houses in high altitude areas etc. A list of R&D projects being supported by government finance during 1986-87 is given in Appendix IV.

Some of the salient achievements in R & D programme in solar thermal technologies are:

1) 500 and 1000 watts capacity (hydraulic) solar thermal pump have been developed and three such pumps are installed for field demonstrations and field evaluation.

2) A system using point focussing concentrating collectors and steam engine to generate 22 kW electricity has been developed and installed at Salajipally in Andhra Pradesh. Using the same technology, stirling engine as prime mover is under field testing. Also a techno-economic feasibility study for setting up a megawatt scale (30 MW) solar thermal power generation station has been completed.

3) Based on a feasibility study on setting up a solar pond for industrial process heat and power generation a project has been funded for field application mainly for providing industrial process heat in the first phase.

4) Using various concepts of passive housing and cooling, three solar passive houses are being constructed in three typical climatic zones of the country.

5) A system of highly efficient, medium temperature, line focussing concentrator and associated system for producing process steam at a rate of 100 kg per hour and at a temperature of 150°C has been installed at milk factory.

6) The field performance data is being collected on a solar cold storage plant operating at sub-zero temperature based on aqua-ammonia system.

7) Solar drying of fish, solar dehydration of grapes and other high value products, solar application for extraction of ethyl alcohol from sweet sorghum juice have been developed with encouraging results.

A list of solar thermal energy demonstration/extension programme upto January 1987, would give an idea of the scope of R & D and applications achieved in India (See Appendix V).

Solar Photovoltaics

The development of low cost solar cells and improvement in efficiency, life and reliability of modules and systems have been a central objective of the

R & D programme on PV system. A large number of R & D projects covering various aspects of PV technology at national laboratories, IITs, and Universities are sponsored (a list of R & D projects sponsored during 1986-87 is given in Appendix VI).

The R & D programme on solar PV system has made significant progress and a base has been created for activities on a large scale. Some of the specific achievements in this field are:

1) Electronic grade silicon is now being produced in India. A production facility of 25 tonnes per annum has been established using indigenously developed know-how.

2) Two public sector organisations namely Central Electronics Ltd. (CEL) and Bharat Heavy Electricals Ltd. (BHEL) are manufacturing single crystal based solar cells on regular basis. A third organization, the Rajasthan Electronics & Instruments Ltd. (REIL) has begun production of modules and systems during late 1985-86. The production capacity of these organizations is over 1 MW per annum. These solar cells are being used for water pumping, street lighting, operation of TV and Radio, process technologies etc.

3) REIL developed a solar street lighting unit based on a PL-11 lamp capable of operating throughout the night with just two PV modules, thus also eliminating the need for a separate timer. (The Andhra Pradesh Electronics Development Corporation also began supply of PV lighting units for demonstration programme).

4) Recognizing the potential of amorphous silicon as the future technology, an integrated R&D programme in this field was initiated in 1983. The programme involved seven research groups in different institutions in the country and covered tasks ranging from deposition-parameters of amorphous silicon films, characterisation of the films and solar cells to preparation of silane gas etc. This programme made significant progress as follows:

a) [illegible] solar cells with [illegible] of 7.[illegible] and 7.[illegible] have been fabricated by the [illegible] for the [illegible] of [illegible], [illegible] and IIT, [illegible]. [illegible] of 40 sq. [illegible] have been demonstrated.

b) Deposition rates have been increased to about 5 Angstrom/Sec. in single chamber glow discharge systems.

c) Different conducting coatings have been studied for use as substrate material.

d) The characteristics of plasma deposition have been studied and correlated with film properties.

e) The preparation of silane gas has been demonstrated through different routes including one starting from rice husk.

f) On the basis of the above achievements and developments, a high powered Science and Technology Mission project on development of Amorphous Silicon Solar Cell Technology has been initiated to be implemented during Seventh Plan with the objective of

   - intensification and acceleration of R & D effort.
   - establishment of a Pilot Plant with a capacity of 500 KWp/annum on a single shift basis.
   - development of systems compatible with amorphous silicon modules and their field evaluation.

g) R & D on other aspects of PV technology such as silicon material processing, thin film devices based on compound semiconductor materials and photo-electro-chemical solar cells are continued and showing encouraging results. Among the thin film devices being studied are those based on copper indium diselenide and cadmium telluride etc. A project on ion implantation and laser annealing was completed during 1986-87. Projects relating to systems development and evaluation have also made headway.

Apart from R & D efforts, there are large-scale field demonstration projects operating in India which provide very crucial and performance-evaluating data as a feed-back loop for the R & D system. The principal components of the demonstration programme are the electrification of villages through provision of street lights, community lighting/TV systems, supply of water pumping systems, installation of small power plants and use of PV system for communication and signalling by the Military Police, Railways and Off-shore oil stations. During 1986-87, the demonstration programmes are achieved or over-achieved.

Table 3: PV Demonstration in 1986-87

	Systems	Target for 1986-87	Systems supplied upto 31-12-1986
1	Water pumping systems	300	229
2	Street lighting systems	3000	3068
3	Community lighting/TV systems	45	18
4	Battery Charging units	300	300
5	PV power plants	1000 KWp	27 KWp

Research Facilities in the Institutes Visited

During the UNIDO-mission, the Indian institutes visited were: Indian Institutes of Technology in Delhi and Kharagpur and Appropriate Technology Development Association. The above account on R & D status gives some idea about the involvement of these institutions in R & D of Solar energy technologies. In fact, all the three institutions are quite deeply involved not only in solar energy R & D, but also in field testing and demonstration programmes.

While the two IITs are involved in almost all facets of solar energy R & D in both thermal and PV systems, the ATDA has been largely involved in developing solar cooker and solar water-heating. Perhaps it would be worthwhile to mention some distinguishing features of these institutes in terms of their capabilities and facilities for solar energy R & D.

IIT, Delhi

Being located in Delhi, this institute is rather favourably benefitted from the proximity of the government decision making body in attracting funds for solar energy R & D. It has created a separate Centre for Energy Studies unit under the Physics Department. About 20 scientists staff members work on solar energy technologies. It also offers courses on solar energy and energy management to its B-Tech and M-Tech. students. Apart from that, a number of Ph.D. students work on solar energy technology problems.

As mentioned earlier, IIT, Delhi has been working both on solar thermal and solar PV system. IIT Delhi is the leading group on modelling of solar application in India in terms of technical and economic performance and design parameters. To illustrate, on solar thermal, the IIT Delhi has rich R&D experience in solar passive buildings, solar water heating systems, solar air heating and drying systems, solar evaporative cooling, solar distillation and solar ponds.

On PV systems, IIT Delhi has done extensive development of spray pyrolized CdS/Cu_2S and SnO_2:F/Si thin film solar cells for which efficiencies as high as 10% have been obtained. P-I-N cells have been made on FTO/ITO substrates and an efficiency of 8% is obtained. A tracking system has been designed, fabricated and tested which is being used for evaluation of 300 W panels.

Over a period, IIT Delhi has developed a very well organized laboratory facilities for solar energy R&D. It has a plan to develop a computer-based data system for system optimisation work. It also organizes both national and international training programmes and workshops on energy technology systems in which solar energy technologies are one of the principal inputs.

IIT Kharagpur

It is one of the largest IITs in India with many departments like Aquaculture, Agricultural Engineering, Naval technology and Architecture planning unique in IIT system. Recently it has organized a full-fledged B-Tech programme on energy engineering in which solar energy technology is one of the principal subjects. About 30 scientist faculty are involved in various aspects of solar energy R&D along with almost equal number of M Tech and Ph.D. students involved in the field. About 10-15 students do B-Tech in energy technology per year.

Interestingly, solar energy R&D is principally housed in Material Science Department with a fairly well equipped laboratory and data storage and retrieval system.

Being located away from Calcutta metropolis around a rural setting, IIT Kharagpur seems to be more attuned to rural or agricultural applications of solar energy technologies. Thus, its R&D and field demonstration work on solar drying for fish, grains and many other high-value agricultural commodities are worth emphasizing. Similarly, it has developed a simple solar cooling system for preserving vegetables and other agricultural products in a typical hot tropical humid conditions in order to increase the keeping quality.

One of the most interesting and significant works has been the production operation and storage of silicas from rice husks for preparing amorphous silicon and polycrystalline silicon from rice husks. Given the surplus of rice husk available in the region, this R & D has obviously tremendous potentiality for agro-industrial complex in the nature of agricultural refinery and consequent employment potential. IIT Kharagpur has been quite successful and advanced in this research project with very encouraging results.

Apart from the above mentioned areas, this IIT has also done work on various solar thermal applications like solar hot water and solar thermal power systems. But a more significant work has been on relevant data storage and retrieval system facilities for optimization of design parameters of various solar technology systems.

ATDA, Lucknow

This is an autonomous body (NGO) with focus on development of appropriate technologies with particular focus on rural applications. The strength of this institution has been development of need-based simple technologies relevant for immediate rural applications. Given its direct linkage with extension and development work in rural areas, ATDA is perhaps one of the few organisations ideally suited to promote and extend various solar energy technologies in the rural areas.

ATDA does not have a very sophisticated laboratory or workshop. However, its workshop has sufficient facilities to fabricate and assemble simple technologies like solar cooker, solar hot water system and solar drier. It has designed its own solar cooker (box type) and presently working on a solar cooker design for indoor cooking and for solar cooking at night.

ATDA has a number of committed and experienced scientists in its staff along with equally skilled technicians. It has recently shifted its workshop in a bigger way in a rural setting in the outskirts of Lucknow city.

Government Interest and Current Programme

As mentioned earlier, India is perhaps one of the few countries in the world which has her government's firm commitment both in terms of organizational infrastructure, planned programme and budgetary allocation for the promotion of renewable energy sources, of which solar energy technologies are one of the main components.

Organizationally the renewable energy programme got a specific direction and focus when "The Commission for Additional Sources of Energy" (CASE) was created in the Department of Science and Technology in March 1981. It got a further boost when the Department of Non-Conventional Energy Sources (DNES) with CASE attached to it was created in September, 1982 in the Ministry of Energy. The DNES along with CASE is thus the main Central Department which looks after renewable energy programmes including solar energy R&D and applications in the country. At the State level, nodal agencies in each State has been created to implement the planned programme. The DNES has a total plan budget of Rs 114.15 crores in which Rs 815.00 lakhs was for Solar Thermal Energy and Rs 795.00 lakhs for solar PV programme.

In order to propagate the large-scale use of solar energy devices, Government of India is providing financial help to the consumers in the form of subsidies. The amount of subsidies vary from 25% to 100% depending upon the category of users to which it belongs such as private/public sector, Govt. agencies, educational institutions etc. Apart from federal subsidies, some state governments also provide some additional subsidies for certain devices (e.g. solar cooker, solar hot-water etc.).

In addition to the subsidies to the users or consumers, Government of India have extended various fiscal incentives to industries, and research institutions engaged in New and Renewable Sources of Energy (NRSE) systems including solar energy systems and devices by way of concessions/exemptions under central taxes such as Income Tax, Customs Duty and Excise Duty. Various State Governments have also allowed exemption under States Sales Tax.

Besides financial help, Government of India also has made various financial institutions agreed to treat institutional credit for the manufacture and installation of renewable energy systems on the same terms and conditions as are applicable to the priority sector. Financial institutions will thus provide loans on suitable terms both for manufacturers and for users who wish to instal solar energy equipments. Apart from financial institutions, the Indian Renewable Energy Development Agency, under the direct control of the DNES, also provides loans for renewable energy devices.

As a result of the Government's positive interest and push, a large number of commercial manufacturing enterprises (more than 150), including some well known giant public enterprises and private business houses have taken the business in solar energy technologies. These enterprises are mainly catering to the needs for the large-scale demonstration projects - a government initiated market. However, being in the market and due to demonstration effects, these enterprises have developed their own sales promotion in non-demonstration-project private markets, particularly, in the area of solar thermal hot-water system, solar cooker and solar drier system. The consumer subsidies are, of course, a positive incentive for creating such private commercial markets. The size of the market could be appreciated from the data given below:

Table 4: Solar Devices Installed in the Country [illegible]

Sl.No.	Devices	No.
1	Domestic Hot Water Systems	1192
2	Solar Kilns	35
3	Non-Domestic Solar Hot Water Systems	1878
4	Solar Crop Driers	28
5	Solar Water Distillation Units	6162
6	Solar PV Street Lighting Systems	6608
7	Solar PV Pumps	600
8	Solar PV, TV & Community Lighting Systems	340
9	PV Medical Refrigerator	2
10	Integrated Energy Villages (Solar System being one of the major components)	40
11	PV Power plants	27 KWP
12	PV Battery Charging Units	300
13	Solar Cookers	72000

As mentioned earlier, government subsidies and other financial incentives did help greatly in promoting large scale demonstrations. It is now felt that for many devices, there has been sufficient demonstration efforts in convincing the consumers of their advantages and benefits. With this confidence, it is now being planned to gradually reduce the rate of subsidies. However, it is also realized that for many of the solar devices economics is not favourable in comparison with the conventional energy sources, particularly the initial investment and more importantly when the conventional sources of energy is itself subsidized. It is also true that for some applications like in remote rural areas, solar devices have the distinct cost advantages. While there has been conscious R&D efforts to reduce the costs, it is understood that time has not yet come to completely withdraw the subsidies which most likely would seriously dampen the market demand.

While a new subsidy rates are being considered, DNES has proposed the following expanded programme for solar energy for government consideration during 1990-95.

Table 5: Annual Energy Generation/Saving from Various Solar Energy Devices

Sl.No.	Items	Units
1	Power from Solar Systems	440 MW
2	Solar Thermal System	6 MTCR
3	Photovoltaic Pumps	45 MW
4	Solar Battery Charges and Stand Alone Systems.	3.8 MW

According to this expanded proposed plan of DNES, the Government share of the cost for solar thermal will be 20% in 1990-95 and can be brought down to 10% in 1995-2000. Similarly, for photovoltaic, the Government share will be 40% in 1990-95 and 10% in 1995-2000. This proposal is under discussion presently.

Meanwhile, DNES has realized the importance of having a centralized solar energy testing and standardization facilities. With this aim, DNES has created the Solar Energy Centre near Delhi with objectives: i) Product development, ii) Test and Standardization of various solar devices, iii) Pilot Plant Study of devices/Systems/Materials developed under the R & D programmes; iv) Training of Manpower, v) System Engineering and Field Demonstration; vi) Coordination between R&D institutions and Industries within the country and outside. The development of this Centre with a budget of Rs 37.75 lakhs in 1986-87 is in progress and is likely to be completed by early 1988. However, with some facilities already created in the Centre, some of the above mentioned activities have already been undertaken .

<u>Areas of R & D Worth-sponsoring According to UNIDO-Workshop Guidelines</u>

Some of the specific areas of R & D work specific to the three Institutes visited, which in my view worth-considering for funding on priority basis are as follows:

<u>ATDA, Lucknow</u>

1) Design and Demonstration of Solar Cooker for indoor cooking and cooking in the absence of solar incidence with suitable auxiliary facilities (e.g. ATDA is trying with electric bulb).

2) Solar heating in biogas system - design development and demonstration.

3) Field demonstrations and promotion of solar cooker, solar dryer and solar hot water system in the rural areas.

III. [illegible]:

1) Optimization of thermal system design in terms of economics and efficiency under various field conditions.

2) Small decentralized PV power plants and field demonstrations.

3) Regional training programme on a continuing basis.

III. [illegible]:

1) R & D Solar drying of fish and other high value agricultural and animal products and field demonstrations.

2) R & D on Solar Cooling System and field demonstration.

3) Solar Cell production from Rice husks and feasibility study to set up agro-industries in this field.

4) Training system for testing, standardization and demonstration centre.

Appendix IV: Solar Thermal Research and Development Projects (1986-87)

1 Design, Development and Testing of thermosiphon domestic hot water system without reverse flow, IIT, Delhi.

2 Extraction of Ethyl alcohol from Fermented Sorghum Juice by Solar Energy - Phase-II, N.A.R.I., Phaltan (Maharashtra).

3 Evaluation of Seasonal Thermal Storage in aquifer for heating and Cooling, Punjab University, Chandigarh.

4 Design, Development and Evaluation of Solar Kiln, IIT, Delhi.

5 Development and Evaluation of low temperature Thermal Energy Storage material, Punjab University, Chandigarh.

6 Development of Solar Dehydration system for field trials for dehydration of grapes to produce Raisins, University of Poona, Pune.

7 Field Demonstration of Solar Thermal Pump, BHEL, Hyderabad.

8 Development of High Performance Ethylene-Propylene, Diene Terpolymer System, Shri Ram Institute for Industrial Research, Delhi.

9 Preparation of Status Report on Photochemical Reactions for chemical Energy Storage, Andhra University, Waltair.

10 Utilization of Solar Energy for drying of Agricultural and Food materials in improved solar dryer, Jadavpur University, Calcutta.

11 Investigation of solar drying of fish for food and feed, IIT, Kharagpur.

12 Design Development of Instruments and Devices for Passive Solar Architecture Applications, IIT, Delhi.

13 Indo-German Project on theoretical and Experimental Investigation of Solar Passive Buildings, IIT, Delhi.

14 Design, fabrication, transportation and supply of experimental solar TAP walls/Direct gain sidings for 30 Huts in Himachal Pradesh and Uttar Pradesh, Sectors of Indo-Tibetan Border Police, SEC, New Delhi.

15 Development of Solar Thermal Pump with evacuated tube collector for installation in the premises of solar energy centre, BHEL, Hyderabad.

16 Design, Analysis and Studies on Solar Collectors with Heat Transfer Fluids for their Applications, in Industrial Heat Processing, Refrigeration and Air-conditioning, IIT, Delhi.

17 Construction of Solar Powered Chick Brooder at Baligram, Lucknow, NEDA, Lucknow.

18 Setting up Solar powered milk chilling centre at Raebareily, NEDA, Lucknow.

19 Renewable Energy system at Sericulture Research Station, Pampore, P/o Cammoreo, Pampore-192 121.

20 Development of Stirling engine based autonomous solar powered plant in collaboration with USSR, C.S.M.C.R.I., Bhavnagar.

21 Technoeconomic feasibility study by PAIC for setting up of a 30 MW Solar Thermal Power Generation plant, PAIC, Chandigarh.

22 Development of Panels of various designs using evacuated collectors and setting up a demonstration system for water sterilization, IBP Co. Ltd., Sewri (East), Bombay.

23 Design & Development of vapour absorption pumps and heat transformer for domestic and agricultural industrial applications, IISc. Bangalore.

24 50 KW Power plant at Gwal Pahari (Gurgaon), SEC, New Delhi.

25 Solar drying of Kendu Leaves, DST & ENV., Orissa, Bhubaneswar.

26 Installation of Solar Water Heating System for 60 Quarters of Indo Tibetan Border Police in Leh, Srinagar, C.P.W.D., New Delhi.

27 Solar Pond, GEDA, Baroda.

28 Design Development of efficient air-heaters for solar drying applications, IIT, Delhi.

29 Development Optimization and Study of Solar Thermal Systems using linear solar concentrator, IIT, Delhi.

30 Stirling Engine, SEC, New Delhi.

31 Development of a micro-computer model of Thermal behaviour of building, T.E.R.I., New Delhi.

32 Analysis of Solar hot water, IIT, Delhi.

33 Design, Development, Fabrication and Testing of vacuum tube collectors - Phase II, School of Energy Studies and Material Science, Pune 411 007.

34 Comparative Studies on the nutritive value of food using solar and other fuels for cooking, Sri Parasakthi College for Women, Courtallam.

35 Techno-economic feasibility of setting up solar thermal power generation stations based on Tower system at six locations in India and the study of relative merits of the plants, vis-a-vis the technological options available, Energy Society, New Delhi 110 016.

36 Demonstration of Solar thermal power Generation system for meeting the irrigational and other needs of Remote rural areas, Birla Vishwakarma Mahavidyalaya (Engineering College), Gujarat.

37 Effect of Interstitial Pressure and temperature on thermal conduction through porous and dispersed system and its application to solar thermal storage, University of Rajasthan, Jaipur.

38 Alternative Energy Sources in Kumaon Hills, Kumaon University, Nainital 263 002.

39 Augmentation of Network of Radiation Stations in India, Meteorology Deptt. New Delhi.

40 Medium Temperature High Efficiency tracking solar energy collectors for rural and industrial application, IISc., Bangalore.

41 Black Bottom Shallow solar pond Technology Transfer, L.D. College of Engineering, Ahmedabad.

42 Design and Development of continuous absorption refrigeration and air-conditioning systems, IIT, Madras.

43 Design construction and evaluation of solar passive houses Phase - II, IIT, New Delhi.

44 Investigations for developing luminiscent collector for conversion of solar energy concentrators into electrical and thermal energy, Kumaon University, Nainital.

45 Chemical Storage of Solar Radiation, Delhi University, Delhi.

46 Community Solar Cooker, SEC, New Delhi.

47 Dynamics of Solar Pond, IISc., Bangalore.

48 Development of Solar Refrigeration using zeolites for rural areas, Sardar Patel Renewable Energy Research Institute, Vallabh Vidyanagar, Gujarat.

49 Three Ton Solar Powered Refrigeration plant for Sub-zero operating temperature - Phase II, Vallabh Vidyanagar (Gujarat).

50 Test facilities for Solar collector, NPL, New Delhi.

Appendix V: Solar Thermal Energy Demonstration/Extension Programme
State-wise Achievements upto January, 1987

	Name of the State/ Union Territory	Non domestic Solar Water Heating Systems Installed			Domestic Solar Water Heating Systems			Air Heaters/ Crop Dryers	Solar Timber Kilns	Solar Stills
		No.	capacity (1 pd)	Area (m²)	No.	capacity (1pd)	Area (m²)	Number	Number	
1	Andhra Pradesh	21	96,000	1,920	36	3,600	72	1	4	–
2	Assam	8	2,000	40	–	–	–	3	–	–
3	Arunachal Pradesh	–	–	–	–	–	–	–	–	–
4	Bihar	1	4,000	80	–	–	–	–	–	–
5	Chandigarh	4	6,000	120	–	–	–	–	–	–
6	Delhi	95	2,95,650	5,913	192	15,200	304	1	2	1,404
7	Gujarat*	262	5,58,500	11,172	552	68,300	1,366	5	7	3,163
8	Goa, Daman and Diu	1	3,000	60	–	–	–	–	–	–
9	Haryana	29	68,000	1,306	19	1,900	38	–	1	–
10	Himachal Pradesh	21	12,600	260	–	–	–	–	2	–
11	Jammu and Kashmir	5	19,000	380	–	–	–	–	–	20
12	Karnataka*	27	26,400	576	57	7,050	141	1	1	–
13	Kerala	16	13,300	266	–	–	–	1	–	4
14	Maharashtra	18	56,000	1,275	–	–	–	–	–	25
15	Madhya Pradesh*	109	3,39,850	8,098	18	1,130	23	1	1	273
16	Orissa	38	42,200	738	–	–	–	–	–	88
17	Punjab*	61	1,27,900	2,558	30	3,000	60	1	2	40
18	Rajasthan*	39	15,750	315	10	1,000	20	–	–	–
19	Tamil Nadu	58	2,73,100	5,502	300	30,000	600	1	–	–
20	Uttar Pradesh	202	1,70,100	3,400	–	–	–	12	12	111
21	West Bengal	–	–	–	–	–	–	1	1	–
	Other Nodal Agencies	13	23,700	454	–	–	–	–	–	978
		1,084	21,54,900	44,392	1166	1,31,200	2,666	28	34	5,948

*These States have generated several more projects and requested for additional allocation of funds in the current year.

Appendix VI: List of R & D projects supported by the Department during the year under review (as on 31-1-1987)

	Title of the Project	Institution
1	Development of Amorphous Silicon thin film Solar Cells.	IACS, Calcutta
2	Research, Development and production of Amorphous Silicon Solar Cells.	University of Poona, Pune
3	Development of Amorphous Silicon Solar Cells.	IIT, Delhi
4	Development of techniques for the production operation and storage of silane from rice husk for preparing a-si.	IIT, Kharagpur
5	Production of Silanes for amorphous silicon & Polysilicon applications.	IISc., Bangalore
6	Amorphous silicon Solar Cells - Development and Evaluation Studies.	IIT, Madras
7	Investigation on hydrogenated Amorphous Silicon films.	NPL, New Delhi.
8	Polycrystalline Silicon from Rice-Husk	IIT, Kharagpur.
9	Photoelectrochemical Solar Cells using transition Metal Dichalcogenide Crystals.	Sardar Patel University Vallabh Vidyanagar.
10	Solar Energy Conversion through photo-electrochemical systems.	IISc., Bangalore
11	Energy conversion in Photoelectrochemical systems.	IIT, Delhi.
12	Photoelectrochemical Energy Conversion.	IIT, Delhi
13	Development and Demonstration of concentrator Photovoltaic systems for specific stand alone rural application.	Kalyani University, Kalyani
14	Development of thermoelectric generators for Solar (and other) energy conversion phase II.	IIT, Delhi.

Appendix VI (contd.)

Title of the Project	Institution
15 Photovoltaic Solar Energy Conversion and Storage-ion implantation and laser annealing studies.	IIT, Delhi
16 Characterization of copper-Indium-Di-Selenide and formation of thin film heterojunction Solar Cells: CdS:CuInSe2	IACS, Calcutta
17 Indium-Tin-Oxide based interfacial layer Hetero-Junction Solar Cells-Phase II.	IIT, Delhi
18 Development of Nontracking luminescent concentrators for Conversion of Solar energy.	IIT, Madras
19 Studies on In P based heterojunction Solar Cells in P/ITO and InP/CdS.	IACS, Calcutta
20 Study of Ternary chalcopyrite semiconducting films as photovoltaically active materials.	University of Rajasthan, Jaipur.
21 Development and demonstration of solar energy concentrator for Photovoltaic panels.	IIT, Delhi.
22 Feasibility studies on the development of organic dye solar cells.	IIT, Delhi.
23 Development of thin film CdTe heterojunction solar cells.	Sri Venkateswara University Tirupati.
24 Solar Cells Technology Assessment	TERI, New Delhi.
25 Evaluation of individually managed solar photo-voltaic water pumping systems in the States of Andhra Pradesh, Orissa, Tamil Nadu.	Administrative Staff College of India, Hyderabad.
26 Project on study of High efficiency Deep water pumps for application in solar PV systems.	REIL, Jaipur.
27 Proposal for research on Decentralised energy options in Rural Sector.	TERI, New Delhi.
28 Evaluation of individually managed Solar Photovoltaic water pumping systems in the States of Bihar, UP and West Bengal.	National Productivity Council, New Delhi.