PPLICATIONS OF
OLAR ENERGY IN
SOUTH & SOUTHEAST ASIA

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APPLICATIONS OF SOLAR ENERGY IN SOUTH AND SOUTHEAST ASIA

Proceedings of the Seminar
held on 19-23 February 1979
at the Asian Institute of Technology
in Bangkok, Thailand

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Seminar on the Applications of Solar Energy in South and South-East Asia
19-23 February 1979, Bangkok

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Seminar on the Applications of Solar Energy in South and South-East Asia
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FOREWORD

This seminar organized at the Asian Institute of Technology by the Government of France, was opened on February 19, 1979 by H.E. the Vice Prime Minister of Thailand, Mr. Sunthorn Hongladarom, and an address welcoming the participants was given by H.E. Dr. Thanat Khoman, Chairman of the Board of Trustees of AIT.

The seminar brought together for a whole week twelve French specialists headed by the President of the Commissariat a l'Energie Solaire (COMES), Professor Henri Durand, with invited representatives of twelve Asian Countries, namely: Bangladesh, Hone Kong, Fiji, India, Indonesia, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam.

The principal aim of the seminar was the promotion of open discussions between scientists of an industrialized country, which ranks second in the world for its effort in research, development and demonstration in the field of Solar Energy, and their Asian colleagues, who brought their experience of the specific problems arising in the adaptation of such a technology to the needs of this part of the world.

Solar Energy covers a vast panorama of techniques and applications, ranging from very high temperatures (almost 4000°C) to deep-freeze, from mechanical power through steam engines to a very original method of making electricity directly from sunshine with photovoltaic cells (as it has been used for over 20 years in artificial satellites). If one also adds the indirect forms of solar energy, such as wind power, or the photosynthesis which makes vegetation grow, one can see how diversified the uses of solar energy may be.

From the very first days of the Conference, topics quite specific to some of the participants were raised. For instance, densely-populated islands like Hongkong or Singapore cannot devote too much land to huge solar collectors and have to find their own solutions, as for instance a "solar-assisted" ventilation system described by a Professor of Singapore University. Again, while France is very active in the field of solar space heating (which constitutes one third of its energy needs), the problem in South-East Asia lies mainly with solar air-conditioning. On the other hand countries with a very large agricultural economy, like India, Bangladesh or Indonesia, are very much interested in getting the highest amount of energy from their agricultural wastes, by gaseous fermentation or by direct or indirect combustion.

During this conference, all the specialists attending exercised their ingenuity in order to discuss solutions to some of their needs, which should abandon the costly oil-based energy and favour renewable sources like solar energy. Specialized sessions were held on solar electricity, on solar water pumping and irrigation, on the application of solar technologies in agriculture, and on the uses of the so-called "bio-mass" (which represents the vegetal or animal potential which can be transformed into energy).

The publication of the Proceedings of the Seminar has unfortunately been delayedby difficulties encountered in collecting the necessary material from the many participants, an operation made all the more complex by the fact the Seminar was organized through three different institutions located in Paris and Bangkok. So as not to delay the publication any longer it was decided by the Organizors and the Editors that the Proceedings would include the Country Papers in full as they were presented with only minor editorial changes and that the other papers presented at the Seminar would appear in the form of detailed abstracts prepared by the authors.

Grateful acknowledgements are due to the many Organizations and Individuals who by their contributions and devoted efforts ensured the success of the Seminar. Special thanks go to the Government of France and to the Asian Institute of Technology for sponsoring this Seminar, to Mr. H. Durand, President of the COMES, to Mr. F. Miguel, to Mr. F. Bertin, D. Pierlot and their staffs, to Dr. R.H.B. Exell and the staff of AIT, particularly Mrs. Chalaporn Yunchanondh.

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Seminar on the Applications of solar Energy in South and South-East Asia
19-23 February 1979, Bangkok

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AGENDA

Monday 19 February 1979

08.30 Morning session : OPENING CEREMONY

Presentation of the national programs

13.30 Afternoon session :

- Topic : USE OF LOW TEMPERATURE SOLAR HEATING
- Speakers :
  - Mr. K. RAO (University of Singapore)
  - Mr. B. DEVIN (C.E.A., France)
  - Mr. M. DAGUENET and Mr. TARTAZANI (University of Perpignan, France)
  - Mr. F. MEUNIER (University of Orsay, France)
  - Mr. F. BRUNE (C.F.P., France)

Tuesday 20 February 1979

08.15 Morning session :

- Topic : PHOTOVOLTAIC CELLS
- Speakers :
  - Mr. H. DURAND (President of C.O.M.E.S., France)
  - Mr. Y. MARFAING (C.N.R.S. Bellevue, France) and Mr. D. CHUAH (University of Sains Malaysia)
  - Mr. D. ESTEVE (L.A.A.S., Toulouse, France)

13.30 Afternoon Session :

- Round table No. 1 : Inventory of resources and measuring techniques (Mr. R. EXELL, A.I.T., Chairman)
- Round table No. 2 : Air conditioning and the solar house (Mr. B. DEVIN, C.E.A. Paris, Chairman)

Wednesday 21 February 1979

08.15 Morning session :

- Topic : SOLAR ENERGY APPLIED TO WATER SUPPLY PROBLEMS
- Speakers :
  - Mr. R. BOULITROP (S.N.E.A. Paris, France)
  - Mr. B. DEVIN (C.E.A. Paris, France)
- Round table No. 3 : on the same topic (Mr. R. BOULITROP, Chairman)

13.30 Afternoon session :

- Round table No. 4 : Solar Electricity (Mr. Charuay BOONYUBOL, University of Chulalongkorn, Thailand, Chairman)

Thrusday 22 February 1979

08.15 Morning session :

- Topic : SOLAR ENERGY IN AGRICULTURE

- Speakers :

  - Mr. P. VERNET (I.R.E.P. Grenoble, France)

- Round table No. 7 : Training and information
  (Mr. VALLS, A.I.T., Chairman)

- SEMINAR CONCLUSIONS
  (Prof. R.B. BANKS, President of A.I.T., Chairman)

Seminar on the Applications of Solar Energy in South and South-East Asia
19-23 February 1979, Bangkok

COUNTRY PAPER ON SOLAR ENERGY (BANGLADESH)

The Delegation from Bangladesh

Introduction

Never before have we reached such a critical juncture in history when there was an energy problem of such a serious magnitude as is confronted by the world to-day. All the conventional energy sources are being depleted rapidly and it is merely a matter of decades before we shall have used these to the last dregs. Obviously, the survival of the human race is dependent on the discovery of new energy sources which may not be necessarily oil, coal or natural gas. In a situation like this solar energy seems to be offering a substantial alternative, which is non-polluting at the same time.

Energy consumption from conventional sources in Bangladesh is only 25% while the remaining 75% is met out of non-conventional sources like firewood, cow dung, straw, rice-husk, jute sticks etc. At this time the consumers of natural gas are some industries (for raising steam, heating and production of fertilizer) and part of the urban population in some cities (for cooking only). The scope for using this gas is being continuously extended. The proven reserve in Bangladesh is estimated to be about 9×10^{12} S.C.F. Unfortunately it has not been possible to supply gas to the rural areas because of the enormous cost involved in establishing the network of pipelines. Hence the rural population, who consume about 25% of the total energy for cooking, drying and processing of agricultural produce, depends mostly on agricultural waste (20 million tons/year) and firewood (0.6 million tons/year). This use is greatly supplemented by using sunrays directly. However, the forests are being depleted very fast and the agricultural products are not so abundant as before. This situation demands urgent attention towards the development of other sources of energy like solar energy, wind power, hydro-power and bio-systems.

Since the wind velocity is not steady in Bangladesh within reasonable limits and there are frequent storms, tornadoes and cyclones, the use of wind power does not seem to be feasible. On the other hand the potential of hydropower is severely limited. Consequently, solar energy seems to be a promising supplementary source of energy.

Measurement of Intensity of Solar Radiation

Efficient utilisation of solar energy requires a good understanding of the characteristics of the incident solar radiation. Because of the high degree of complexity and temporal and spatial variations of the quantity of solar radiation reaching the surface of the earth, simple calculation from theoretical models is not possible. This understanding is, therefore, gained from direct measurement of the solar radiation. Measurements and analysis of the solar radiation at ground level in Dacca (23^{o}N) have been carried out. To quantify some of these characteristics a measurement programme was initiated in the Bangladesh Council of Scientific & Industrial Research Laboratories (BCSIR) in collaboration with the Rice Research Institute. The programme for measuring global radiation intensity was carried out continuously for a three year period from 1975 to 1977. The apparatus used for collecting data was a standard recording type of pyrheliograph.

Photovoltaic Cells

The Bangladesh Atomic Energy Commission is considering more sophisticated use of solar energy by conversion through photovoltaic cells. Banks of solar cells can be used to charge storage batteries so that the energy can be made available at any time also. This has the advantage that both the generator (solar cells) and source of energy (battery) are portable. Work has already been started in the Atomic Energy Commission Laboratories on silicon solar cells.

Solar Cooker

The common method for converting solar energy into heat energy is by the use of a flat plate collector for heating matter, air or other fluids. Bangladesh, like most of the developing countries, because of limitations in technological resources, has not been able to make a breakthrough in solar collector designing and testing. However, scientists and technicians of the Bangladesh Council of Scientific and Industrial Research (BCSIR) have studied the feasibility and economic viability of a solar cooking device of a direct reflector type. This consists of a polished aluminium reflector of paraboloidal shape which concentrates heat directly on the blackened bottom of a cooking utensil. The reflector is mounted on a stand with three adjustable legs to tilt the reflector to keep it facing the sun.

A group of scientists carried out a typical experiment on this solar cooker in a sunny day in the month of March 1978 at 11.00 a.m. The apparatus and the appliances used were:

(a) An aluminium reflector of paraboloidal shape measuring about 10 ft^2 face area.

(b) An aluminium saucepan of 11.5 cm diameter, 10.0 cm height and 372 gm in weight. Its bottom was blackened by depositing a layer of soot.

The solar intensity was simultaneously calculated and found to be 300 Btu/ft^2 per hour. It is, therefore, estimated that the solar cooker with an aluminium reflector of an effective face area of 10 ft^2 and 70% reflectivity would deliver a heat supply of 300 x 10 x 0.7 x 0.293 watts = 615.3 watts.

In an experiment with the above cooker on a sunny day it has been observed that a three course meal (rice, fish curry and pulse) for four persons could be cooked in about 2½ hours. So, a solar cooker of about 700 watt could be just sufficient for a family of 4 to 5 persons when the time factor is not too important. However, there is a lot of scope for improvement of the above cooker keeping the size and material requirement the same.

Solar Drier for Fish

Bangladesh has a vast potential of fish resources at different fishing centres and in the Bay of Bengal. A substantial portion of the catch is dried and supplied to different parts of the country as dried fish. There are acute problems of fly larvae infestation of the larger fish species which require 5 to 7 days to dry. These normally get heavily infested when the traditional method of solar drying is adopted. An improved method to dry fish with the solar radiation has been developed and tested by scientists of Australia, Sri Lanka, the Bangladesh Atomic Energy Commission, and the Bangladesh Council of Scientific and Industrial Research. The drier proved successful in killing fly larvae and also adult flies, and cutting down the drying time to about 4 days.

The drier thus developed and tested was a tent made of clear polythene sheets with a black polythene sheet placed at the back and on the floor. There was a provision for a sufficient number of vents in the drier tent for air being drawn through the vents at the base and exhausted through the vents at the top of the drier.

The black surface of the floor is used as a solar collector by absorbing solar radiation passing through the clear polythene increasing the temperature of the air within the drier. In a tent made of all clear polythene sheet the inside temperature can be raised up to 37°C only, while in the modified version the temperature can be raised up to 48°C when the outside temperature is 28°C.

The process of drying fish in Bangladesh is mostly carried out in the winter season when the maximum altitude of the sun in Bangladesh is about 45°. The shape of the drier was chosen to present the clear polythene sheet roughly normal to the sun's rays. By adjusting the vents the temperature of the air within the drier can be raised to 45°C maintaining it for a period of 20 hours; this was found to be sufficient to kill all the fly species (adults and larvae) found in Bangladesh.

Conclusion

The utilisation of the world's fuel, such as oil, gas and electricity has increased very rapidly during the last 25 years. It is feared that such a rate of consumption will lead to a desparate energy crisis throughout the world. Moreover, the prohibitive cost of large generators and nuclear reactors, transmission and distribution systems would not allow us to meet the energy needs of our rural population for many years to come.

Collaborative effort should, therefore, be made to evolve technologies to make efficient utilisation of solar energy as inexpensively as possible.

It does not matter who discovers the appropriate technology for using solar energy but how soon that discovery is made.

Seminar on Applications of Solar Energy in South and South-East Asia
19-23 February 1979, Bangkok

COUNTRY REPORT : FIJI

P. JOHNSTON*

Introduction : Energy Use in Fiji

Due to a late decision regarding attendance at this seminar, it is only possible to prepare a very brief paper. Fiji is a small country of 600,000 people and over 300 islands with a total land area of 18,000km^2 spread over 180,000km^2 of ocean excluding a 368km (200 nautical miles) economic zone. The population is 65% rural and the GDP/capita is about US$ 1000.

As shown in Table 1 below, in 1977 gross energy consumption was about 760 thousand tonnes of coal equivalent or 1280kg per capita of which half was commercial and imported (petroleum, LPG, and coal) and half was indigenous and non-commercial (bagasse and wood). Of the commercial energy consumption, 30% was electric and 70% non-electric. Of total energy consumption, half was used in industry including sugar-milling, one-fourth in transport, and one-fourth for commercial and domestic use. Agricultural use has not been separated into another category. Since 1950 commercial energy use in the Pacific Islands has been increasing at an average rate of 11% per year compared to 7% in developing countries in general.

* Energy Policy Planning, Ministry of Economic Planning (Fiji)

During the early 1970s petroleum fuel imports accounted for 5½% of GDP compared to typically 8% since 1974. During the past 2 years, GDP in current dollars has grown about 20% while the import cost of petroleum fuels has risen by 45%. Efforts to exploit indigenous energy sources have had little impact except for the development of a 40MW hydroelectric scheme planned for completion in 1981. Investigations are under way into geothermal energy potential and several companies are about to begin offshore drilling operations in the search for oil and gas.

Table 1. Gross Energy Consumption by Percentage in Fiji - 1977 (Total consumption = 22 x 10^6GJ = 7.6 x 10^5 tce)

Sector	Imported		Local		Total
	Petroleum	Coal	Bagasse	Wood	
Industrial	10.3	2.8	31.5	-	44.6
Transport	24.7	-	-	-	24.7
Domestic	6.2	-	-	18.6	24.8
Commercial	5.8	-	-	0.1	5.9
Total	47.0	2.8	31.5	18.7	100.0

Notes: 1. Domestic includes subsistence; Commercial includes Government and miscellaneous.

2. Data are actual except wood based on survey.

Solar Energy Use in Fiji

Fiji is a humid tropical country with high cloud cover (typically 50%) and rainfall varying from 1700mm per year in the 'dry' zones to over 3000mm in 'wet' zones. No study has been made of solar conditions for energy utilization but approximate conditions are shown in Table 2 below.

Table 2. Typical Solar Conditions in Fiji

Location	Insolation (Langleys/day) June/July	Insolation (Langleys/day) Dec/Jan	Bright Sunshine (Mean hrs/ day
Wet Zone	300	450	5.2
Dry Zone and Smaller Islands	380-450	570-700	6.9

The very limited direct use of solar energy in Fiji is summarized below:

a) Solar Timber Kiln

In 1975 a pilot scale solar timber kiln of 5m^3 capacity was constructed and extensively tested. Details of construction and results are given in the form of a booklet "The Design and Operation of a Solar Timber Kiln", Fiji Forestry Department Bulletin No. 67 of 1977. An improved 12m^3 (5000 s.ft) capacity kiln costing F$4000 (US$4800) compares favourably economically with air drying. However (despite widespread publicity and company tax benefits for energy systems based on indigenous energy sources) no commercial kilns have been built in Fiji.

b) Solar Water Heating

There are in Fiji about 900 domestic solar water heaters of which 90% are conventional copper thermosiphon designs manufactured under license. Currently only 2.6% of all urban households use solar water heaters due to high costs, about US$1000 per system which is equivalent to per capita annual GDP. Solar water heaters are used in several Government health centres and hotels but widespread use will require a substantial cost reduction. Several alternative designs have been developed by the Government's Public Works Department but costs are still beyond the reach of most of Fiji's population.

c) Solar Distillation

Some of Fiji's smaller islands rely on rainwater catchment and storage for potable water. During the dry season there may be little or no rain for 4-5 months. There have been several attempts to design and construct water systems for such communities combining a solar still and rainfall collector with typical results being 96 l/m^2 of collector surface per month through rainfall collection increased to 154 l/m^2 by adding solar distillation. In no case have solar stills remained in operation beyond an initial experimental period. The Public Works Department considered a portable floating still to be towed to islands in times of drought but abandoned the idea due to high cost and low yield. Instead water is transported when needed by barge.

d) Solar Steam Cooking

In 1977 two solar cookers based on a Brace Research Institute (McGill University) design, and consisting of a simple flat plate collector and insulated cooking box, were built and tested at the University of the South Pacific. Performance was poor: three hours of bright sunshine ($3.0 JCm^{-2} min^{-1}$) were required to bring the water (500ml) in the cooking area to boil. During a month of testing, it was never possible to actually cook any food to satisfaction.

e) Photovoltaic Cells

There are in Fiji several installations of photovoltaic panels for powering telecommunications repeater stations and marine navigation beacons in remote locations. Our real interest in photovoltaics is in their potential for rural lighting. In a country of small communities in rugged terrain spread over hundreds of islands, a widespread electric grid is impossible. A technically attractive option for domestic lighting is the use of fluorescent lights powered by photovoltaics through a storage battery. So far cost quotations have been too high for this to be given serious consideration in Fiji.

Concluding Remarks

As indicated above, solar energy use in Fiji is insignificant at present. The areas in which utilization is technically viable - particularly water heating, lighting, and drying - are presently too expensive for widespread use given our limited financial resources.

P. Johnston
Central Planning Office
15 February 1979

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SOLAR ENERGY DEVELOPMENTS IN HONG KONG

E.A. BRUGES*

In recent years interest in solar energy has been stimulated by the mass media through articles in the press, television programmes and radio interviews. However, it can hardly be claimed that public response has been strong. This is probably due to the high density of population in the urban areas, which inhibits the possibility of any one individual achieving any benefit from a solar installation. Indeed, since much of the early solar developments related to the provision of hot water on a relatively small scale local interest is not strong since hot water is not in great demand, coupled with the short "winters" and long "summers". It could be that if cooling were more easily achieved a greater interest in solar technology would develop. This does not mean that there are no solar installations in Hong Kong, indeed, there are a number of private hot water systems, of which some are quite old, and one large system, 500 m^2 for hot water, is presently under construction for the New World Centre in Tsimshatsui. This centre is a commercial development including two hotels, shopping complex, offices and apartments.

If solar technology has not quite reached Hong Kong this does not mean that there are no plans for the future. As a large user of energy the Public Works Department and Urban Services Department

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of the Hong Kong Government are interested in the application of solar energy to provide hot water, the PWD for hospitals and prisons, and the USD, in particular, for bathhouses and swimming pools. In order to obtain some idea of the savings which might be achieved feasibility studies have been prepared by the writer for a bathhouse and for winter heating of swimming pools.

The bathhouse in question has a southerly aspect and it is proposed to place the solar collectors on the south-facing wall and on the roof. The total area of the collectors is 60 m^2 and these will provide 80% of the average heating requirement during the winter months. The flat plate collectors are designed to be single-glazed with a selective surface and the tilt angle is chosen to optimise winter performance. The collector system, since it is small, is connected in parallel with the existing oil-fired boiler across the storage cylinder. Water is circulated through the collectors by a small pump which is subject to the conventional differential control between the hottest and coldest parts of the system. No protection is provided against frost, which is a possibility, but in the event of a very severe condition the pump could be operated to prevent the water from freezing. In summer the bathhouse does not provide hot water from the existing boiler, which is only operated in the winter (Nov.-Mar.), but the solar collectors will provide hot water in the summer, whether it is used or not.

The USD has a large number of swimming pool complexes which usually comprise an Olympic size pool, 50 m x 21 m, and a number of other pools for diving, for small children etc., and a training pool which is also of 50 m x 21 m dimensions. One of these large pools is an indoor pool (Morrison Hill) which is heated by hot water oil-fired boilers and a number of the open-air pools (Aberdeen etc.,) are heated in a similar way. The writer has been involved in preparing feasibility studies for solar heating of both types of pool, indoor and outdoor, during the winter months. The USD has requested that priority be given to the indoor pool notwithstanding the difficulty presented by the Morrison Hill site and the problem of locating special lightweight collectors on the roof.

The indoor pool can carry about 850 m^2 of collector surface and the outdoor pools will also need about 850 m^2, if a reasonable proportion of the heating is to come from the solar system. An adequate oil or gas-fired boiler has to provide back-up heating for the inclement winter days and to make up large heat losses when the wind speed exceeds 2m/s——about annual average. Of course, it is necessary that the outdoor pools be covered between sunset and sunrise and this is already done for the few pools which are heated. The indoor and outdoor pools each present their own problems, the indoor pool gains no direct heat from the sun but has no great heat loss whereas the outdoor pools absorb a lot of solar energy but lose heat easily by evaporation from the surface when there is any appreciable wind. Both schemes are subject to the axiom that solar energy must be used throughout the year, unless the cost of the installation is so low that return on one's investment is not an issue. In the case of the swimming pools, which all require retrofit solar installations, the cost of installing 850 m^2 is such that a winter only heating scheme is not viable, since the Hong Kong winter is relatively short (Nov.-Mar.). This means it is necessary to consider what to do with the energy which the solar systems collects in the summer and, unless there is an alterative heating requirement, the only useful application would seem to be cooling. This is attractive because humidity is high in summer and the amenities could be improved by dehumidifying the MH pool hall and air-conditioning the changing rooms.

Once one is committed to a winter heating system the investment is such that summer cooling is obligatory. Unfortunately cooling is not viable, either by means of a Rankine engine/vapour compression refrigerator or LiBr—H_2O refrigerator unless the thermal source is close to 100^oC or even higher. This means that high performance collectors have to be made locally, since imported collectors are so expensive, and this has brought the writer into the manufacturing side. Conventional flat plate collectors have been made on request by the China Cold Storage Co., but it seems another Hong Kong manufacturer may produce a more sophisticated type of collector and is prepared to design special collectors for the swimming pool projects.

In the private sector there is a certain amount of interest especially among organisations needing hot water, e.g. hotels. However, it may be that there is a reluctance to go ahead until some data is available from the government's pilot schemes. The greatest activity is in the department of mechanical engineering of Hong Kong University where much experiemental and design work is in hand, the leading projects being the studies for the bathhouse and swimming pools and the following new projects.

A small, 13 m^2 collector area, hot water and space heating unit is on loan from the Ying Manufacturing Corp. of Gardena, Los Angeles. There is a 300 gallon hot water storage tank and 3 large single-glazed solar collectors. These are lightweight because of the polycarbonate glazing. A number of solar collectors have been built in recent years by the writer to ascertain the problems associated with local manufacture.

A solar collector test facility has been completed which will enable calorimetric tests according to ASHRAE/NBS standards to be carried out as well as studies of the local weather characteristics. The solar radiation is measured by an Eppley pyranometer, which is a primary instrument, all other observations being in accordance with international recommendations. The observations can, if required, be monitored and analysed by a computer.

It is planned to purchase a small LiBr-H_2O chiller and to instal the necessary solar collectors, which will be made locally. A number of designs are being investigated which relate both to the PWD/USD projects as well as to other needs.

Two interesting student projects relate to air-conditioning using desiccants and to the development of a low cost solar driven pump. At an earlier stage a low cost tracking system was built using a bi-metallic sensor.

During 1979 it is expected that a full set of computer programmes will have been developed for design and simulation studies. No doubt some of the programmes already developed in the US can be adapted. Accordingly, it is believed that within a year a substantial contribution will have been made to the design of collectors, which it is hoped will be made in Hong Kong and exported to the region, a number of demonstration units will exist in the University along with a test facility and that Government will build at least two schemes designed for the bathhouse and swimming pools. No doubt the private sector will become active once the viability of heating and cooling schemes is clear, although a number of other applications could also be of interest to the industrialist. At this stage there seems no interest in large scale systems for housing schemes but these cannot be ruled out, especially in the New Territories.

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INDIA'S SOLAR ENERGY PROGRAMME

J. GURURAJA*

Programme Objectives

India being a tropical country has abundant sunshine which could be exploited for a wider variety of applications. Recognising the potential role of solar energy in supplementing the energy needs of the country, particularly in the rural areas, the Government of India has accorded a high priority for the development of appropriate solar technologies. A broad-based and integrated national programme has emerged under the aegis of the Department of Science and Technology. The objectives of this national programme are:

- Promotion of research and development through liberal government financial support.

- Utilisation of results of R&D towards development of devices, products and systems through industrial participation.

- Testing and evaluation of various solar technologies under field conditions to determine their economic viability and social acceptability.

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- Transfer of technology and

- Commercialization through incentives and subsidies with a view to generate adequate markets.

<u>Principal elements of the Programme</u>

The principal elements of the programme are:

i) Establishment of radiation data base

ii) R&D on solar thermal applications

iii) R&D on photovoltaic applications

iv) R&D on indirect applications

v) Development of products, devices and systems, and

vi) Commercialisation

<u>Coordinated approach</u>

In pursuit of the objectives of the programme, a coordinated approach has been evolved with the active participation of the following organisations from the inception stage in each major area of stage application:

a) R&D establishments, such as, CSIR laboratories, educational institutions, etc.

b) Industry (BHEL,CEL and others)

c) User agencies

d) Extension agencies

Such a coordinated approach was considered advantageous from the point of view of development of technology and it's applications. The participation of industry from the beginning is intended to provide the necessary engineering inputs for transforming the R&D results into prototypes and production-oriented designs, and the participation of user agencies is intended to provide the necessary feedback from the users and that of the extension agencies is to provide the multiplier effect leading to widespread utilisation, wherever feasible.

Fields of application identified as relevant to India's needs

Judging from the present scale of use of conventional energy and the dominant role of non-commercial energy in rural areas, the priority areas of application in India will have to be necessarily those that would contribute to increased production and reduction of human drudgery. On the basis of this criteria, the productive applications of solar energy are considered to be:

- Pumping for irrigation based on:
  - (i) Solar thermal
  - (ii) Photovoltaic (micro-irrigation)
- Small power plant for rural industries
  - Solar thermal (50 kW and above)

- Solar drying

  - agricultural crops (paddy, maize, etc.), cash crops (pepper, tea, tobacco, groundnut, cashew, copra, chillies, etc.), marine products (fish), forest products (timber), etc.

  - Cold storage for preservation of perishable articles

  - Medium temperature heat in the form of hot water, process steam for industrial applications both in urban and rural areas (agro-based industries).

The applications that contribute to improvement in the quality of life (indirectly productive applications)

- Cooking

- Space heating and cooling

- Water heating

- Pumping for drinking water supply

- Distillation to convert brackish water to potable water

- Domestic lighting

- Small-scale power units (photovoltaic systems) for communication, educational TV and radio, etc.

Current activities and recent technological developments

Current activities in India range over most of the above-mentioned application areas. Significant technological progress has been made in some of the areas such as water heating, drying, cold storage, etc.

Collector Development

Flat plate collectors suitable for heating water up to $60^{o}C$ (single glazing) and up to $95^{o}C$ (double glazing with booster mirrors) have been developed. The collectors consist of roll-bond aluminium absorber panels, extruded aluminium frame, fibre-glass insulation and single/double glass covers. The lower temperature range collecters are being commercially manufactured in the country and have been utilised in several water heating projects. The higher temperature range collectors have been used for solar power generation. These collectors are also being used as thermal energy collectors for operating absorption refrigeration systems. The collectors have non-selective coating of storing black enamel paint.

Experience has shown that the aluminium bond-duct absorber panels are prons to corrosion if the water quality is not closely controlled. For this reason, it is necessary to install a demineralizer in all close-circuit water heating systems employing such collectors. Since aluminium collectors are unsuitable for domestic solar water heaters, efforts are underway to develop collectors using absorber panels made of galvanised iron, special quality steel and copper. Various bonding technologies for attaching tubes carrying the heat transfer fluid, to the absorber plate are being investigated.

At present, there are no accurate estimates of the total market potential for solar water heating systems. Efforts are underway to collect reliable information on the pattern of use of hot water in domestic, industrial, commercial and rural sectors as well as the temperature level at which hot water is required for various purposes and the sources of fuel currently used for heating water. However, from preliminary indications it is clear that at least in the organised sector, considerable markets could be developed even at present day costs and more so as costs are brought down either by volume production or by low cost designs. Contrary to popular belief, the potential for solar hot water system in rural areas appears significant especially for agro-based industries such as handloom dyeing, leather tannery, hand-made paper, etc., where conventional fuel, if commercially obtained, is proving to be increasingly expensive and if non-commercial fuels are used, are posing problems of high social cost.

With a view to encourage use of solar water heating systems, a number of demonstration installations have been put up. One of the installations of big size is for a hotal and a similar unit for a hospital is under construction. These have been well received and from all indications, such systems are likely to prove cost effective, if produced in large quantities.

Considerable R&D work is currently underway in selective coatings at various centres. These investigations cover electroplating technique of black chrome and black nickel, low-cost spraying and dipping techniques (black nickel) on various substrate materials. The establishment of a commercial scale facility for selective coating of absorber panels is underway.

Current activities on the development of concentrators are more laboratory-oriented than in the case of flat plate collectors and have not yet reached the application stage. With a view to strengthening R&D in this area, steps have been taken to involve more agencies including an industry to evolve production-oriented designs suitable for industrial process steam generation and for power plant applications. The emphasis is an cylindrical line focussing collectors with single exis tracking, although some work on paraboloid dishes are also pursued. Supporting this development there are many studies currently underway on reflecting materials, fabrication techniques, tracking mechanisms, receiver designs and system integration and optimization.

Since more advanced technological capabilities are needed to develop concentrating systems than are required for flat plate systems, it is worthwhile exploring possibilities for international cooperation to secure maximum advantage in arriving at appropriate designs suitable for local conditions.

Air heating systems for drying applications

A wide variety of air heating systems have been proposed and some have been built and tested. Although air heating systems are relatively simple, market penetration has been slow; their main applications are for drying of agricultural products, marine products and forest products in rural areas where reliability, ruggedness and maintenance-free operation are prime considerations, besides low cost. The main problem seems to be the lack of manufacturing or fabrication facilities and proper institutional mechanisms at the local level to promote and popularize grain dryers. The Department of Science and Technology has supported several R&D and demonstration projects. Consequent to the successful development of 1-ton paddy dryer at Annamalai University, the work of building commercial size units was taken up and two grain dryer units are in operation and a third one is under construction.

Cold storage applications

Like solar drying applications which would have an important role in post-harvest technology, solar refrigeration is an equally important area of application that could contribute to the preservation of perishable articles. R & D is in progress in as many as six institutions. Most of the institutions working on the absorption refrigeration system have concentrated on 1-ton unit using ammonia-water as the medium. Preliminary tests have been successful. It appears that the system has to be sufficiently large to be economical and one of the problems being faced in design is that of scaling up of present prototype designs.

Solar pumps

In most developing countries the need for water pumping for irrigation and for drinking water supply is very acute and particularly in India, the potential benefits from successful development of solar pumps are considered so significant that a high priority has been accorded to the R & D in this area. More than 3 million agricultural pump sets are already in operation in the country, with capacities ranging from 3-5 H.P. and driven either by electricity or by diesel engines. Only about 40 per cent of India's nearly half a million villages have so far been electrified and complete rural electrification is still a long way off. There is also a dire need to find alternatives to dissel pumping because reduction in oil consumption is vital since nearly two-thirds of our oil requirements is imported, which the country can ill-afford. Thus from the point of view increasing agricultural production with concomitant improvement in the purchasing power of the rural population, it is very crucial to explore solar pumping systems with the utmost urgency. The technical progress achieved so far is such that the major barrier seems to be the prohibitively high capital cost, not to speak of the skills required to operate and maintain solar pumping installations. Technological simplicity and cost breakthrough are vital if solar pumping is to find a place in the rural scene.

Three types of requirements can be identified. These are:

(a) Small capacity pumps (less than one kW) for pumping water from deep bore wells for rural drinking water supply,

(b) 2-5 kW capacity pumps for pumping water from open wells or from bore wells for irrigation (relatively small land holdings by individual farmers), and

(c) Lift irrigation pumps for pumping large quantities of water from canals, rivers or streams. In this case, capacities in the range of 20-50 kW are envisaged.

Under category (a), the possibility of employing photovoltaic pumping systems are being seriously considered. If the projected cost goals are indeed realized by the middle of this decade ($1-2 per peak watt), then such systems could find widespread use both for drinking water supply and for micro-irrigation. Today, in India less than 20 per cent of its entire population is provided with protected water supply and particularly in rural areas chronic shortage of surface water coupled with its unsuitability for drinking purposes have posed serious health problems and water-borne diseases. Deep underground water available in most places is an answer to this problem but this has been hampered by lack of suitable pumping devices and sources of power to run them. Thus if cost-effective photovoltaic pumping systems could be developed then such systems could be used not only for drinking water supply installtions but also for micro-irrigation. The point regarding micro-irrigation is that average land holding by individual farmers in India being so small (less than a hectre in most cases) that for many types of crops, relatively small quantities of water would suffice and that photovoltaic systems could become viable particularly as this application would contribute to increased production. Attempts are under way to install a few such pumps and generate techno-economic data.

In the higher range of capacities as identified under category (b) and (c) above, various system concepts are being experimented with. Some of these are:

i) Immiscible organic fluid direct action pump (no moving parts)

ii) Prime mover driven pumps

iii) Electrically driven pumps from local grids energised by solar power plants.

At present, the main emphasis is on the development of small capacity prime movers. Laboratory level work on prime movers, such as, spiral expander, single stage and multistorage turbine, sliding vane rotary engine etc., has been in progress for some time and recently engineering development work has been initiated. Various solar pumping systems will have to be built and adequately tested under field conditions before we could come to meaningful conclusions about the most suitable system for a given requirement. Ultimately it is the cost that will decide the future of solar pumping units.

Solar power plants

From the point of view of India's needs, the scope for decentralised power production based on solar energy has to be considered as of special significance to remote locations where electricity from central stations may not be available in the foreseeable future and indeed, if possible at all, it might turn out to be too expensive. Thus, there is a need but this need can be fulfilled only if simple systems requiring little maintenance and possessing high reliability could be built at costs which the community could afford.

On the basis of energy requirements of small rural communities, it was felt that solar plants in the range 10-50 kW capacity would be required. Keeping this in view, a 10 kW experimental power station has been installed at Madras with a view to gaining operational experience and to collect data that could be used for later designs. The 10 kW plant recently installed by Bharat Heavy Electricals Ltd. in collaboration with FRG has a flat plate collector field (95^{o}C hot water) and an energy conversion system based on Freon-114 as the working fluid system is fully instrumented to collect performance data.

Power plants based on cylindrical parabolic collectors and parabolic dishes are also being investigated.

Photovoltaic applications

As already stated, the main areas of applications are communications, small power sources for energising community radio and TV for educational purposes, pumping (drinking water supply schemes), for micro-irrigation and for domestic lighting etc. With a view to achieve expeditious realization of these applications, practically all promising areas of research have been funded and a coordinated programme has emerged under the aegis of DST. Good progress has been made in the area of monocrystalline silicon solar cells at the Central Electronics Ltd., where fabrication of solar cells and panels is being undertaken. Some field testing activity of solar photovoltaic systems including photovoltaic pumping is currently under way. Efforts are also under way to achieve substantial cost reduction through low cost materials and fabrication techniques. Significant progress has also been made on thin-film CdS solar cells (IIT, Delhi) and on polycrystalline silicon solar cells at the National Physical Laboratory. R&D projects on materials (extraction and purification of solar grade silicon from rice husk, amorphous silicon, etc.), on concentratry-solar cells, and tracking systems have also been funded.

Commercial activity

Despite these activities, commercialization is yet to reach the take-off stage mainly due to the high capital cost of solar devices and also due to lack of well engineered systems with adequate service life and system reliability. About a dozen firms have started manufacture of solar hot water systems only against orders but production capacity has not yet reached significant levels. Efforts are under way for transfer of knowhow to private entrepreneurs so that a sustainable solar hot water industry could be established.

Indirect applications of solar energy

R&D on the indirect applications of solar energy has not been covered in this note. Considerable work is in progress in the following areas:

1. Bio-gas technology (All India Coordinated Project)

2. Biomass production (energy plantation, hydrocarbon plants, algae production etc.)

3. Fuel from Bio-mass (task force report and projects initiated)

4. Wind energy

5. Hydrogen energy (task force report and a few on-going projects).

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INDONESIA: SOLAR ENERGY STRATEGY

M.S.A. SASTROAMIDJOJO*

The main centers of activity in solar energy research in Indonesia are the following: Institutes, Organizations or Agency's

1. Dept. of Advanced Technology (A sub-division of the Dept. of Research and Technology).

2. I.T.B. (Institute of Technology, Bandung)

3. I.A.B. (Institute of Agriculture, Bogon)

4. S.E.R.C. (Solar Energy Research Centre, Gujah Mada University, Jogyakarta).

The above institutions for the third-five-year plan beginning in April 1979 are assigned the following objectives.

1. Solar village (Advanced Technology group)

2. Biogas (I.T.B.)

3. Solar technology application in agriculture (I.A.B.)

* Director, Solar Energy Research Center (S.E.R.C.), Bandung, Indonesia

4. Big scale solar energy conversion to electrical power. (S.E.R.C.)

Outside these four Institutes many universities are engaged in solar energy research and have included solar energy in their curricula.

Cooperation with the U.S.A., Japan, Germany, France and Australia will be developed in the next five years.

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SOLAR ENERGY PROGRAMMES IN UNIVERSITIES IN MALAYSIA

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1. University of Malaya

The faculty of Engineering at the University of Malaya in Kuala Lumpur has been carrying out research on the direct utilisation of heat generated from solar energy. Research topics include water heating, air heating, rice and timber drying, distillation, dehumidification, and selective surfaces. The topics selected were mainly based on, and geared to, the needs of the country.

Flat plate solar water heaters are now available for domestic and commercial applications. However, their high capital cost US$ 600.00 for 40 gallon domestic unit is a major barrier to public acceptance. Research is being conducted at the present moment to provide high temperature solar water heaters for industrial applications.

Solar drying is still at the R & D stage with work being in progress at the University and the University of Agriculture. At the former, the study has been conducted in two parts - the solar air heater

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performance and the drying characteristics of rice and timber separately. In the coming year, it is hoped to merge the two parts into one to form a prototype solar rice and timber dryer. It was decided not to research into sophisticated topics like solar-thermal power generation and photovoltaics at the moment until the basic and more economically viable applications like domestic and commercial hot water heating and crop drying systems were fully investigated and proven to be reliable under local environmental conditions. Later studies would be based on improving their efficiencies, reliability and durability. (1,2,3)

2. University of Agriculture

The solar Energy Working Group at the University of Agriculture in Serdeng has centred its solar energy programmes on research and development in renewable resources of energy, such as solar energy, wind energy, energy from agricultural and animal wastes for agricultural applications. Its research and development is being planned in the following areas:

1. Solar drying of agricultural products.
2. Solar powered rural industrial processes.
3. Solar distillation of polluted water.
4. Solar cooking
5. Solar pump for irrigation
6. Solar cooling for storage and handling of food and agricultural products. (4,5,6)

3. University Sains Malaysia

The programme is to make a feasibility study of setting up solar silicon generator so that they can be used on a small scale as self-contained electric power supplies for electric lighting and other household uses in remote towns or villages.

In conjunction with this study, solar radiation constants are being measured. Since 1974 three solar electric generators of electrical power 25w, 24V; 7.2w, 12V; and 1.4w, 12V were used to give daily electrical charges to storage batteries, which discharged nightly for three hours per night through the electrical lamps, with the corresponding powers. The results showed that there is sufficient charging power from sunlight for three hours usage of electrical lighting per night, for the solar electrical generators mentioned above. Also, the average annual sunshine hours is sufficient for the conversion of sunlight into electricity by silicon solar cells.

Following these studies a silicon research and technology laboratory is being set up with technical and financial aid from the French Government and in consultation with Prof. Y Wanfaing, Director of the Solid State Physics Laboratory, Bellevue, France. The activities of this research laboratory are to fabricate silicon solar cells for the purpose of direct conversion of sunlight into electricity and to train our physics students to meet the employment requirements of the government and semiconductor industries in Malaysia.

In conjunction with the National Electricity Board of Malaysia and LAAS-CNRS of France (Laboratoire D' Automatique D' Analyse des Systemes - Centre National de la Recherche Scientifique), a 1 Kw high intensity silicon solar electric generator is scheduled to be set up some time this year to study the tracking reliability and performances of the cells with respect to the efficiency yield, cooling, thermal effects and local atmospheric effects. Dr. D'Esteves, deputy-director of LAAS, is the project leader for this scientific study.

Whilst we look forward to large scale terrestrial applications of solar cells it would be necessary to continue to gain first hand experiences with them. (7,8,9)

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SUMMARY REPORT ON NATIONAL PROGRAMME (PAKISTAN)

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Although the consumption of conventional energy sources like oil, gas, coal and electricity is very small, about 200 kg of coal equivalent per capita per year, as compared to the industrial and oil rich countries (more than 3000 kg), Pakistan has to spend a large amount of foreign exchange, about $450 million per year, to import a little more than 3 million tons of oil alone. Except for the use of electricity for tube-wells and oil for tractors in certain villages these conventional energy sources are used in the industrial and urban areas, and more than 75 percent of our population living in the rural areas has to fulfil its power and heat requirements from the animal and human muscular energy and from the use of wood, cattle dung and farm wastes respectively. It may be mentioned that there are about 4500 villages out of which about 800 only are electrified.

The energy consumption pattern of Pakistan in the recent years has been somewhat as shown in the table below,

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	Energy Sources.	Unit.		MTCE.**	Percent
i)	Conventional				
	Oil.	Million tons	3.98	6.00	20
	Gas.	Million million Cuft	0.124	4.5	14.5
	Coal.	Million tons	1.06	1.06	5
	Electricity (Hydro & Nuclear)	GWH	6200	2.8	8
				14.3	47.5
ii)	Non-Conventional, wood, cattle dung & farm wastes.			16.4	52.5
				30.7	100

** Million tons of Coal equivalent

With the increasing population, and in order to increase our productivity, more and more energy and power is undoubtedly needed. Huge investments are being made for the exploration of oil and gas.

As Pakistan lies in the sunny belt ($21^{o}N - 36^{o}N$), solar energy offers a potential energy source, provided solar appliances can be developed to suit economics and social acceptance. Keeping this in view, the interest in the R & D of solar appliances has remained alive since early sixties but is dwindling as no large scale development or practical application has been made in Pakistan except in the 6000 gallons per day solar desalination plant constructed at Gwadur, a town of about 10,000 people on the coast of Baluchistan.

On the R & D side, organisations like the Pakistan Council of Scientific & Industrial Research, Pakistan Atomic Energy Commission, Energy Resources Cell of the Ministry of Fuel & Power, the Physics Departments and Mechanical Engineering Departments of the Universities at Lahore, Peshawer and Karachi kept up some activity during the last 15 years.

In 1977 the Ministry of Science & Technology approved a Solar Energy Project for design, fabrication, performance evaluation, economic analysis and practical demonstration of:

1. Domestic Solar Water Heaters.

2. Heating and Cooling of rooms with solar heat and natural (passive) systems.

3. Family size solar stills, 10-15 gallons per day.

4. Solar dryer for the dehydration of agricultural products.

5. Demonstration of a small water pumping unit and power unit for lights, fans and television using solar photovoltaic cells.

6. Desalination.

By now this project is nearing its 50 percent completion. Biogas units at certain farms have also been put into operation by the Energy Resources Cell and the Appropriate Technology Development Organisation. The establishment of a Solar Energy Research Institute is also under the consideration of the Government and some plans, funded by the U.N., for providing energy and power to four villages for demonstration purposes have also been submitted to the Government by the U.N. officials. These funds can be better utilised to set up a facility for the R & D and fabrication of polycrystalline and EFG Process Silicon cell respectingly.

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APPLICABILITY OF SOLAR ENERGY IN PAKISTAN

N.H. QURESHI*

1. In Pakistan the importance of solar energy has been recognized for quite a long time. This was primarily because the country had to face an energy crisis right from its birth. In 1948, the commercial energy-mix comprised coal 59.8% and oil 37.1%. The bulk of the coal was imported from India and due to disruption in supplies the main consumers such as Railways and Industries had to switch over to oil. As the indigenous production of oil was also insufficient, the Government while concentrating their efforts to explore new sources of oil and gas also focussed its attention on R&D efforts to utilize non-conventional sources of energy.

2. The Pakistan Council for Scientific and Industrial Research (PCSIR) initiated the studies but the pioneering work for utilization of solar energy was done during the sixties by the Pakistan Atomic Energy Commission. The Commission worked on the following projects:-

   a. Solar lights for rural areas

   b. Fabrication of silicon solar cells

   c. Solar water pumps

* Director General, Energy Resources Cell, Ministry of Petroleum and Natural Resources, Government of Pakistan.

d. Solar water chillers

e. Solar water heaters

f. Family size water heaters

g. Solar dryers

h. Solar desalination

The activities, however, slackened after some time. But early in the seventies the tempo picked up again in the wake of hike in prices of imported oil, which pushed the country's import bill to over 400 million dollars annually-approximately one third of the total annual foreign exchange earnings. Several agencies became effectively engaged in development work. The Mechanical Engineering Department of Peshawar University has geared up for mass fabrication of solar cookers. The University of Engineering and Technology, Lahore are concentrating on refrigeration based on solar energy. The PCSIR have also initiated R&D work in several aspects of utilization of solar energy. The Energy Resources Cell, Ministry of Petroleum and Natural Resources, charged with the responsibility of promotion of utilization of renewable sources of energy, has given special attention to promote the application of solar energy in sectors where there is a possibility of its utilization on commercial basis.

3. The prospects for solar energy utilization in Pakistan are discussed in two broad categories:-

(1) Application of solar energy in urban areas, and

(2) Utilization of solar energy by rural population.

Application in Urban Areas

4. In the urban areas solar energy can be utilized in the following sectors:-

(1) Cooking,

(2) Heating of water, and

(3) Heating and cooling of buildings.

In urban areas natural gas, liquefied petroleum gas and kerosene oil stoves are commonly used for cooking purposes. A large percentage of the population in urban areas is still using firewood or charcoal made from firewood for cooking purposes. Kerosene oil has to be imported from abroad. The country's forest wealth is also limited. Thus the use of solar cookers could save foreign exchange spent on importing kerosene oil and it could remove some of the demand for firewood. If a suitable solar cooker could be designed to be used in kitchens and could be marketed at a reasonable price, it would have a wide acceptability.

Water Heating

5. In urban areas the house of the middle income group and above are equipped with water heaters based on the use of natural gas or electricity. These water heaters are not only expensive but the recurring costs of natural gas and electricity are substantial. A water heater based on solar energy could have a wide applicability provided its price was within the reach of the middle class.

Heating and Cooling of Buildings

6. The heating and cooling of buildings offers a very wide field for the utilization of solar energy. It could be used extensively in public buildings particularly in the north where the climate is extreme both in winter and summer.

Utilization of Solar Energy in Rural Areas

7. In the rural areas utilizations of solar energy has much wider scope to improve both the quality of life of the villagers as well as their economic condition. Like the urban areas the rural masses could utilize solar energy for cooking purposes as well as for water heating. Apart from the use of solar energy for cooking and water heating the special uses for which the solar energy could be utilized immediately in rural areas have been identified as follows:

Generation of electricity for purposes of

a) Lighting,

b) Pumping of water for

   i) Drinking purposes

   ii) Irrigation purposes

   iii) Reclamation of water logged areas

c) Desalination

8. The conversion of solar energy into electricity by using photovoltaic cells holds great promise for the rural population located in remote areas. In Pakistan there are over 46,000 villages of which about 20,000 villages can be taken to be in those remote areas which are unlikely to receive electricity from the power grid lines. In a village the electricity would be used for lighting, pumping water for drinking and irrigation purposes and providing power for small scale village industries.

Crop Drying

9. Solar radiation has been used from time memorial for drying of various agricultural products like grain, fruits, vegetables, timber, etc. The product to be dried is normally spread on suitable ground or on a platform exposed to direct sunshine. This method of drying is quite simple and cheap where labour costs are not excessive. It is frequently required to turn the product for uniform drying. The drawbacks of this method are contamination by dirt, insects and bacteria and also loss due to wetting by rain. The product is in general not homogeneous and of high quality because there is no control over the drying conditions. However, the moisture content of the product is reduced. To remove this drawback and to ensure that the product is dried to required specifications, two types of system based on the use of solar energy which are being considered are

(1) Direct line glass/plastic cover solar driers, often referred to as natural convecting driers or cabinet driers.

(2) Indirect heated solar driers, in which air heated in a solar air heater is supplied to a separate drying chamber.

These systems would be studied for the drying of serial grains as well as for space heating and other industrial applications.

Reclamation of Water-Logged Areas

10. For fighting the menace of water logging and salinity, the Government is installing tubewells based on the use of electricity or light diesel oil. In such areas, pumps using solar energy could also be utilized. Solar pumps at suitable sites could be installed and their performance, viz-a-viz a diesel engine driven pump evaluated.

Desalination

11. A solar desalination plant was set up at Gwadar with a capacity over 7000 gallons of fresh water per day by the Pakistan Atomic Energy Commission. Experience gained from the operation of this plant has indicated that there are bright prospects for using solar desalination to meet the potable water needs of a large number of settlements along the Mekran Coast, Cholistan and the remote areas of Baluchistan, Sind, Punjab and NWFP. Saline and brackish water are readily available in these areas and there is an abundance of sunshine. Transport of oil or other kinds of fuel would be very costly. As most people in these areas live in small settlements solar desalination would be most attractive for supplying them salt free water for domestic use.

Conclusion

12. Pakistan is a developing country. 50% of its requirements of energy are met by non-commercial energy sources such as agriculture and animal wastes. The remaining half is met by commercial energy. In the fiscal year, 1977 consumption of commercial energy was 44 million metric tons of coal equivalent with the per-capita consumption of

commercial energy at about 193 kilogram of coal equivalent. The per capita consumption of commercial energy is even lower than the average per capita consumption of 300 kilograms recorded for the developing countries and it is nowhere near the world average of 1000 kilograms of coal equivalent. With the population rate of growth at 3% per annum, the supply base of energy would have to be expanded at a much faster rate. Among all the other alternatives solar energy holds a better promise for the future.

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A NATIONAL PROGRAMME FOR SOLAR ENERGY DEVELOPMENT IN THE PHILIPPINES

ERNESTO N. TERRADO*

Introduction

The Philippine's desire to develop its appreciable solar and other nonconventional energy potentials is best viewed against the backdrop of its overall energy situation.

An archipelago consisting of some 7,100 islands, lying between latitudes 5^{o} to 21^{o}, the country has a total area of 300,000 square kilometers. Estimates in 1975 place the polulation at 42.7 million. The 1975 Gross National Product (GNP) stood at 113.4 billion pesos or US$15.1 billion at current prices. This GNP figure is linked to an energy consumption in the same year of 74.4 million barrels (MMB) of oil equivalent, over 95% of which came from imported crude. The only significant commercial indigenous contribution was from hydro-resources. This year, the national consumption figure is expected to hit 83.4 MMB, corresponding to an annual per capita usage of 1.9 barrels.

In 1987 or only ten years from now, the total energy consumption could increase to about 190 MMB. By then, the population is estimated to be about 56 million such that the per capita energy

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consumption shall be 3.4. While this is small by world standards, the energy bill would certainly be an overwhelming burden for the country's economy if the present proportion of imported fule sources is maintained. Presently, oil importation already accounts for some 35% of the country's total import bill.

There is clearly a need for the country to diversify fuel sources and to maximize usage of indigenous energy. Government recognition of this need took concrete form in early 1976 with the establishment of the Energy Development Board (EDB) by Presidential Decree No. 910 which also declared it a policy of the state "to achieve self-reliance in the country's energy requirements". The EDB functions were to formulate policies, establish programs, administer, regulate and implement activities for the exploration, exploitation and development of fossil and nuclear fuels, geothermal resources and "Other less conventional forms of indigenous extracted energy resources".

A National Energy Plan was subsequently drawn up in the latter part of 1976 which, for the first time in the country's energy planning exercises, officially considered non-conventional energy resources, such as solar energy, as having significant contributory potential. This recognition was further formalized by Presidential Decree No. 1068 which directed the EDB to "accelerate the research, development, demonstration and utilization of non-conventional energy". A later decree, Presidential Decree No. 1206, which expanded the EDB into a Department of Energy carried over all pertinent provisions of PD 1068. Nonconventional energy was defined as being mainly solar energy, with the important categories of direct solar, wind and biomass energy.

As a major policy consideration, it was recognized that the fragmented nature of the Philippine Islands makes localized energy sources, such as solar, extremely relevant. It was also recognized that the geographical situation of the country has imbued it with abundant solar energy and biomass resources.

Resource Potential

Based on weather bureau data for the Metro Manila area taken 1960 to 1964, the average insolation for the country is about 400 cal/ cm^2 per day with yearly bright sunshine totalling over 2000 hours. The humidity, however, is rather high and averages about 85%. For direct solar applications, systems using flat-plate solar collectors are probably more generally suitable than those using concentrating collectors.

Available wind data show that there are many areas in the Philippines with wind speed exceeding 10 kilometers per hour. Some of the places with consistently strong winds are Basco, Batanes; Cuyo, Palawan; and Iloilo, Panay with winds averaging over 17 kph all year round. The number of such sites are numerous enough to warrant a wind energy utilization program for water-pumping and low-power electricity generation.

One problem with wind-energy usage in the Philippines is the fact that most of the places with high mean wind speed are also those with high incidence of tropical cyclones. On the average, about 19 tropical cyclones pass through the country each year, some of which possess center winds exceeding 200 kph. Ingenious "typhoon-resistant" designs are clearly needed, including perhaps systems which can be dismantled conveniently before the typhoon strikes and reinstalled easily after it has passed.

Undoubtedly, the largest solar energy potential (indirect) in the country occurs in the form of biomass resources which we define here to include agricultural and forestry wastes, trees, animal manure, etc. Whether burned directly or converted to solid, liquid and gaseous fuels, the energy content of these sources are, of course, traceable back to solar energy fixed by the process of photosynthesis.

Agricultural and forestry wastes, in particular, appear to have the largest potential. By direct burning of bagasse, coconut shell and husks and sawmill wastes, the agro and wood-processing industries in the Philippines generated power and process heat in 1976 equivalent to about 7 MMB of oil or about 8% of the country's total usage of commercial energy at that time. The amount of waste utilized by these industrial uses represents only about 12% of the total agro-forestry wastes being produced in the country. Estimates indicate that the total figure could be about 3 million tons or an oil equivalent of 60 MMB. Conceding that the larger portion of this total may be really unavailable or unusable, the remaining portion is definitely still of such magnitude as to merit serious plans for further large-scale utilization.

Man-made forests or energy plantations represent another immense potential biomass resource. The tropical forests of the Philippines are decidedly more productive than equivalent areas in the temperate zones. In terms of the giant "ipil-ipil" species (leucena leucocephala), which is receiving considerable attention in the Philippines today, the yield averages about 27 bone dry tons per hectare per year. With a heating value of 8144 Btu/lb., the energy equivalent of a million barrels of oil is in principle obtainable yearly from about 12,000 hectares of ipil-ipil land. A recent study revealed that at least 300,000 hectares of marginal lands, i.e., not suitable for conventional agriculture, are available in the Luzon and Visayas area alone. Planted totally to ipil-ipil, the energy potential would be about 28 MMB yearly.

Sugar cane is, of course, well-known to be a high yielding biomass crop. The fermentation of cane juice to ethanol could be a major source of fuel from this crop. If 15% ethanol is mixed with gasoline, (the blend is called "Alcogas" in the Philippines), the nationwide effect (1977 demand) would be a displacement of 2.25 MMB of gasoline or a foreign exchange savings of about US$30 million a year.

Considering animal manure, it is estimated that about 13 million metric tons of cattle, carabao, hog and chicken wastes are produced yearly in the country. Converted entirely to biogas, the energy equivalent would be about 3 MMB of oil. The potential biogas contribution could be increased by the use of sewage and human waste, although no significant work in this area is currently being done in the Philippines.

In addition to the solar energy potential, other non-conventional resources, which are more site-dependent, offer the possibility for significant energy contribution if properly utilized. These include Natural Hot Springs and Surface Gas Emanations.

The Philippines is a volcanic country and has considerable geothermal resources. Geothermal <u>steam</u> for large-scale power generation is a current major activity of the country's National Power Corporation. Associated with the geothermal fields are hot spring sites, many with water temperature close to $100^{o}C$. Depending on the proximity of such sites to rural communities, there appears to be tremendous potential for utilizing these hot springs for crop drying, refrigeration and low-power generation.

Similarly, low-pressure surface gas emanations (including both marsh gas and small natural gas fields) abound in the country. Over a hundred sites, many of which are situated inside population centers, have been identified. The gases are usually emitted along with artesian well water and often contains over 95% methane.

Development Policies and Strategies

The considerable resource potentials described in the preceding section are hoped to be tapped by applying various conversion technologies. Some of these technologies are still in the research and development (R & D) phase. Others are in the "demonstration" phase—that intermediate stage between the laboratory and practical use. A surprisingly large number are well-developed but, for various reasons, have been applied sparingly or have been left to gather dust, so to speak. One major reason, of course, is the long era of cheap oil which suppressed most initiatives to utilize other alternatives.

In a country with scarce financial resources, R & D is essentially a luxury; emphasis in a development program must be on relatively well-established or available technologies. However, it is not wise nor feasible to entirely avoid R & D involvement. It is thought that the key is to be highly selective and to lean as much as possible to adaptive R & D work.

It is not difficult to identify conversion technologies which, although potentially useful to the needs of a country like the Philippines, require sophisticated, capital-intensive activities in order to sustain an effective level of R & D. Large-scale Solar Thermal conversion systems (solar to heat to electricity) and Photovoltaic Electric Power Systems are two examples in this category. Both require an industrial base that can turn out precision lenses, special refractory materials and semiconductors. The goal of drastically lowering the cost of solar cells, either by using new materials or novel mas-manufacturing processes is clearly out of the Philippine context. It is very unlikely that local efforts could significantly contribute, much less make a breakthrough, in this R & D area. In this case, it is thought that the better strategy is to keep close watch of progress abroad and transplant desirable technology to Philippine soil as soon as it is ripe and ready.

What is more difficult in program-making is the ranking of project areas identified as relevant. In the Philippines' case, there are two primary considerations. The first is that government policy puts a high priority to rural development. Thus, non-conventional energy applications which would redound to the benefit of rural dwellers, which incidentally comprise the majority of our population, are clearly of utmost importance.

The second consideration is the fact that most relevant rural applications of non-conventional energy technologies do not really displace imported fuels to a significant degree. For example, the introduction of a solar dryer often complements only or substitute for direct sun drying of crops or foodstuff. That there are real benefits is unarguable: the products of solar dryers have better quality or longer storageability and this could mean more income for the user. The same situation holds with say, the introduction of a water-pumping windmill in a remote site where water is hauled manually or by means of a simple hand-pump.

The sociological benefits of such rural applications and their long-term cumulative effect on the country's economy cannot be discounted. In terms of aggregate energy output, however, the figures do not seem significant. A hundred small-scale solar dryers may have the annual energy equivalent of only 70 barrels of oil; a hundred 1-kW windmills the equivalent of only 900 barrels.

The overall Philippine program on energy development is premised on the desirability of reducing the usage of imported energy. The effectiveness of a fuel substitution program whether it is for coal, geothermal or solar, is therefore gauged by the dent it makes on the total oil usage. The problem is that it is very difficult for a non-conventional energy program focused solely on village-level applications to make a sizeable reduction on oil import figures.

For this reason, equal development emphasis is planned for applications which may be urban-based but which nevertheless have potential large-scale output. Two such applications are industrial solar water heating and the use of "Alcogas" for motor fuel. Each of these applications, is fully exploited, can displace oil consumption in the order of a million barrels annually. Table I shows a list of identified priority project areas grouped in their rough order of importance. The development program itself would call for the dispersal or ready systems (e.g., biogas digesters), techno-economic demonstrations of available technologies (i.e., industrial solar water heaters) and adaptive R & D of less-developed conversion systems.

Table 1 Priority Project Areas

<u>Evaluation of Potentials</u>

- Nonconventional Resources Survey
- Solar/Wind Monitoring Network

<u>Available Technologies: Large-Scale Output</u>

- Power & Fuels from Agro Wastes
- "Alcogas" for Motor Fuel
- Energy Plantations/Wood-Thermal Plants
- Industrial Solar Water Heating

<u>Available Technologies: Rural Emphasis</u>

- Biogas from Rural & Urban Wastes
- Windmills for Water Pumping & Low-Power Electricity
- Solar Crop Dryers
- Solar Stills
- Utilization of Surface Gas Emanations
- Utilization of Natural Hot Springs

<u>Others: More R & D Required</u>

- Solar Refrigeration
- Solar Pumps
- Solar Power, etc.

The project area under "Power and Fuels from Agro-Industrial Wastes", for example, would call for a nationwide extension of the present practice of industrial burning of wastes for heat and power as as well as the introduction of bioconversion techniques (new and old) to process wastes also into gaseous and liquid fuels.

The areas under "Evaluation of Potentials" are merely supportive in nature but are nevertheless vital in providing baseline data and information not only at the beginning of the program but continuously.

Implementation

The Programme is envisioned to be a continuing process which shall be reviewed periodically in order to update priorities and program thrusts. The basic element is a series of specific projects in the various non-conventional energy areas which shall be supported primarily by government funds in the initial phases. Table 2 is a list of current RD & D projects. The share of private sector spending for development projects would hopefully increase as feasibilities are established and as pilot system approach the commercialization stage.

Table 2 Non-Conventional Energy Program Current RD & D Projects (1977-78). Total Funding: ₱10 million

1.	Direct Solar		
	1. Solar Airconditioning	-	Bureau of Energy Development (BED)
	2. Solar Test Facility	-	BED
	3. 10 kW Solar Power Plant	-	BED/Germany
	4. Solar Water Heater for Dairy Plant (2500 gal)	-	San Miguel Corporation
	5. Solar Water Heater for Hotel (1500 gal)	-	Zamboanga Factors
	6. Domestic Solar Water Heater Dispersal Project	-	BED
	7. Solar Distillation	-	University of the Phils. UP/Bureau of Animal Industry (BAI)
2.	Wind Energy		
	1. Wind Power for Radar Station	-	PAGASA (Weather Bureau)
	2. Hybrid Rural Windmill	-	Project Santa Barbara (PSB)
3.	Biomass Energy		
	1. 500 kW Dendro-Thermal Power Plant	-	National Power Corporation
	2. Pyrolysis of Wastes	-	BED/UP/Georgia Tech.

3.	Producer Gas from Wastes for Irrigation	-	UP/National Irrigation Authority
4.	Regional Demonstration Biogas Plants	-	B A I
5.	Biogas Utilization for Internal Combustion Engine	-	Maya Farms
6.	Economic and Net-Energy Analysis of Biogas Systems	-	National Institute of Science and Technology
7.	Integrated Biogas System Using Cow Manure	-	B A I
8.	Anhydrous Alcohol-Pilot Plant	-	P S B
9.	Rural Electrification Using Wastes	-	Economic Development Foundation
10.	Continuous Flow Drying System Using Rice Hulls as Fuel	-	UP Los Baños
11.	"Alcogas" for Motor Fuel	-	Philippine National Oil Company

4. <u>Integrated Rural Systems</u>

1.	Integrated Energy System for Island Community	-	Human Settlements Commission (HSC)
2.	Alternative Energy-Sources for a Rural Food Processing System	-	PSB/Barangay Teknolohiya
3.	Alternative Energy System for a Rice Producing Community	-	H S C
4.	Commercial Waste Conversion System	-	H S C

5. Hot Springs

1.	Design of 10-kW Hot Spring Power Plant	-	De La Salle University
2.	Drying of Agricultural and Fishery Products Using Hot Springs	-	UP Los Baños
3.	30-kW Hot Spring Power Plant	-	B E D

6. Surface Gas

1.	Utilization of Surface Gas Emanations at Libon, Albay and Minalin, Pampanga	-	P S B

7. Supportive Projects

1.	Comprehensive Energy Resources Survey	-	BED/National Census
2.	Non-conventional Energy Public Information Program	-	B E D

The participation of the private sector is recognized as one of the most crucial elements in the Programme. Various approaches are being taken to encourage such participation. In Presidential Decree 1068, for example, there is a provision for tax incentives to the private entity "who would install non-conventional energy devices for use in their home or business establishments". Under this provision, a home-owner who installs a solar water heater in his home may be allowed to treat his investment as deductible expense from his gross income.

This incentive provision is hoped to stimulate the early appearance of a local solar energy industry. Except for one or two backyard-scale solar water heater manufacturers, the country has presently no solar industry to speak of. The present impasse is due to a vicious-circle situation: solar energy devices often have high "first costs" which discourages users from shifting away from conventional systems. A market for non-conventional energy devices opened up by tax incentives, would hopefully encourage the local mass-manufacture of such devices and thus bring down their cost.

Together with a continuing public education and promotional drive, the above implementation strategies are hoped to enable the attainment of ambitious fuel-substitution targets that have been set for the long-term even as more modest but nonetheless significant benefits are realized in the near term. With a sustained development program, it is believed that non-conventional energy sources could account for some 8% of the Philippines total energy requirement by 1987 or an equivalent 15 MMB of oil.

Seminar on the Applications of Solar Energy in South and South-East Asia
19-23 February 1979, Bangkok

RESEARCH AND DEVELOPMENT ON SOLAR ENERGY IN SINGAPORE

A COUNTRY REPORT

LEUNG SHIU KEE*

Energy Utilisation

The energy requirements in Singapore are almost totally met by imported petroleum products, about 40 per cent of which is for electricity generation. In 1976, the electricity consumption per capita was 1,772 kWh and is now increasing at a rate of about 10 per cent per annum.

About 33 per cent was utilised for manufacturing processes, 18 per cent for lighting (including street lighting), and 28 per cent for air-conditioning. There has been concern over the rising cost of energy production in the past few years; the policy of the Singapore government is to stress energy conservation rather than development of alternative forms of energy.

Solar Energy Data in Singapore

Solar technology in Singapore, like in many other countries, is still in its infancy stage. However, its potential applications in the country and the immediate surrounding regions are well recognised.

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It might be mentioned here that solar radiation recorded in the meteorological station shows a fifteen year average of 4.32 kWh/m^2 (432 mWh/cm^2, 371 cal/cm^2 or 15.5 MJ/m^2) per day, with the highest and lowest monthly averages in March (4.82 kWh/m^2 per day) and December (3.69 kWh/m^2 per day), respectively. Thirty per cent of the days in a year receive between 4.00 and 5.00 kWh/m^2 per day of solar radiation; another 30 per cent receive more than 5.00 kWh/m^2 per day. The general climatic conditions are certainly favourable to the tapping of solar energy.

Past and Present Research and Development

Studies on solar energy with a view to tapping it as an alternative energy source have not been conducted on a long term basis. Elementary displays such as solar distillation setups have appeared in student exhibitions of secondary schools and the Singapore Polytechnic, but work that is anywhere close to research and development in nature is done mostly as degree projects at the University of Singapore, which comprises the only Faculty of Engineering and Faculty of Architecture and Building Sciences in the country. Instruction on solar energy applications is also found at the University in the form of one of the topics in energy conversion courses given by the Mechanical Engineering and Electrical Engineering Departments. The effect of solar energy on building design is naturally a topic in the architecture curriculum.

It would be of interest to review briefly the formal research projects carried out to date. Of nineteen reports on research related to solar energy submitted to the University of Singapore, all but one (an M.Sc. dissertation) are based on undergraduate projects completed in the past five years: three from the Chemistry Department (Applied Chemistry, now Chemical Engineering), fifteen from the Mechanical and Production Engineering Department. A breakdown of the number of reports by research areas shows three on environmental data, five on collector design, seven on water heaters, one on solar still, one on solar refrigeration, and two on windmills. Details of these are shown in the Appendix. The timing of projects and distribution of project areas reflect well the interest and activity of energy researchers in Singapore, most of whom are university lecturers who supervised these projects. Presently, staff members of the Department of Building Sciences are also investigating the building aspects of the usage of solar water heaters and other devices.

Apart from projects originated at the University, the Ministry of Science and Technology currently sponsors, under its Research Grant Scheme, a project on solar powered air-conditioning. The project, undertaken by staff of the Mechanical and Production Engineering Department, includes the design, testing and analysis of the performance of a solar powered air-conditioning system, and aims at establishing the technical and economic feasibility of the system under local weather conditions.

Another study related to solar energy, namely the investigation of energy conservation in buildings, is currently in progress; it is sponsored by the Building Control Division of the Ministry of National Development and again involves staff of the Engineering and Architecture Faculties.

Research and development work on solar energy is known to take place at the Singapore Institute of Standard and Industrial Research (SISIR). SISIR is working on the economics of flat-plate solar energy collector production with the ultimate aim of evolving a locally manufactured collector system which would be relatively less costly to produce. This entails monitoring of the performance of collectors built from cheaper materials and simple in construction.

<u>Solar Energy Applications</u>

Actual solar installations in Singapore are few in number. As a matter of fact, the establishment of a commercial agent for solar water heaters or the announcement of intention of incorporating such heaters in proposed buildings has never failed to appear as a news item in the local press. There have been a few isolated cases of home use of solar water heaters in the past, significant scale came only within the past year. To date it is known that a solar water heating system is in operation in the 30-bed St. Mark's Hospital; all the other installations will be in proposed buildings: a shopping complex in Upper Thomson Road, blocks of 32 private apartments at Faber Hills, and a 750-bed University teaching hospital at Kent Ridge.

It is generally felt that unfamiliarity with the potentials of solar devices, together with retro-fitting costs for existing buildings, are the main reasons for the low appeal of solar heaters among Singaporeans.

Solar water heaters available on a commercial basis in Singapore are all of the flat-plate type and foreign design; some of these are assembled locally. At present, there are four local manufacturers that import parts or whole units from Australia, New Zealand and Israel. These are joint ventures that rely on both foreign technology and foreign markets.

It would be interesting to see to what extent the work carried out by SISIR, described earlier on, might interact with the functioning of these manufacturers. No fabrication or adoption for use of other solar devices on a regular or commercial basis is known so far.

Conclusion

In Singapore, solar energy development is not a high priority item in official energy strategies. As pointed out at the Asian working Group meeting, it may be necessary at the present stage for government to provide financial incentives if solar energy is to make a significant impact as an attractive energy supply in countries of this region. Given sufficient official support, Singapore has the potential to develop and benefit from a framework for research, development, and production of solar energy devices and systems for both home and foreign applications. The cooperation among scientists, engineers and industrialists of the region is essential for the realization of this potential.

APPENDIX I

LIST OF PROJECTS ON SOLAR ENERGY COMPLETED AT THE UNIVERSITY OF SINGAPORE (UP TO 1977)

Environmental Data

A1. Tan, B.C., An investigation of solar radiation at Singapore. Physics Department, 1963.

A2. Leong, J.C., and Soh, N.T., An investigation of solar radiation at Singapore. ME Dept., 1973.

A3. Chee, C.S., and Tan, L.K., Study of solar radiation information for solar energy utilization. ME Dept., 1977.

Collector Design

B1. Koh, C.L., and Ong, K.W., Testing of performance of three types of solar collectors. ME Dept., 1976.

B2. Chew, K.W., and Tng, T.L., Design and construction of solar tracking system. ME Dept., 1976.

B3. Ng, K.L., and Ng, K.S., Evacuated tube solar collector. ME Dept., 1977.

B4. Chou, S.K., and Chua, C.C., Analytical studies on a flat-plate solar energy collector. ME Dept., 1977.

B5. Loh, K.W., and Mui, C.H., Experimental studies of flat-plate collectors. ME Dept., 1977.

Water Heater

C1. Chan, C.K., Storage of energy in a solar water heater. Chemistry Dept., 1973.

C2. Seow, C.M., A preliminary study of storage chemicals in solar water heater. Chemistry Dept., 1974.

C3. Ong, B.L., A preliminary study of energy storage in sodium thiosulphate pentahydrate crystals for solar water heater. Chemistry Dept., 1975.

C4. Tan, K.H., and Tang, K.F., Cylindrical solar water heater, ME Dept., 1973.

C5. Tay, K.L., and Koo, W.Y., Solar water heater with natural circulation. ME Dept., 1974.

C6. Lim, H.B., And Tee, S.S., Design studies on a full size solar water heater with once through circulation mode for domestic use. ME Dept., 1975.

C7. Goh, G.H., and Kang, S.G., Solar water heater using parabolic reflectors. ME Dept., 1976.

Refrigerator

D1. Lee, L.P., and Lee, S.L., Preliminary analysis, design and construction of a solar powered refrigerator. ME Dept., 1974.

Still

E1. Ong, C.K., and Lim, K.K., Direct solar still. ME Dept., 1973.

Windmill

F1. Tan, K.C., and Tan, T.L., Windmill: model study and analysis of wind data. ME Dept., 1976.

F2. Ho, K.F., and Ho, T.W., Analytical and experimental study on horizontal axis windmills. ME Dept., 1977.

(c) Research into the exploitation of Solar, Wind, Biomass and other non-conventional sources be enhanced.

and (d) Assistance be welcome from International organizations to promote these facilities.

10. Acknowledgements

The participants wish to express their gratitude to Co.M.E.S. for sponsoring this important Seminar & to the A.I.T. for hosting the Seminar. Our participation at the Seminar was made possible through the generous assistance of the C.N.R.S. as well, with the cooperation of the Cultural section of the French Embassy in Sri Lanka. We wish to thank them and the Government of Sri Lanka for affording the opportunity to participate at the Seminar.

APPENDIX II

PAPERS ON SOLAR ENERGY RELATED TO SINGAPORE

1. Chia, L.S., "Sunshine and Solar Radiation in Singapore", The Meteorological Magazine, Vol. 98, No. 1166, 1969.

2. Tan, K.J., and Goh, T.N., "Solar Insolation in an Equatorial Region (Singapore)", Solar Energy, Vol. 19, No. 1, 1977.

3. Lim, B.P., and Rao, K.R., "The Environmental Control of Building", Journal of the Singapore National Academy of Science, Vol. 6, No. 1, 1977.

4. Nathan, G.K., Rajasooria, G.P.D., Tan,K.C., and Tan, T.L., "Prospecting for Wind Power in Singapore", Proceedings of 3rd IES/IEM Engineering Convention, Singapore, 1977.

5. Tan, K.J., and Goh, T.N., "Design Data for Solar Water Heaters in Singapore", IES Journal, Vol. 17, No. 1, 1977.

6. Rao, K.R., and Lim, B.P., "Solar Energy Availability at Singapore", Proceedings of 7th International Solar Energy Congress, New Delhi, 1978.

7. Goh, T.N., and Tan, K.J., "Solar Radiation Studies for Utilization of Flat-Plate Collectors in an Equatorial Region", Proceedings of 7th International Solar Energy Congress, New Delhi, 1978.

Renewable Energy Resources Information Center

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Editorial

The considerable amount of literature being published worldwide on renewable energies makes it very difficult to be kept properly informed on what has been recently achieved or on what is going-on in that field. It also results in much confusion as to the present real status of the various technologies involved, a question of utmost importance for developing countries which need to know very clearly what appropriate technologies are immediately applicable and what still need additional developments for economical practical utilization.

RERIC's objectives are to improve awareness of available information mainly through its newsletter "RERIC NEWS" and to contribute in clarifying the applicability of existing appropriate technologies through state of the art and review papers published in its "Renewable Energy Review Journal"

To perform those two functions efficiently RERIC requires the contributions of its readers in several ways: by sending in any type of information or news items for insertion in the newsletter, by providing RERIC with copies of relevant documents both published and unpublished, by writing state of the art papers for publication in RERIC's review journal. Such contributions will benefit all our readers and make RERIC publications what they are planned to be: a forum for exchanging information and ideas. The value of what you will receive from RERIC is directly linked to the quality and volume of your own contributions to its activities. Please remember to be more than a reader of RERIC's publications but become also a participating member, for your colleagues and for your own benefit. Thank you!

The Editors

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LIMITATIONS AND PROSPECTS OF SOLAR ENERGY UTILISATION IN AN URBAN AREA OF THE HOT HUMID ZONE

BILL B.P. LIM*, K.R. RAO**
AND SUTHIPUNTHA SUJARITTANONTA***

Solar Radiation Availability in Singapore

The Republic of Singapore consists of the island of Singapore and some smaller islands within its territorial waters. Due to its island maritime climate, cloudy conditions prevail, and sunshine hours are limited to an average of 5.6 hours per day.

The Meterological Service in Singapore has been measuring the total solar radiation for some years. The monthly average daily total solar radiation varies from 3.81 kWh m^{-2} d^{-1} in December to 4.96 kWh m^{-2} d^{-1} in March. The annual mean daily total radiation is about 4.46 kWh m^{-2} d^{-1} for 66.5% of the days. The year to year variation of the monthly mean radiation is of the order of 10 to 15 per cent over the 10-year average value. The average daily mean radiation intensity at mid-day lies between 550 and 700 Wm^{-2} and the distribution pattern of radiation flux throughout the day is generally symmetrical with respect to noon.

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The Department of Building Science, University of Singapore, monitored the total and diffuse solar radiation for about 12 months for the purpose of separating the direct and diffuse radiation measurements.

It was found that the diffuse radiation occupies a substantial proportion of the total solar radiation. The recording also shows that the diffuse radiation varies little with the amount of cloud present, indicating that diffuse radiation is fairly predictable throughout the year. It may be concluded that flat-plate collectors which absorb the total radiation from the sun and the sky are more effective than concentrators which are more appropriate in areas where direct radiation is predominant.

Energy Consumption in Singapore

Since the industrialisation programme in Singapore from the early 1960's, the annual growth rate of electricity consumption has exceeded 15% until 1973, when a nation-wide "Save Energy" following the oil crisis of November 1973 reduced this rate to 3.69% in 1974. However the consumption rate increased again to 7.21% in 1975. Since Singapore imports all her fuel oil, it is certainly to the national interest to save energy.

Air-conditioning consumes much of the energy available. It is estimated that this single item takes up 25-30% of the total electricity units consumed (Ref. 1). Air-conditioning is used in office buildings, shopping complexes, certain industrial establishments, and apartments and homes. In a typical high-rise office building, for example, the following percentages are often found (Ref. 2):

Air-conditioning	($40W/m^2$)	55%
Lighting	($18W/m^2$)	25%
Others (lifts, electrical appliances, etc.)	($15W/m^2$)	20%

In domestic buildings which are mostly high-rise, electricity consumption due to cooking, hot water, and lighting is not considered excessive. No space heating is required. However, room air-conditioners are used to cool spaces such as bedrooms, and a "window-unit" of 2-HP (1491.4 W) is often used to cool a space of 100 m^3. This is likely to double the electrical consumption of a household if only one such unit is used for 8 to 10 hours per day. If domestic air-conditioners are used extensively, there will be a sharp increase of electrical demand, thus making further strain on the power stations which has been estimated to be S$700 million (US$335 million) for 1,010 MW (Ref. 1, 1976). As "window-units" are usually added to the rooms after the completion of the buildings, oversized wiring systems must be provided in the beginning in anticipation of future installation, thus the overall costs of construction are increased.

Power consumption by air-conditioning of commercial buildings may be reduced by better "house-keeping" and management, such as switching-off during lunch hours, operating at half-capacity in the beginning of the day when the buildings are cooler, and regular maintenance of equipment. For new buildings, guidelines are now drawn up for designers to provide adequate insulation ventilation and lighting with specific reference to energy conservation. For example, the Overall Thermal Transfer Value (OTTV) proposed by the ASHRAE (Ref. 3) is introduced as a standard of calculation of thermal insulation for air-conditioned buildings, and maximum "U"-values are stipulated for roofs and walls of non-airconditioned buildings.

Active Systems and Their Applicability in Singapore

Active solar energy systems involve many complex components. Elaborate collectors collect solar energy and convert it to heat. A fluid, either air or liquid, conveys this heat to a heat exchanger or to storage. Such a system requires mechanical means such as pumps or fans to circulate the fluid, and efficient methods of heat exchanger and storage are required.

As there is no requirement for space heating in Singapore, active systems would firstly find their application in space cooling of buildings, and secondly in heating of large quantities of water or gas (including air) for industrial use. In cooling, of the many refrigeration methods presently used in air-cooling systems, three are considered to be possible under Singapore conditions as follows:

(a) Compression

Solar energy can be utilised to produce motive power which in turn is used to drive a compression-type of air conditioner. The conversion usually takes the form of a Rankine cycle or Stirling cycle engine. However, neither of the machines are commercially available.

(b) Solar absorption cooling

Solar collectors can be used to provide heat for an absorption cooling system. A low temperature of about $4.5^{\circ}C$ may be obtained which is suitable for space cooling. Such systems work best with fluid temperatures between $120^{\circ}C$ and $150^{\circ}C$, a level at which normal flat-plate collectors are less efficient. Concentrating collectors are thought to be particularly suited to absorption cooling because they can provide high temperatures with relatively high efficiencies. However, a lower temperature unit may operate satisfactorily with a fluid temperatures between 60°C and 100°C.* This means that flat-plate collectors with selective surface coating and double glazing can be used.

(c) Solar desorption and evaporative cooling

Evaporative cooling occurs when water vaporizes. In Singapore the air is generally too humid and hence the evaporative cooling will not be effective. However as the Solar desorption and evaporative cooling system employs a process of dehumidification to provide dryer air, which thus increases the evaporation rate. Desiccants such as silica gel or triethylene glycol are used. A simple system has been tested at the Turkmenian Academy of Science laboratories at Achkabad** using the absorbent property of lithium chloride solution (in water). The solution flows over a solar-heated roof. Some of the water evaporates so that the solution becomes more concentrated. It is then sprayed into an air stream, where it absorbs moisture. This dehumidified air stream can also be used to produce chilled water by evaporative cooling.

* Solar absorption cooling units available commercially include York, Arkla Industries, U.S.A. and Yazaki Buhin, Japan.

** Reference is made by S.V. Szokolay to Baum, V.A. et al, Utilization de l'energie Solaire dans les Conditions particulieres des regions a climat torride et aride pour la climatisation en ete. paper EH96, Sun in the service of Mankind Conf. Paris, 1973.
Szokolay, S.V. Architectural Science Unit Review 1, April 1975 University of Queensland, Brisbane, Australia.

None of the above-mentioned methods have been used in Singapore. As an experiment, an Arkla-Servel solar powered absorption Unit (10 kW) is now being tested at the Faculty of Engineering, University of Singapore. Some of the reasons for the lack of interest are as follows:

(a) The amount of solar radiation actually available in Singapore has not been fully understood, and approximate estimate of solar energy would not be reliable in the evaluation of the efficiency of the system to be used.

(b) The marketing of solar cooling system is difficult as conventional systems are already highly competitive.

(c) Solar cooling systems have not been proven, and designers and developers are reluctant to use them.

(d) Capital costs of solar systems may be higher than that of conventional systems. For speculative-type development it is more beneficial to keep the initial costs down, even though the running costs and energy consumption are higher when the buildings are in use.

(e) Large span of roof areas are required for the installation of flat-plate collectors. This is not often possible, due to the restricted roof space, to accommodate these collectors in addition to the normal services such as water tanks.

(f) There is a lack of local expertise to adapt systems designed overseas for specific projects under local conditions. There is also insufficient experience locally to maintain solar systems.

(g) The cost-effectiveness at current prices is still doubtful.

Passive Solar Cooling Systems and Their Applicability in Singapore

The passive solar energy systems require fewer controls and are less complicated than the active systems. Heat flows by natural convection the systems can function without external power sources.

In these systems solar energy can be used in the following ways:

(a) Solar induced ventilation by the chimney effect

Solar energy is used to induce air movement through an occupied space. The movement is created by temperature difference between two surfaces, one of which is heated by the sun. For example, a southern wall of concrete warms the air in front of it in summer, causing it to rise and escape through vents at the top of the wall. This "make-up" air can be cooled further by drawing it through an underground duct.* Dampers are used to control the air flow. The layer of glass may be substituted by a panel with an air cavity, and styrofoam beads are blown into the cavity from a storage drum on cloudy

* This may be seen at the Jackson House, Western Tennesseė by Lee Porter Butler. (Ref. 5, p. 110)

days to prevent heat loss.[**]

A modification of this is the Altenkirch solar house in Israel built in the 50's where the follow east and west walls were filled with absorbent material and arranged so that air could flow vertically. In the morning the east wall is heated by the sun, and a vertical flow of room air is induced in the wall.[***] The air regenerated the sorbent material. At the same time, outside air was drawn vertically through the west wall where it was dehumidified before passing an evaporative cooler matrix at the top of the wall. In the afternoon, the heated west wall became the regenerator as it received the solar radiation and the air flow was altered by the central valve. (Ref. 4).

** This is seen at the Odeillo residences and the Tyrrell House. The Odeillo House, designed by Jacques Michel, uses a Trombe wall solar heating and cooling system. Collector-walls are made of concrete, and are faced with glass. The Tyrrell House, near Manchester, New Hampshire, designed by Total Environment Action Inc., uses two sheets of Sun-Lite (a fibreglass-reinforced polyester manufactured by the Kalwall Crop. of Manchester, New Hampshire) and the cavity is filled with styrofoam beads, known as Beadwall. (Ref. 5, p.124-125)

*** In summer hot air from a sun room escapes through a vent at the roof peak, and is replaced by earth-cool outdoor air which flows into the house through an underground pipe that feeds into the subfloor ductwork. The warm moisture-laden air drips some of its water as it cools, thereby lowering the humidity. (Ref. 5, p.110-111).

The above methods appear to be more applicable in a hot arid climate where the windows are small and wall areas are large. In the hot humid zone where the emphasis has been to provide natural ventilation and to utilise on-coming cooling breeze, wall areas may not be sufficient. It is then necessary to show that the passive solar system is more effective than natural ventilation. Moreover, the cooling effect would be nullified if shadows are cast on the walls by neighbouring buildings - a situation which is difficult to avoid in an urban area. In areas where outdoor conditions in the summer are relatively mild, the system may be workable. However, with maximum mean outdoor air temperature at 30^{o}C and annual mean daily maximum relative humidity at 96% in Singapore it is doubtful whether the inducement of outdoor air would be sufficient to provide thermal comfort without increasing the velocity of the air stream. Thus the chimney effect is to provide natural ventilation only, and cross-ventilation by ordinary windows may be just as efficient.

(b) Nocturnal cooling

Warm objects lose their heat to the cooler night sky by radiation. One of the simplest methods employing this principle is the Skytherm design patented by Harold Hay (Ref. 5). The water-filled plastic bags were installed on the flat roof covered by the movable insulating panels. In summer, these panels are open at night allowing the bags to cool by radiant cooling. The panels are closed during the day to trap in the "coolness" and to shield the bags from solar heat. In Singapore, though the day-time temperature is high (average daily mean temperature 30^{o}C at noon), the minimum daily mean temperature is 24^{o}C, which is the normal design temperature for air-conditioned buildings. It is uncertain whether nocturnal cooling could be applied in Singapore with such a high night-time temperature and the high cloud amount present in the sky. Also, in a high-density urban development such as Singapore where high-rise housing is extensively used, the heat loss of building fabrics after sun-set would not be as effective as in rural areas since tall buildings at close proximity act as "heat-traps"

Application of Solar Water Heaters

Solar water heaters have been used in domestic building for about five years. Installation are mainly of the flat-plate absober type with insulated water tanks, and thermal syphon enables satisfactory flow of water in the system without the use of pumps if the tanks are placed above the absorbers. The advantages of solar water heaters to be used in Singapore may be summarised as follows:

(a) Diurnal temperature difference is small (7-8^{o}C) and annual temperature variation is also negligible (3^{o}C). Water remaining in the collectors overnight does not take long to heat up in the morning.

(b) There is no freezing problem, and no anti-freeze agents are necessary. In some temperate countries the use of anti-freeze agents often result in corrosion of metal pipes.

(c) Water supply in Singapore is relatively free from excessive mineral content, and the water is not considered "hard". Water softeners, filters, and anti-rust agents are not normally used in domestic installations of small households. (However, in some industrial or commercial installations cathodic protectors are used).

(d) As there is no space heating required, high temperature is not necessary. Indeed experience shows that very often even the stipulated design water temperature of $50^{o}C$ may be reduced somewhat if the hot water is only used for bathing, washing, and other domestic needs.

An experimental unit at the Department of Building Science, University of Singapore, has been tested. The commercially available unit consists of two flat-plate collectors of 1 sq. m. each and a 30 gallon (136.5 litres) storage tank. During the period of testing (April and May, 1976) the maximum solar radiation varied between 4.5 to 1 kW hr/m^2 with an average of 3 kW hr/m^2. For a design temperature of $50^{o}C$ the booster was activated from time to time by a built-in thermostat. The electrical consumption was 1.2 kW hr. If the water was heated entirely by electricity, the power required would be 3.52 kW hr. Thus the saving was 2.3 kW hr., or 65% of the total consumption. Further saving would also be possible if the design temperature was lowered, as domestic hot water in the tropics may not be necessarily be $50^{o}C$.

At present several domestic systems have been in use. One private hospital has installed a unit to supply 300 litres of hot water to a small wing. A private golf club has the capacity of providing 1000 litres of hot water to their members.

On the other hand, there are also some difficulties in the use of solar water heaters as follows:

(a) Situated about $1\frac{1}{2}^{o}N$, the summer and winter solstices for Singapore are approximately symmetrical about the zenith. Consequently the sun is apparent for 6 months on the southern side, and in the other 6 months on the northern side. It follows that flat-plate collectors may only be placed on a roof with minimum incline, exposed to the entire sky. Other surfaces such as awnings and vertical walls cannot be used if maximum efficiency is desirable. While normal roof areas are sufficient to house the collectors for low-rise domestic buildings, there may not be enough roof area on high-rise apartments to accommodate the number of collectors required.

(b) The majority of the population in Singapore are housed in high-rise buildings and water consumption is metered at each apartment. It follows that hot water used by each household should be similarily metered if a central system is used. This brings about an administrative difficulty of meter-reading which is considered impractical in large housing estates. It would be uneconomical to design for individual units, one for each apartment.

(c) The demand of hot water in a hot humid climate is not as much as that in the temperate climate. As there is no need for space heating, hot water is used mainly for washing and other household chores. This means that the installation of a solar water heater unit is less attractive economically than that of a conventional water heater of gas or electricity which are relatively cheaper at capital cost.

(d) It is not easy to adapt a solar water heater in an existing house. The result is often unsatisfactory both from the architectural and engineering points of view. Some of the problems encountered are positioning of collectors and tanks, connection to existing plumbing systems, accessibility of panels for cleaning and servicing, and the suitability of existing roof structures and roofing materials. Obviously it is much more logical to incorporate solar water heaters in proposed housing development, but so far it has been difficult to persuade developers to do so.

Prospects of Solar Technology Application

From the foregoing it may be concluded that the immediate application of solar technology would be limited to the supply of hot water, and even this will be met with some resistance, especially at the domestic scale. Commercial applications are more promising, if developers are convinced that short-term returns of say 15 years are possible. These projects include hotels, hospitals, recreational clubs, and other institutions where large quantities of hot water are used. Experience so far shows that the saving should be attractive enough before the solar hot water system is considered.

Since each project is substantially different from the other, local expertise is required to solve the many problems of installation. In general it is preferable for design to be done locally so that modification can be made immediately without referring to overseas designers. Unfortunately, since the solar technology market is small, few local engineering firms are willing to branch into this field.

The solution would be to foster and to encourage the development of solar technology by local talents at all levels. If solar technology is regarded as a new kind of industry and certain incentives are given at its infancy, it is likely to grow. If it is left on its own, it is unable to compete with existing technology of a similar kind, and it may die. The granting of a "pioneering industry" status, for example, may attract both local and foreign investments. As solar industry gathers momentum, not only will experience be steadily built up, more sophisticated systems may also be derived.

Solar-air-conditioning would be the next step after hot water, but it is a more difficult one. So far overseas experience indicates that no substantially saving of energy is available (Ref. 6). For Singapore it has been a wait-and-see attitude. While basic research would be expensive, demonstration units of solar cooling units would be obtained and tested under local conditions. When the systems are shown to be applicable, feasibility studies could be made on the marketing of the systems. Certain taxation incentives could be made to encourage the installation of solar cooling systems, beginning with lower capacity. In this way active systems may be gradually employed.

Passive systems depend largely on the creativity of architects to bring about suitable designs in the urban context. While there are more restrictions in urban development, it may be possible to use the technique to provide ventilation in deep spaces where the ratio of window area to floor area is small. The roof could also be used as a heat-absorber to give the required temperature difference for convection to take place. The air stream so generated may also be used to remove excessive heat due to occupants. If the building is well-insulated and air movement is provided by wall-hung or ceiling-hung fans, a certain degree of thermal comfort may be achieved.

In urban development buildings over-shadow one another, and comprehensive legislation must be readily available to protect solar collectors from being shaded by near-by buildings, similar to existing building regulations which have been designed to provide light and air to windows. However, while frontages and step-backs are relatively easy to control, roofs or high-rise buildings in dense "down-town" areas must be carefully studied so that the juxtaposition of the buildings would not render them useless for the installation of solar collectors. The conditions are simpler if the real estate involved is relatively large, but narrow sites will present difficult problems. What protection is there for a developer who installed a solar collector on a roof? And is it fair to restrict future developers who wish to build higher around him? These are some of the difficulties legislators will have to solve.

Conclusion

The application of solar technology in urban areas is more difficult than in rural areas. For rural areas are usually designed to be self-supporting, and the development of solar technology is in line with this trend. The isolation of farms one from the other, and the distance required to transport fuel, make it more appropriate for solar technology to be used. However, in urban centres there exists an infrastructure of services which present solar technology does not utilise. In fact it is often in competition with existing systems. In economical terms solar technology must be shown to be as viable as conventional systems under local conditions including climate, energy consumption pattern, resources and technical capability. The economic factors of solar technology should now be looked into, so that they could be more competitive for urban use. It is recognised that at this stage of development, certain incentives must be given to solar technology so as to promote its use. To do so each urban settlement must decide the kind of promotion it could give in the interest of the nation.

Appendix A

Proposed Low Energy Experimental Unit, University of Singapore

The foregoing article suggests both active and passive systems should be tested under Singapore conditions to see if they are feasible. A single family experimental unit is proposed, as the scale is small, at the same time all living requirements may be examined.

An experimental low energy unit to be built at the University of Singapore Campus will have its roof as an integrated solar collector. The roof cum flat-plate solar collector consists of a black-painted ribbed steel sheet with glass cover to reduce heat loss, and is insulated with 10 cm of polyurethane insulation. Its primary function is to induce air movement for the living area by a solar induced ventilation system. Heated air which tends to rise toward the top of the roof during the day will help to induce more air movement to the interior spaces.

The house will be constructed in such a way that it will be possible later on to improve and replace the components.

Hot water

The solar water heating system is to be installed to meet the requirement of a hot water supply during the whole year. A common solar hot water system using flat-plate solar collectors is proposed.

The active system will also be tested in this project and 3 units of solar concentrators will be installed on the roof deck tracking the sun during daytime automatically. This concentrator is expected to collect solar energy at temperatures of 200°C to 300°C and to store it in a high-temperature energy storage tank for further experiments in high temperature applications such as, solar refrigeration and cooking.

Cooling

It is proposed that an absorption cooler be installed to demonstrate its feasibility in Singapore.

Cooking

A solar cooker could also be utilized in ideal weather conditions.

It is hoped that after the completion of this experiment more information will be obtained to determine the future trend of Solar Architecture for Singapore and other regions with similar climate conditions.

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APPLICATIONS OF SOLAR ENERGY IN SRI LANKA

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Abstract

Sri Lanka is a tropical island in the Indian Ocean blessed with plenty of sunshine. The country depends on an agricultural economy with a rural population of 80%. Ten percent of the homes have access to electricity and 90% of the homes use kerosene oil for lighting purposes. Seven percent of the villages have access to electricity. About 25% of the technically feasible hydro resources have been developed. The full exploitation of the hydro resources will not be sufficient to electrify all houses. There are no known coal, oil or natural gas deposits. Even an accelerated Nuclear Power Programme will not see marketable commercial nuclear reactors commissioned before 1995. The strategy is to develop the rural economy with energy from renewable resources using a technology suited to the rural economy, reducing

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dependence on imported oil. The ongoing projects on solar, wind and biomass energy should be co-ordinated, encouraged and further developed with support from international organisations. Mutual exchange of information with the other countries in South East Asia would be very useful.

1. Introduction

Sri Lanka is a pear shaped island located in the Indian Ocean between 5^{o} 55' and 9^{o} 50' North Latitudes and between 79^{o} 42' and 81^{o} 52' East Longitudes. The country has an area of around 65,000 sq. kms.

The topography of the country comprises a mountainous area in the South Central part rising in elevation to 2400 m surrounded by a coastal plain which is narrow in the West and South but broadens out to a vast tract in the North. The rainfall is unevenly distributed over the island. The Monsoon rains occur in two distinct periods. The South West monsoon through March to September brings most of the rain to the South Western and Western parts of the country. The annual rainfall varies from below 100 cms in the dry zones in the North West and South East sectors of the island to 500 cms at certain places in the South Western slopes of the hills. The Relative Humidity varies generally from about 70% during the day to about 90 - 95% at night. The country is blessed with sunshine throughout the year with an average solar insolation of 5 KWh per sq. metre per day.

The geographical position of the country has proved favourable for the development of sea ports (Colombo, Galle and Trincomalee) on the shipping routes across the Indian Ocean, and an airport (Katunayake International Airport) situated about 30 kms (20 miles) north of the capital city, Colombo.

2. The Economy of the Country

The population of Sri Lanka is about 14 million, growing at the rate of 1.7 per cent per annum. About 80 per cent of the population lives in the rural areas where the main activity is agriculture.

The per capita GNP in 1977 was Rs.855/= at constant (1959) prices or Rs.2100 at current prices. The rate of growth of GNP at constant prices had been about 3.5 per cent annum during 1971 to 1976. In 1977 the real GNP increased by 4.4 per cent. The sectoral composition of the GNP in 1977 at constant (1959) Factor Cost Prices is as follows:-

		Amount Rs. M.	Percentage
1.	Agriculture, Forestry, Hunting and Fishing	3,828	32.0
2.	Mining and Quarrying	311	2.6
3.	Manufacturing	1,505	12.6
4.	Construction	480	4.0
5.	Electricity, Gas, Water and Sanitary Services	37	0.3
6.	Transport, Storage and Communication	1,198	10.0
7.	Wholesale and Retail Trade	1,623	13.6
8.	Banking, Insurance & Real Estate	229	1.9
9.	Ownership of Dwellings	360	3.0
10.	Public Administration & Defence	703	5.9
11.	Services	1,703	14.3
	GDP	11,977	-
	Net Factor Income from Abroad	-25	-0.2
	GNP	11,952	100.0

(Source: Central Bank of Ceylon Annual Report, 1977).

Sri Lanka is still heavily dependent on the export of tea, rubber and coconuts for its foreign exchange earnings. In 1977, the earnings from these three products amounted to Rs.4,769 million or about 72 per cent of total export earnings. The industrial sector which has hitherto grown mainly under a protected local market has exported goods worth Rs.866 million in 1977. Owing to adverse trends in the International Markets for these three major exports, the country has experienced serious foreign exchange problems for over two decades since mid-fifties. The trends have changed for the better during the last two years.

In 1977, 42 per cent of the import bill was spent on consumer goods (food and drinks alone came to 36 per cent), 44 per cent on intermediate goods (petroleum was 24 per cent) and 12 per cent on investment goods.

Sri Lanka's economy is a mixed economy where the Government Sector aims to provide the basic infrastructure and concentrate on activities where the private sector cannot come in. Development planning at the National level is the task of the Ministry of Finance and Planning while Plan Implementation is done by the line Ministries with the Ministry of Plan Implementation keeping track of progress and appraising and advising the Government on the areas which need attention.

Planning at the regional level is expected to gain strength after the recent appointment of District Ministers. Already an integrated approach to rural development has been given emphasis through Integrated Rural Development Plans for three Districts prepared by the Ministry of Plan Implementation. Similar Plans are also being prepared for some of the other Districts.

3. Patterns of Energy Consumption

The total energy consumption for the year 1977 in Sri Lanka was estimated at 10,000 GWh (Electricity Replacement) of which 1200 GWh was produced by Hydro Electricity, 2800 GWh from oil products and 6000 GWh from traditional fuels such as firewood and agricultural residues.

The per capita annual consumption of energy in 1977 was:

85 KWh	(Electrical)
200 KWh	(Commercial)
715 KWh	(Total)

The consumption of commercial energy in the different sectors of the economy was approximately as follows:

Domestic Sector	20%
Industrial Sector	33%
Transport Sector	40%
Other	7%

3.1 Electricity

At present the Hydro-electric stations that have been commissioned have a power capability of 329 MW and an energy capability of 1500 GWh per annum. Thermal Power Stations with a total capacity of 59 MW have been installed to supplement the hydro-electric power during periods of drought.

The table below gives the Electrical Energy Consumption in GWh expected for the period 1979-1984:

Class of Consumption	YEAR 1979	1980	1981	1982	1983	1984
Domestic	116	124	133	142	153	163
Small & Medium Industry	295	332	357	384	414	446
Large Industry	420	480	552	634	729	838
Commercial	170	191	206	222	239	258
Bulk Supplies	276	293	311	330	350	371
Rural Electrification	10	12	14	15	16	17
Street Lighting	16	16	17	17	18	18
Investment Promotion Zone	16	22	38	63	94	125
Accelerated R.E. & Extra Industry	02	05	10	15	20	25
Transport Electrification	-	-	-	15	20	25
TOTAL	1321	1475	1638	1837	2053	2286
Energy Demand (GWh)	1508	1685	1866	2089	2319	2592
System Load Factor (%)	56	57	58	58	58	58
Power Demand (MW)	307	338	367	411	456	510

The total Hydro-power potential from small and medium sized hydro-power plants has been estimated to have a power capability of 1592 MW and an energy capability of 6229 GWh per annum. With the commissioning of the Canyon Power Project of 30 MW in 1981, the Bowatenna Power Plant of 40 MW presently under construction, the hydro-power plants under the Accelerated Mahaweli Development Programme, and the Samanalawewa Hydro-power Project, are expected to bring the hydro-power capability to 780 MW, and energy capability to 3043 GWh per annum. The remaining economically exploitable hydro resources will probably be harnessed during the period 1984-1994.

At present only 7% of the villages have access to electricity and only 10% of the homes are electrified. Full development of the hydro-power resources will not be able to provide electricity to all the homes.

3.2 Oil Products

Sri Lanka has so far not discovered any coal, oil or natural gas. Crude oil is imported in sufficient quantities to meet the local requirements of petroleum oil products whilst the surplus chemical naptha and fuel oil is presently exported. The fuel oil will be processed into middle distillates by a hydrocracker to be installed shortly.

The table below gives the crude oil processed in Sri Lanka in Million Metric Tons:

1971	1.54
1972	1.78
1973	1.77
1974	1.52
1975	1.47
1976	1.47
1977	1.50

The cost of oil imports rose from 7% of the import bill in 1973 to 20% in 1974 and 24% in 1977. With the rise in curde oil costs the country will have to look forward to developing alternative sources to oil. It has been predicted that the shortage of oil supply in the world will inevitably begin around the period 1985-1995.

More than 90% of the households use kerosene oil for lighting purposes.

3.3 Firewood

The area under forest cover in Sri Lanka is roughly 0.6 million hectares (1.4 million acres) under proclaimed forests, a similar area of proposed reservations and about 2 million hectares (4.4 million areas) under other crown forests. A major portion of firewood is supplied by the rubber plantations which become available due to the replanting of rubber cultivations under the Government Subsidy Scheme. Substantial amounts of fuel are also supplied in the form of wood-waste from saw miles, paddy husks and from wastes available from coconut plantations and tea plantations.

Firewood plays a very important role in the domestic fuel economy of Sri Lanka. The firewood that could be extracted annually from the proclaimed forests, crown forests and other reservations without damage to the ecology has been estimated to be less than 0.1 million tonnes. Saw mills and wastes from coconut cultivations account for about 0.5 million tonees annually and about 1.0 million tonnes of firewood are estimated to be available due to the replanting of rubber trees. The present day demand is estimated at 4.0 million tonnes annually of which about 2.4 million tonnes come from unidentified sources.

Large areas of forest are being cleared for village settlement schemes under the Mahaweli and other Multipurpose Projects, making available large stocks of firewood. However the impact of this on the supply of firewood to cities is not felt owing to transport difficulties. Burning down forest areas to enrich the soil by chena cultivators is a major problem in the proper development of this resource. The irregular and irrational exploitation of forests for firewood and timber could eventually cause irreparable damage to the environment and seriously inhibit the development of this energy resource. It has to be maintained that indiscriminate felling of trees in the catchment areas in the central hills has to be controlled, as it will otherwise affect the regular flow of precipitation into the reservoirs.

4. The Need for Alternative Energy Sources

Presently the main source of energy consumption in Sri Lanka are derived from Firewood, imported oil and hydro-electricity.

At the present rate of consumption of firewood, the forests are being rapidly denuded. Even to maintain the present levels of consumption of firewood, a planned reforestation programme is vital.

The supply of crude oil is getting more expensive and scarce day by day. Yet it will not be easy to replace oil as a Transport Fuel. Substitutes for oil will therefore have to be found in other sectors.

The availability of hydro-electric resources will just about meet a 10% per annum growth rate till about the year 1995.

In spite of the very sincere efforts that are being made to expedite the construction of certain hydro-power projects to be commissioned on schedule, there may be significatn delays. Such delays will become unavoidable if adverse soil conditions or climatic conditions are faced during the course of construction work.

It has been observed that, owing to the liberal policies of the Government the demand for electricity has been growing at about 20% over the past year. If these demand patterns continue to grow at these rates, the need for new sources of energy to supplement the demand for electricity will arise within a few years.

Of the alternatives available, the most promising are nuclear and solar energy. The present efforts of the Atomic Energy Authority established in Sri Lanka are mainly concentrated on the use of Radio-isotopes for University teaching purposes. Even if the Atomic Energy Authority were to embark on an accelerated Nuclear Power Programme today, it is very unlikely that currently available commercial nuclear reactors could be commissioned before the year 1995.

It should also be remembered that any energy plan must be viewed in the overall context of the meaningful improvement in the standard and quality of life of the people. This plan must be viewed within the context of the social, economic and cultural factors which are the ultimate determinants of energy demand.

In this country the majority of the population are involved in the rural agricultural economy and will have no access to basic needs, namely:

a. a minimum requirement of private consumption (food, clothing and shelter).

b. access to communal services (drinking water, sanitation facilities, public transport, health and educational facilities).

and c. adequately productive and fairly remunerative employment.

The progress of domestic agriculture displaces more and more labour which should be absorbed in industries that are associated with agriculture. Industrial development calls for the utilization of energy.

With scarcities in oil resources and electricity from the central grid, the rural sector will be heavily dependent on the renewable energy resources - solar, wind, biogas and mini hydro schemes for its industrial growth based on its agricultural economy and to meet its basic needs. The technology and material used to harness this energy should be easily accessible to the rural sector.

The initial industries to be linked to an agricultural economy should include a supply of water for irrigation, conservation and drying of grains, supply of fertilizer, processing and transport of agricultural produce, etc.

4.1 Summary

It is very clear that alternative sources of energy are needed to backup and supplement the hydro resources certainly beyond 1990, if not earlier. Even if we embark on an accelerated Nuclear Power Programme today, Sri Lanka would not see commercial nuclear reactors of marketable size commissioned before 1995. Therefore, the demand for energy between now and 1995 to supplement hydro sources and limited oil imports should be met by renewable energy resources.

5. The Renewable Energy Resources

Solar radiation, wind, biomass and micro-hydro resources are generally freely available and require some capital investment in hardware for collection and conversion into useful forms. These technologies are highly developed mainly in the developed countries, with probably the exception of biomass. Due to the low demand, the cost of these processes is still high.

5.1 Solar Radiation

Photovoltaic cells for direct conversion of Solar Energy into Electricity are expected to come down in price within the next decade. This subject deals with the interaction of photons with matter and therefore calls for a deep understanding of Theoretical Physics, as in the case of nuclear energy. This technology cannot yet be accommodated in a Rural economy, may be used to power VHF radio links between remote post offices and rural exchanges.

Solar panels for heating and cooling of buildings have been found to be economically competitive in recent years. It would interest those who have no access to power for heating and air-conditioning from a central electricity grid, such as rural health centres and hospitals. Conversion of solar energy into thermal energy and thence to electrical energy has not yet been proved to be adaptable into a rural economy. Low cost solar stills could produce potable water to rural households in areas where well water is brackish, and provide distilled water for car batteries and rural science laboratories. Solar driers will be useful for the quick drying of agricultural products and fish under hygenic conditions.

5.2 Wind Energy

Wind energy is best utilised for lifting under-ground water for irrigation purposes, and to provide motive power. The best wind potential has been found in the Hambantota area (South East) and the Jaffna area (North). Except for the South Western parts of Sri Lanka, in the other parts of the island, where there is a good wind potential, the dry season coincides very well with periods of high wind, which makes it very attractive to use wind mills for water pumping. Pumping under-ground water by windmills have been found to be competitive with kerosene pumps, at prevailing interest rates, kerosene prices (subsidised), expected maintenance costs and depreciation over 10 years.

5.3 Biomass

Conversion of Solar Energy by Photosynthesis and bacterial fermentation processes to produce fuel gases such as methane and hydrogen has its applications in Sri Lanka. Biogas generators have a good potential in the cattle farms. They could be used for cooking, lighting and preserving fruit and vegetables and for school science laboratories.

Forest fuels, which provide a major energy source, have to be maintained by a planned reforestation programme.

5.4 Micro-hydro

Micro-hydro stations could be advantageous in certain remote areas as decentralised sources of power.

6. The Rural Energy Demonstration Centre for the Asian Region at the Pattiyapola Village under the aegis of the United Nations Environment Programme and the Sri Lanka Government

The United Nations Environment Programme at the Third and Fourth meetings of its Governing Council decided "to accord high priority to the establishment in some of the typical rural areas of the countries of Asia, Africa and Latin America of a few demonstration centres harnessing individually or in combination the renewable resources of energy locally available".

The Asian Demonstration Centre in Sri Lanka has plenty of sunlight, strong winds and animal and agricultural wastes, and borders an existing natural lake. The average solar insolation has been estimated at 5 kWh/sq.m. per day with an average wind regime of 12.3 mph. at the site. The project envisages harnessing three renewable sources (solar, wind and biomass energy) in an integrated manner to produce electricity for lighting the houses, pumping drinking water and providing motive power for cottage industrial growth for as many families of the Pattiyapola Village as possible (about 200) living within a radius of 1½ miles (2.4 kms) of the site. The system is to make available annually about 60,000 kWh of electrical energy at 230V AC for the consumers. The cost of the various components were estimated as follows:

Solar (Rated 10 - 20 kW capacity)	US $ 55,000
Wind (Rated 20 kW capacity)	$ 26,000
Battery Bank (300 kWh per day)	$ 25,750
Biogas (Rated 50 kW capacity)	$ 23,250
Power Distribution	$ 12,500
Overhead Tank of 3000 gals.	$ 15,000
Water Purification Plant	$ 5,000
Meteorology Observatory	$ 3,000
Misc. including contingencies	$ 20,000
Consultants (3 trips to total 6 weeks)	$ 12,000
Training 2 local engineers for 3 months	$ 5,000
	US $ 202,500

($ 160,000 Foreign
($ 42,500 Local

A project agreement was signed between the Sri Lanka Government and the UNEP in September 1976 with the Ceylon Electricity Board as the executing agency to have the Demonstrating Centre operational by November 1978 with the UNEP contributing US $ 191,000 and the Sri Lanka Government contributing US $ 42,500 in local currency.

The UNEP consultants have, from time to time, made changes due to improvements in technology during the period of construction and the project now expected to be operational in June 1979. The UNEP has also enhanced its contribution by US $ 105,000 to US $ 296,000. The Ceylon Electricity Board spends about US $ 3,000 per year in local currency to maintain their staff at the site.

The objective of the project is "to demonstrate the technical, economic and social feasibility of harnessing solar energy, wind energy and biogas energy to meet the energy needs of a remote village and to prove that the existing state of the art of appropriate technologies for harnessing renewable energy resources under the conditions prevailing in rural areas of developing countries could justify the use of such technologies".

The project is composed of a wind electric system, a solar electric system based partly on thermal power generators and partly on photovoltaic generators and a biogas plant. The electricity produced by the three systems will be stored in a battery bank, transformed to 230 V AC and distributed in the conventional manner. The proponents of this system have claimed that, if successful, the concept would revolutionize the life style of no less than 800 million people living in small isolated village conditions in developing countries of Asia, Africa and Latin America.

6.1 Current Status

The 3,000 cu.ft. biogas plant has been installed. 4 Windmills, each rated at 2 kW, are being installed. A Photovoltaic panel of 2 kW capacity has arrived and arrangements are being made to erect it when the batteries arrive. A parabolic concentrator raises steam to run a Rankine engine unit capable of generating 7 - 10 kW.

At the request of the United Nations Environment Programme, a standing Committee consisting of Meteorologists, Social Scientists, engineers and Economists working in Sri Lanka Institutes and Government Departments has been appointed to monitor the progress of The Rural Energy Demonstration Centre.

7. Work Conducted in Sri Lanka on Solar, Wind and Biomass Energy

7.1 Stills

A prototype still with a collector area of $3m^2$ and an output of 12 litres per day has been installed at a cost of Rs.2,000 (US $ 125) as a source of drinking water in one of the remote villages by the Ceylon Institute for Scientific and Industrial Research. The still has a concrete basin lined with ebonite compound made of natural rubber. Assuming the still has a life span of 10 years, the cost of the distilled water will be about 5 cts per litre.

7.2 Driers

The C.I.S.I.R. has developed a solar Cabinet Drier for agricultural produce. The drier attains a temperature of $70^{o}C$ with a good natural circulation of air. It has been tested for the drying of chillies, passion fruit peel, cashew nut, agar and bananas; and has been found to give reduced drying times with improved quality of the dried product. Experiments are also carried out on solar air heaters.

The development of paddy driers will be useful to avoid deterioration of grain during storage. The feasibility of using solar driers in crop drying is under investigation at the Universities of Peradeniya and Moratuwa and the Industrial Development Board.

7.3 Water Heaters

The National Engineering Research and Development Centre has developed a heater making use of a flat plate collector with a discarded oil drum of 40 gallons as the storage tank. It provides water at a temperature of 60^{o}C at a rate of 4 litres per minute during periods of bright sunshine. About 25 such units are known to have been built for domestic purposes. The installed cost of the unit, excluding the external plumbing, was about Rs.1200 (US $ 75) in early 1977.

Some solar water heaters have been designed and tested at the Universities of Peradeniya and Moratuwa.

7.4 Cookers

Solar cookers using conical, spherical and parabolic concentrators have been tested at the University of Peradeniya. A solar cooker has been produced by the National Engineering Research and Development Organization. The design and development of a solar steam cooker is being undertaken by NERDC and the CISIR.

7.5 Pond

Theoretical studies of the thermal behaviour of solar ponds are in progress at the University of Peradeniya.

7.6 Refrigeration

The University of Peradeniya has carried out experimental studies of intermittent refrigerators operated by solar collectors. It has been shown that 1 lb. of ice could be produced from a collector of 4 sq.ft. on a clear day. The University has also investigated the solar operation of vapour absorption cycle air-conditioners under the climatic conditions of Colombo.

7.7 Wind Mills

Except for the sail boats used by the fisherman, there is little tradition in the utilization of wind energy in Sri Lanka. The Government of the Netherlands through the Steering Committee, Wind Energy for Developing countries has assisted in the setting up of a Wind Energy Unit in the Water Resources Board with the objective of designing and testing small scale water pumping windmills and of promoting manufacturing and utilisation of these Windmills. This unit has successfully designed and constructed two prototype windmills that are now under test in Colombo. At high speeds, the windmill turns automatically out of the wind and orients itself back into the wind when the gusts of wind have passed, protecting it against storms.

A 10 ft. diameter windmill with 8 blades supported by a 30 ft. high tower would altogether weigh approximately 200 kgs. with materials costing around Rs.2,000/- (US $ 125). It could pump 0.45 litres/sec (360 gallons per hour) in 9 MPH winds and 1.45 litres/sec

(1160 gallons per hour) in 18 MPH winds for a pumping head of 13m (43 ft.).

A 16 ft. diameter windmill with 12 blades supported by a 6m (20 ft.) high tower (adjustable to 25.30 or 35 ft.) would altogether weigh 450 kgs with material costing around Rs.4,000/-. It could pump 0.95 litres/sec (760 gals/hr) in 9 MPH winds and 4.0 litres/sec. (3220 gals/hr) in 18 MPH winds for the pumping head of 13m (43 ft.).

Only basic materials are used such as angle iron, flat iron, G.I. pipes and P.V.C. pipes, freely found in Sri Lanka. A workshop with a normal turning lathe, drilling machines, electric welding equipment, spanner sets, etc. is necessary.

The National Engineering Research and Development Organization has developed three types of windmill pump. One has a 3 bladed rotor driving a centrifugal pump with an estimated capacity of 20,000 gallons/hr against a total head of 1 M (3 ft.) in a wind of 8 - 10 MPH. Another can deliver 100 gals/hr against a total head of 9m (30 ft.) at wind speeds of 6 - 8 MPH. The larger unit with a 12 blade rotor has an output of 1000 gals/hr against a head of 10.5m (35 ft.) in a wind of 6 - 8 MPH.

The University of Peradeniya is conducting investigations into the relative merits of horizontal axis and vertical axis wind mills under conditions prevalent in the country.

7.8 Biogas

The generation of methane (biogas) through the anaerobic fermentation of biomass has been studied and various types of gas generating and utilising systems have been tested at the University of Peradeniya.

The Industrial Development Board has a programme for the popularisation of the biogas generators.

Ten biogas generators provided by the Government of India are being installed in various places by the Department of Agriculture.

8. Institutional Arrangements

The Ceylon Electricity Board is the authority for the generation, transmission and distribution of electricity in the island. The Ceylon Petroleum Corporation is responsible for importing, refining and distributing Petroleum products in Sri Lanka. The Department of Conservation of Forests is responsible for the management of the Forest while the harvesting of timber is the responsibility of the State Timber Corporation.

Up to now there is no separate body to coordinate, monitor and plan the demand and supply of the different forms of energy although independent units are functioning to regulate particular forms of supply. The Ministry of Finance and Planning has initiated some exercises towards the development of an energy policy for Sri Lanka. There is also no central special body to promote energy conservation methods in the industrial and domestic sectors. Efforts are being made to promote the use of renewable energy resources like solar, wind, biomass and minihydro systems and create an awareness in their potential as future energy sources, particularly in the development of the rural sector. A few institutions have initiated work in this connection. There is no effective central body for research and development of renewable energy resources and the promotion of such resources.

9. Conclusions

In view of the importance that Energy plays in the development of the society, it is realised that:-

1. It is desirable to have an energy policy and a Central Planning Unit to monitor the future demands, assess the various sources available, develop and establish an Energy Strategy. This unit should be able to coordinate the activities of the organisations dealing with the different forms of energy and implement policy decisions.

   The various institutions concerned with energy supply and demand should set up their own units for the collection and analysis of internal data and effectively liaise with the Central Planning Unit.

2. There is a need to develop renewable energy resources to bridge the gap between the demand and supply of energy, and to meet the energy needs of the rural economy that has always had little access to conventional energy forms. It is concluded that:-

   (a) Existing institutions that are already working in these fields be encouraged to continue their work by providing incentives.

   (b) An evaluation of the ongoing work in the Rural Energy Development Programmes of Sri Lanka be carried out.

(c) Research into the exploitation of Solar, Wind, Biomass and other non-conventional sources be enhanced.

and (d) Assistance be welcome from International organizations to promote these facilities.

10. Acknowledgements

The participants wish to express their gratitude to Co.M.E.S. for sponsoring this important Seminar & to the A.I.T. for hosting the Seminar. Our participation at the Seminar was made possible through the generous assistance of the C.N.R.S. as well, with the cooperation of the Cultural section of the French Embassy in Sri Lanka. We wish to thank them and the Government of Sri Lanka for affording the opportunity to participate at the Seminar.

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Seminar on the Applications of Solar Energy in South and Southeast Asia
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DEVELOPMENT OF SOLAR ENERGY IN THAILAND

SOMPONGSE CHANTAVORAPAP*

I. Problem of Energy Development

The most fundamental problem facing Thailand in energy development is the rising price of imported crude oil and its products. It has been spending a great share of foreign exchange on importing this source of energy which has resulted in more and more deficits in trade balance. The other problem of equal importance is the rising energy supply gap between provincial areas as served by the Provincial Electricity Authority and metropolitan areas as served by the Metropolitan Electricity Authority. As energy plays a much greater role in today's economic and social development of the country, the situations leads to increasingly wider disparities of incomes, standards of living, and the welfare between Thailand and developed countries and between the two groups in the country.

The problem is aggravated by lack of an energy master plan which could be implemented; lack of indigenous capabilities to unpack and absorb the technologies which have already been transferred to the country; lack of all levels of researchers in some areas of specialization, i.e., energy conversion, use and conservation; few experts in the

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field of energy technologies to monitor technologies of energy development and utilization in the region and worldwide; and lack of trained development personnel and extension workers on rural oriented energy technologies to transfer the appropriate and proven ones to be widely used by the people.

II. Potential of Solar Energy

Thailand stands between 5^{o} - 21^{o} north latitude, and 96^{o} - 106^{o} east longitude, covering an area of about 514,000 sq.km.

According to the record, the average solar insolation in Thailand is reasonably high. It is about 430 cal x cm^{-2} x d^{-1} at Chiangmai in the North, 430 and 425 cal x cm^{-2} x d^{-1} at Khonkaen and Kalasin in the Northeast and 400 cal x cm^{-2} x d^{-1} at Bangkok in the central area. The yearly average insolation on a horizontal surface at Bangkok is more than 1500 x 10^{3} kcal x m^{-2} x y^{-1} with the monthly average of 145.5 x 10^{3} kcal x m^{-2} x m^{-1} in March and May, 141.5 x 10^{3} kcal x m^{-2} x m^{-1} in April, 122.0 x 10^{3} kcal x m^{-2} x m^{-1} in June 119.0 x 10^{3} kcal x m^{-2} x m^{-1} in July and August, 114.5 and 111.0 x 10^{3} kcal x m^{-2} x m^{-1} in September and October, 121.5 and 129.5 x 10^{3} x m^{-2} x m^{-1} in November and December, 129.5 and 123.5 x 10^{3} kcal x m^{-2} x m^{-1} in January and February.

Based on the records at Bangkok and the total area of Thailand, Thailand is endowed with the yearly potential of solar energy in the order of 771,000 x 10^{12} kcal x y^{-1} which is 6425 times of its yearly energy consumption in 1977 or 308 times its known conventional non-renewable energy resources (except hydro and fuel wood).

III. Need for Solar Energy Technologies

In Thailand, only the population in the Bangkok metropolitan, Provincial municipalies, and the District and Subdistrict sanitation areas is served by a power and fuel distribution network. The village and rural areas where most farmers live, generally depend on a limited supply of petroleum products such as diesel fuel, gasoline or kerosene and on "non-commercial" energy sources.

Electricity for lighting, recreation and education is desired by at least 5 million families in 47,725 villages. The number of villages without electricity will become 55,000 in the next 20 years and the Provincial Electricity Authority has to finance the rural electrification work on its own. Large numbers of small solar electric generators will be one of the alternatives.

Nonconventional sources such as fuel wood and agricultural residues for cooking can be gathered by most farmer families. Solar cookers can hardly be used unless considerable promotional and extension work is involved, preferably undertaken by government and local authorities with a view to reducing the depletion rate of the forests and the disastrous consequences of deforestation, i.e., warming effect by raising the level of CO_2 in the atmosphere, destroying land resources and silting up waterways by soil erosion.

Reducing the poverty of farmers in Thailand will necessitate a much higher per capita consumption of energy in the rural area for production, preservation and processing activities which can hardly be satisfied by conventional sources of energy. At present, lifting of water from the Mekong River and its tributaries for second crop irrigation and drinking purposes and from the deep well water for cattle raising and drinking purposes in the Northeast, which is the driest and poorest region of the country, is powered by electricity, by diesel or gasoline. A solar pump has to compete with a windmill pump to be used in remote area and to replace pumps being powered by diesel or gasoline, which are now becoming scarce.

A lot of agricultural products such as rubber, rice paddy and other field crops; marine products such as various kind of fish, oysters, lobsters; forest products such as lumber and its products (furniture) is produced by the majority of the population in the country. Products such as second crop paddy and low grade tobacco leafs, fruits and other foodstuffs openly dried sometimes become spoiled by rain and moisture, and often yield inferior contaminated products. Technologies for solar drying are needed to improve the situation and encourage more production. It will help not only the producers to get a fair price for their products but also the consumers to buy more hygienic ones. The extensive application of solar drying technologies to preserve some kind of fruits, vegetables and marine products up to standard can more easily open foreign markets for such products.

Natural water in the Northeast and near the coast is too saline for ordinary use. Many educated people believe that even the tap water and bottled fresh water are not suitable for drinking. Solar stills, portable ones, will be easily accepted in the market if it produces reliable pure water. Solar stills of large capacity for poor communities will need a change in the attitudes of people towards clean but tasteless water.

Using domestic hot water is not popular in Thailand. The solar water heater will possibly be used in sports clubs, barber shops, hair-dresser saloons; cleaning shops, hospitals and medical clinics; health centers, hotels, garages, and textile, ceramic, bottling and food industries. It must be equipped with an auxiliary heater and storage to ensure reliable services. It will hardly be used by private sectors unless the investment can be recovered by savings in the fuel bill and replacement within 5 years. However, a few investors in town houses, apartments, hotels, hospitals and high income individuals show interest in using solar water heaters for buildings under design.

The cooling load in the Bangkok metropolitan area on week days is quite high throughout the year. There is a tendency to use solar air conditioning in government office buildings if it is technically and economically feasible. Solar refrigeration will have a potential for food preservation in the rural areas and for supplying ice in the fishing villages. It will never be widely used unless its technology is proven, it is easily operated and maintained, and its cost is much reduced.

IV. Development Plan

The National Energy Administration (NEA) proposed a five-year (1977-8) programme entitled "Survey and Development of Alternative Sources of Energy" and submitted it to the National Economic and Social Development Board (NESDB) in 1976. It was approved with the appropriation of US$750,000.- but the personnel and technical assistance requested for the effective development and implementation of the work programme was suspended because the detailed work programme entitled "Study and Development of Renewable Sources of Energy" dated October 1977 is still under consideration by the Subcommittee on Energy Planning under the NESDB recently established. The main activities in this programme can be categorized as follows:

1. Determination of Renewable Energy Potential

This activity can be accomplished through the setting up of 26 solar radiation measuring stations, compilation of existing wind speed data, and assessment of biomass.

2. Investigation of Need and Supply Sources of Energy

Sampling field survey on a typical village will be performed to determine energy demand, existing sources of supply, its utilization, and relevant information needed in the rural energy development plan.

3. Research and Development

The research and development on the utilization of renewable energy are carried out according to priority for each source as follows:

3.1 Solar: Low cost collectors, water heating, crop drying, space cooling and air conditioning, distillation, pumping, conversion into mechanical power, small scale power plant and solar cells.

3.2 Wind: Deep well water pump, shallow water pump, electric battery charger.

3.3 Biomass: Low cost digester and gas holders, biogas utilization - cooking, lighting, fuelling engines and integrated farming.

4. Development and Demonstration

Regional centers will be set up throughout Thailand to train local development personnel and extension workers on known and proven technology, and to educate and assist rural people in the application of new energy technology.

5. Promotion

During the demonstration technical guidance in fabrication, installation, operation, and maintenance will be provided to potential manufacturers, enterpreneurs, and interested individuals.

6. Evaluation

Assessment at the beginning and evaluation at all stages of the work plan, especially the transfer of new technology to the rural community, will be performed periodically so that mistakes at each stage can be recognized and remedied or modified immediately for successful implementation of the programme.

V. Current Development of Solar Energy R & D Activities

Solar energy R & D activity is rather new to the country. Its main objective is to monitor the technology which is being done and achieved abroad to transfer and adapt it to suit local conditions for its application.

There are more than 50 solar R & D activities, mostly academic in nature, being planned but only some have been carried out by government agencies, educational and research institutes.

The Thai organizations which deal with R & D activities in the field of solar energy include:

King Mongkut Institute of Technology (KMIT) (Faculty of Energy and Material Technology)

Chulalongkorn University (College of Engineering: Mechanical Engineering Dept., Electrical Eng. Dept. College of Science: Dept. of Physics, Dept. of Chemical Technology)

Prince of Songkhla University (Faculty of Eng.)

Khonkaen University (Faculty of Eng.)

Applied Scientific Research Corporation of Thailand Dept. of Forestry (Division of Forest product)

Dept. of Agricultural Technology (Agricultural Eng. Division)

Center for Military Research and Development

National Energy Administration (Technical Division: Study and Development of Renewable Sources of Energy Project)

Electric Generating Authority of Thailand (Dept. of Energy Technology)

The National Energy Administration will act as a coordinating body to formulate and implement the Natural Energy Master Plan which includes solar energy, and the National Research Council will be responsible for the coordination and financial support of scientific research.

The followings are only highlights of the solar energy R & D activities in progress:

1. Cooking

A practical solar cooker has been developed either with flat-plate or parabolic concentrator collector which operates satisfactorily. The estimated cost is about 600-1,000 baht per square metre of collector, yet it is not widely accepted due to social problems; eg. cooking in sunlight is not pleasant, there is not enough solar energy for one meal; and firewood is still available. KMIT Thonburi campus is developing solar cookers with thermal storage, and the National Energy Administration is using the hot box for boiling eggs, and warming food at its natural energy research and fuel test center.

2. Water heating

There are many commercial solar water heater models distributed in Australia, Israel, Japan, U.S.A., Europe, and Thailand. Most of solar water heaters are made with flat-plate collectors with fins and tubes. Recently, there has been a growing trend to use evacuated-tube collectors with selective coatings. Large-scale operations such as in hotels, hospitals, factories, etc. need auxiliary heaters and storage to provide continuous use of hot water. The fabrication cost of a complete solar water heater set is about 4,000-5,000 baht per square metre of collector. At present Research and Development on developing a low-cost solar water heater and a high efficiency solar water heater is in progress.

3. Drying

One of the most ancient applications of solar energy is drying. With suitable design, a solar dryer will reduce the time by half when compared with traditional and open drying and in addition it provides a more hygienic product. Two types of solar dryer, namely free convection and forced convection for large scale application, have been developed up to the stage of demonstration. Further work needs to be carried out for solar tobacco dryers, lumber dryers etc.

4. Distillation

Solar distillation has been known for more than 100 years. Aluminium or stainless steel is generally used for portable solar stills with black butyl rubber as absorber. Unit cost for distilled water is 15-20 satangs per litre.

A Low-cost solar still is made with brick and mortar. Its absorber is made of cement mixed with black ferrous oxide powder.

5. Refrigeration and Air Conditioning

Research work has been done on both the vapour compression cycle with freon as working fluid and the absorption cycle with ammonia or lithium bromide as working fluid.

Intermittent absorption cooling has been developed in many countries such as India, Pakistan, etc. This system is comparatively cheap but not yet practical and of low efficiency.

Continuous solar cooling which employs a concentrator collector as heat source for ammonia in generation at over 200°C is still expensive and more research work remains to be carried out.

Solar cooling using flat-plate collectors as heat source for lithium bromide solution in the generator achieved some success, especially in the U.S.A. and Japan, and is commercially available, but cost reduction is a vital factor for viable marketing.

Another area for solar cooling research is evaporative cooling, which is suitable in a country with low relative humidity.

An agreement between NEA and the YAZAKI Co. of Japan for a joint development of a two RT solar air conditioning system in Thailand has already been settled.

6. Heat Engine

There are many types of heat engine such as low temperature engines, e.g. Rankine cycle engines, which use a flat-plate collector with freon or ammonia as working fluid to drive the expander. This type of engine is suitable for small power application. The high temperature Rankine cycle utilizes a concentrator collector or heliostat with high pressure steam as the working fluid. This engine is usually found in electric generation. The high temperature Stirling or Brayton cycle utilizes a concentrator collector to produce hot gas which in turn drives a reciprocating or rotary expander.

The aforementioned solar heat engines are still too expansive to compete with gasoline engines.

7. Water pumping

There are many ways to use solar energy for water pumping, such as by using a heat engine to drive the pump, by using electricity generated from photovoltaic cell, or by producing the vapour from an insoluble working fluid such as pentane to drive a piston pump. Solar water pumps are commercially available but are still too expensive to be used in developing countries.

Research and development on a solar water pump which uses the vapour of a working fluid to drive a piston pump is in progress.

8. Electricity Generation

There are two methods for producting electricity, direct and indirect. The direct method utilizes solar cells made of silicon but the cost is very expensive so there is only a very limited application, such as in remote or isolated areas.

Current development work sets its target to reduce the cost of solar cells to one hundredth of the present cost in 20 years by the newly developed technology for thin film crystalline silicon, polycrystalline silicon, and amorphous silicon.

Research and development work for solar cell technology in Thailand is being carried out by Chulalongkorn University and KMIT.

Indirect solar electric generation utilizes thermal energy with distributed collectors and concentrators, or heliostats with a solar tower to produce steam for driving the generator.

Presently, there is a 35 kW solar electric generator with distributed collectors for sale at about 17 million baht, and a higher capacity system is being tested and developed in the U.S.A. and European countries.

The Electricity Generating Authority of Thailand is expecting to commence a 100 kilowatt thermal solar electric generation project in cooperation with the educational institutes soon.

VI. Present Manufacture and Utilization

Solar energy has been traditionally used in Thailand for evaporating brine in salt farm areas; drying fish, oysters, lobsters in fishing villages, drying tapioca, low grade tobacco leaves, rubber sheet, copra, banana and Vietnamese noodles at several places; and the drying of clothes, kitchen wares, table wares and other household facilities need drying outdoor of most houses.

The first use of solar water with imported technology and adaptive design began in 1959. The unit is composed of a flat plate collector with double glass cover, producing about 60 litres of hot water at 65-70^{o}C each day. There was not much attention paid to such use until Thailand was hard hit by the rise in oil price during the 1973-1974 oil crisis. Ever since scientists and technologists in government offices as well as the private sector have been interested in energy alternatives including solar energy.

Solar water heaters have been designed and commercially fabricated in the country. It was reported that at least 80 units have been sold and used in private homes, hotels, hospitals, factories, and a sports club since 1976.

The techno-economic status of manufacture, sale and use of the products is being investigated by the National Energy Administration.

VII. Conclusion

The development of solar energy in Thailand is in the initial stage. Strengthening of the capabilities for the development of solar energy technologies successfully would require technical cooperation. Assistance is also requested in the form of multidisplinary advisory groups to help formulate short and long range plans, provision of fellowships for training and further study of her man power abroad, provision of prototypes and of experts for demonstration and adaptation in the country, and information for the monitoring of energy technologies for local scientists and technologists to be aware of the R & D activities and commercialization of energy technologies.

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REPORT OF THE SOCIALIST REPUBLIC OF VIETNAM DELEGATION

Dear Dr. President
Dear Representatives

First of all, I would like, on behalf of the Socialist Republic of Vietnam delegation to sincerely thank the organising committee for inviting us to this symposium on the applications of solar energy in South and South-East Asia. I also would like to send greetings to all representatives to this symposium.

The SRVN, lying in an area of 329,600 square kms in the tropical zone the 6th parallel to the tropic of Cancer is well located for the application of solar energy. According to the meteorological material the total annual hours of sunshine vary between 1500 and 1700: north of the 18th parallel between 1800 and 2000, or even between 2200 and 2500 in some places in the provinces south of the 18th parallel.

The average solar radiation intensity in summer is about 4000 kcal/m^2 per day. Of particular significance is the fact that this is unchangeable in the southern provinces thus making it favourable for the application of solar energy almost throughout the year.

I. Main Energy Needs to which Solar Energy can be Applied

1. Solar Drying Needs

This is to serve agricultural production, now a main branch in the economy, and some industries. In agriculture, solar energy is needed for drying an annual average yield of 20 million tons of paddy, maize, sweet potatoes and cassava. Because of the variable weather during harvest days, especially in the southern provinces, the natural drying method which is commonly applied now meets with many difficulties and doesn't meet the requirements. In industry, solar energy is needed in drying wood, fruit, pharmaceutical products, and short-term industrial products such as peanuts, tea, tobacco and sea-salt. Solar drying needs in industry are also great as Vietnam has millions of hectares of forests and hilly areas and more than 3000 kms of sea coast with many salt pans.

2. Solar Pumping Needs

This is to the serve irrigation and drainage, especially in newly reclaimed areas where electric and oil pumps will still be in short supply in the years to come. Only in the Mekong river delta are there irrigated areas reaching 850,000 hectares. The solar pumping needs vary from area to area. The southern provinces need pumps with a suction funnel 2 - 3 metres high or 5 - 15 metres high. The Northern provinces need pumps with a suction funnel 3 - 5 metres or 5 - 15 metres high and the central provinces need pumps with a suction funnel 10 - 30 metres high.

3. Hot Water Needs

This is for household cooking and drinking water, clinics, hospitals, dinning rooms, day-care centres and workshops that need boiling water. It is especially needed in coastal and island population centres where fuel is in short supply.

4. Water Distillation

To serve the population in the areas of salty or polluted water. To help replace parts of the current passive and expensive methods like building rain water containers or filtering.

5. Air Conditioning and Refrigeration

To help preserve farm or sea products like seeds or fresh fish, and prawns. Air conditioning in tropical houses combined with architecture, air ventilation and solar energy application is also necessary.

Moreover it is also necessary in Vietnam to use solar energy to generate electricity for remote or island population areas, and to use it in some industries in the form of "high" temperature.

II. Natural Conditions, Material and Technical Basis for the Application of Solar Energy in Vietnam

1. Natural Conditions

Much attention is being paid to the stormy weather from May to October, especially in the Central provinces.

2. Material and Technical Basis

Under the state policy, solar energy research work has been carried out in a number of Scientific and Technological Institutes and Technical Colleges. This work is guided by the department for new energy programs which belongs to the State Scientific and Technological Commission.

A group of technicians in the Electrical Research Centre of the Power and Coal Ministry has studied solar energy and its application for 3 years now and recorded some initial results. An experimental area has been built including a solarium and equipment for solar energy applications with low temperatures.

All research centres badly need laboratory equipment, all of which is imported. We have not been able to train solar energy technicians within the country.

III. Some Initial Achievements in the Research Work and Application of Solar Energy in Vietnam

1. Water Heating System (with single glass cover)

We have produced water heating systems with different flat plate collectors. A 10-square metre collector with a radiation intensity of 700 $kcal/m^2$ installed in the northern province of Ha Son Binh, last winter could heat 1000 litres of water a day to 50^oC. This collector was designed by the Electric Research Centre and produced by a district engineering workshop. It can even boil water.

2. Sea-salt Production

We have produced a 6 square metre absorber to perform experiments on the quickening of the water vapourization process in the Vanly salt-field in northern Vietnam. An initial survey following the winter months last year found that, from the brine at 21^{o}C and 18.7^{o}Be, after using the absorber, we obtained a quantity of salt two and half times more compared with the normal drying method and of better quality.

3. Sunning Rice-Seeds

To help increase rice seeds output and prevent disease. The first experiment on the method found that 82% of the rice seeds sprouted after being sunned while only 75% of the comparison batch sprouted.

4. Drying (with single glass cover)

We have tested different models of drying with air temperatures reaching 130^{o}C. We are designing a medium scale dryer for plywoods and compressed bamboo board.

We have also conducted research into applying solar energy in water distillation, refrigeration and electric generation at low as well as at high temperatures.

IV. Some Suggestions

The Vietnamese delegation would like to have opportunities to strengthen technological cooperation and exchanges of information on solar energy research work with all delegations in this symposium and other solar energy research organisations in the world.

Dear Distinguished Representatives,

Allow me, on behalf of the SRVN delegation for solar energy to express our sincere thanks to the organizing committee for its care and assistance given to the solar energy research and application work in Vietnam and wishing the symposium great success.

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ESCAP ACTIVITIES ON NON-CONVENTIONAL SOURCES OF ENERGY AND IT'S COOPERATION WITH AIT

Note by the ESCAP Secretariat

Shortly after the oil price increase which occurred in the last quarter of 1973, ESCAP convened the Intergovernmental Meeting on the Impact of the Current Energy Crisis on the Economy of the ESCAP Region in February/March 1974. The meeting reviewed the situation of the region and gave ten points of view for consideration. In that year the Commission declared energy as one of priority areas of ESCAP. Based on the views of the Intergovernmental Meeting and the Commission, ESCAP revised its programme of work in the energy field which comprised mainly two streams of action, one relating to energy planning including the assessment and exploitation of all sources of energy and the other concerning the development of non-conventional sources of energy. Activities on non-conventional sources of energy had been carried out in the following chronological order. A mission on biogas visited some ESCAP member countries in 1974, and two workshops on biogas were held at New Delhi and Manila both in 1975. The Expert Group Meeting on the Use of Solar and Wind Energy was held in 1976. The Workshop on Biogas and Other Sources of Rural Energy took place at Suva, Fiji in 1977 and was attended by Pacific countries only. In the same year the Roving Seminar on Rural Energy Development was organized at Bangkok, Manila, Tehran, and Jakarta from July to October. The Expert Group Meeting on Biogas Development was held at Bangkok last June. It is hoped that a guidebook on biogas would be published late this year.

At the Expert Group Meeting on the Use of Solar and Wind Energy, the Group endeavoured to identify the existing technology and devices for the use of solar and wind energy which could be recommended for immediate application, mainly but not exclusively in rural areas, and to recommend research and development activities likely to yield practical results in the short term, so as to improve the use of those resources.

The Group gave recommendations for the region with respect to the use of solar energy and wind energy and the use of integrated solar and wind energy. The report of the Group, working papers presented by the secretariat and summaries of papers presented by participants are contained in the proceedings (United Nations publication No. ST/ESCAP/7; sales No: E.76.II.F.13). Included in the proceedings are also the lists of organizations concerned with the research and development of solar energy and wind energy. These lists were updated and distributed recently.

One of the recommendations of the Expert Group Meeting on the Use of Solar and Wind Energy was for the establishment of a regional documentation and dissemination centre on solar and wind energy technologies, preferably at an existing library or technological institution within the region. In this respect and with due regard to recommendations at other meetings in Asia, the Asian Institute of Technology (AIT), Bangkok, which maintains close contact with ESCAP, established the Renewable Energy Resources Information Center (RERIC) in May 1978 at the Institute. The scope of the RERIC is to cover subjects of solar energy in the first year, and subjects of biomass, wind and small-scale hydropower in subsequent years. The service will focus on intermediate or appropriate technology. Contacts with other existing centers or organizations and close co-operation with ESCAP will be maintained.

As planned the Center will offer a reference service and publish Newsletters containing on-going projects, forthcoming events, etc. and review journals containing articles on "the state of the art".

ESCAP also participated in international meetings such as the International Solar Energy Congress (ISEC) in 1978 at New Delhi, the UNESCO Asian Working Group on Solar Energy also at New Delhi, and the UNESCO Workshop on Solar Drying in November 1978 at Manila. ESCAP is endeavouring to collect information on research and development. In the 1980-1981 programme it has a programme for a meeting on fuelwood and charcoal which is expected to be organized in co-operation with FAO.

DESCRIPTION OF APPLICATIONS IN THE FIELD OF PHOTOVOLTAIC CELLS

S. BIELIKOFF

R. BOULITROP

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Many experimental applications of photovoltaic cells have been carried out in past years throughout the world and particularly in Africa. This confirms the interest shown in photovoltaic technology and its perfect adaptability to low power, dispersed energy needs.

These experiments concern chiefly low power production from around 100 watts to a few kilowatts in isolated rural zones or at sea. They have already proven interesting :

- either because they are cost competitive with long life chemical batteries,

- or because of a service rendered, as in the present development of water pumps in zones where it is not possible to use conventional mechanized equipment.

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1. COMPETITIVE APPLICATIONS FROM A COST POINT OF VIEW

1.1. - BEACONS

Applications for photovoltaic cells already exist in the field of aerial and marine navigation.

In 1973 the first installations were set up in Saudi Arabia for night ground lighting at the airport of Medine located on a plateau in mountainous region. There are peaks in the vicinity which render access difficult and which must be marked out at night with beacons.

Supplying the beacons with current by electric line proved inadequate and costly because of the difficult access. At present beacons powered by solar generators are operating on seven peaks. They were transported by helicopter and it took only a few hours to install them. (BBT beacons - RTC solar panels).

In the domain of aviation a possible use for solar cells is to power landing lights at small airports far from civilization. The landing lights could be switched on from the airplane by radio.

In the marine sector ELF GABON equips all its production platforms with photovoltaic generators to power safety lights. Similar equipment is being installed by the BARBIER - BENARD - TURENNE (BBT) company in Saudi Arabia.

1.2. EDUCATIONAL TELEVISION

Education is essential if the world is to progress. New teaching methods must be developed to achieve this audiovisual methods at the forefront of innovation have evolved considerably. Educational television has played a major role in this evolution. Professors give their classes in certain establishments and these classes are rebroadcast by television to isolated regions, where they are commented on and explained by local teachers. .../...

Photovoltaic cells are more and more often called upon to furnish power for television sets. In Niger more than 150 villages have been thus equiped since 1968.

Under standard conditions it takes a peak power of 60 watts to run a 36 watts set for 30 hours per week. At 30F/watt this represents 1800 dollars invested in photovoltaic equipment. This is what it costs to power a set for two years with chemical batteries.

The following prices can be given by way of example :

- a low power television set 1000$
- photovoltaic cells with batteries and regulatins apparatus 3000$

1.3. - TELECOMMUNICATIONS

Since 1972 S.N.E.A. has progressively installed solar cells to power VHF radiotelephones on its oil production platforms off the coast of Gabon. Since this equipment was installed, maintenance costs for the network have dropped to almost zero and the system has become almost 100% dependable. This represents considerable progress over the results of other power sources previously used.

S.N.E.A. operates more than 20 oil fields on land and off shore with a surface of over 8,400 km2. Certain fields are 120 km from the administrative center in Port-Gentil.

For security and on the job convenience all platforms have VHF telecommunications equipment. This consists of a one-way telephone and connects all the platforms to each other, to land facilities and to the companies helicoters. Most of these platforms are linked to Port-Gentil by 10 w HF two-way radios with the exception of the southern block (BREME) which has 50 w HF installation because its location makes sending difficult.

.../...

In addition to humidity and corrosion typical of marine conditions, equipment is subject to the moist, equatorial climate of the coast of Gabon. On the site in Port-Gentil, for example, 18/10 or 18/10 Mo stainless stell does not resist corrosion.

Until 1972 the VHF network was powered by traditional means, generators running on gas from the field, vertical gas turbines, and banks of batteries recharged on land. Due to local conditions breakdowns were frequent and numerous repairs had to be made, especially in small installations feeding the VHF network exclusively. Vertical gas turbines require a regular supply of bottles of gas. Batteries which must be recharged periodically created a number of problems such as fall breakage, transport by boat, losses in loading and unloading, deterioration due to improper storage. Operating conditions were such that equipment was undependable and expensive repairs had to be made, for the most part by helicopter.

Since 1972 when solar cells were installed, all these problem disappeared almost entirely. There is no need for maintenance. S.N.E.A. was so satisfied with these results that it has progressively extended the experiment to other countries where the company exploits oil deposits. The latest installations have been made in the Cameroons and in Tunisia.

1.4. - SMALL POWER STATIONS

A large market for photovoltaic solar energy to meet the basic needs of isolated villages is in full development.

We were called on recently to study a project in the Sudan whose purpose was to supply power for a field dispensary and a few dwellings.

Needs were defined as follows :

- for the dispensary :
  - . 1 refrigerator 240 liters, 4°c
  - . 25 night lights, working 14 hours per day

.../...

. 4 lamps, 75 watts, working 3 hours per day
. 2 permanent ventilators in the nursing room
. 1 additional ventilator working 3 hours per day
. 1 water heater supplying 1,500 l/day of water at 60°c

- for the dwellings
  . Lighting for 10 houses - 3 lights per house working 3 hours per day
  . Outside lighting - 5 lights working 6 hours per day
  . Radiotelephone link at a distance of 100 km - continual reception, 1 hour sending per day.

To satisfy these needs the following equipment has been envisaged :

- A solar hot water system consisting of 24 m2 of greenhouse effect flat-plate collectors with copper absorbers and two storage tanks with a total capacity of 1000 liters

- A photovoltaic power station consisting of :
  . a battery of photovoltaic panels with a peak capacity of 2,600 watts
  . a bank of lead batteries with a total of 5,400 Ah
  . a regulator to insure that batteries are not over charged.

In view of capacity and local conditions, the solar installation is competitive with a small generator. Electricity is produced at a cost of 3 $/kWh.

Another installation of this type is being set up at the hospital in San, Mali. It includes a water pumping system, lighting, ventilation and a refrigerator.

2. APPLICATIONS IMPORTANT BECAUSE OF SERVICES RENDERED - WATER PUMPING

The simplicity with which solar pumps can be operated and the possibility of limiting maintenance to one visit per year have led many countries to set up this sort of installation in spite of costs which are still high. Solar pumps are to be found in regions where operating traditional mechanized equipment would have been difficult if not impossible. They make possible the development of local ressources : small scale irrigation of fruit and vegetable crops, irrigation of dah, fiber processing, and increasing livestock production.

2.1. DESCRIPTION OF A SOLAR PUMPING INSTALLATION POWERED BY SOLAR CELLS

The pumping system powered by solar cells includes :

- a battery of solar panels directly converting solar energy into direct current
- a centrifugal vertical long shafted well pump. This pump is widely known in Saharan countries because of its sturdiness. The head of the pump remains above ground level ; the hollow part of the pump is placed at the bottom of the well. A long shaft guided by bearings and turning inside the casing through which water rises connects the moving part of the pump to its head. These pumps do not require complicated regulators to prevent their being damaged when there is no water.

  The length of their shafts can be easily modified which makes it possible to move these pumps from one site to another or to adapt them to changing conditions at the first site.

- a direct current electric motor specially designed for being powered by solar cells. It is placed inside the head of the pump and powers it.

- electric wires : they connect the solar cells to the motor and run through a switch box

- a float switch in the tank cuts the power when the tank is full.

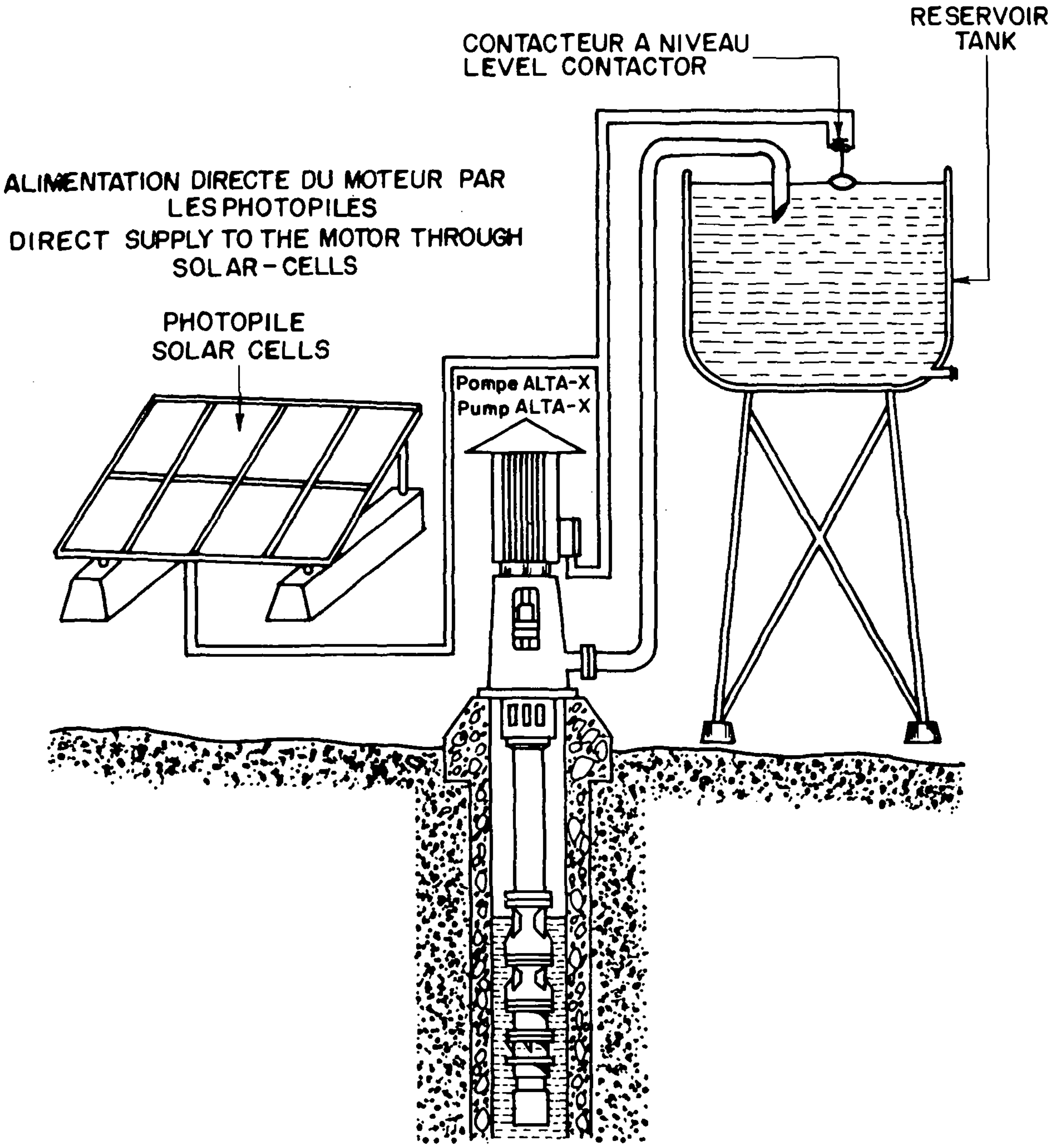
The diagram on the following page describes how this kind of installation works.

It is important to point out that accumulation of electricity in an expensive battery, which is difficult to operate and inefficient, has been suppressed.

Everything is automatic. The pump starts up when the sun rises to 15 ou 20°c above the horizon and stops at a certain threshold of light.

The entire installation is designed to be able to function with no supervision and no maintenance for one or two years. From time to time the surface of the solar cells should be cleaned with water to remove the dust.

ENSEMBLE DE POMPAGE "ALTA-X"
PUMPING UNIT "ALTA-X"



2.2. - DATA CONCERNING THE INSTALLATION OF A PHOTOVOLTAIC SOLAR PUMP

The figure on the next page provides a picture in perspective of the installation with the most important distances. The tables below give the values of these distances under different conditions of use.

ENCOMBREMENTS AU SOL
GROUND OVERALL DIMENSIONS

Puissance (crête) *Power (peak)*	A *m.*	B *m.*	surface au sol area *on the ground*	des photopiles *of the solar cells*
600 Watts	3	5,5	17 m^2	9 m^2
900 "	3	7,7	23 "	14,3 "
1300 "	4,8	7,7	37 "	20,3 "
1800 "	6,7	7,7	52 "	27,4 "
2600 "	6,7	10,5	70 "	38,2 "
3900 "	8,6	12	103 "	59,6 "
5200 "	10,5	15,6	163 "	78,7 "
6600 "	11,8	17,5	205 "	100 "

DISTANCES DES CLOTURES hauteur max 2m.
distances from fences *2m. height max.*

a = 1m. | b = 2,5m. | c = 2,5m.

Latitude	d
Equateur à *Equator to* ±10°	0,9 m.
±10° à *to* ±20°	1,3 m.
±20° à *to* ±30°	1,9 m.
±30° à *to* ±40°	2,8 m.
±40° à *to* ±45°	3,5 m.

DISTANCE DES OBSTACLES A L'OUEST OU A L'EST

DISTANCES FROM OBSTACLES TO EAST AND WEST

$L_1 \geqslant 2$ fois / times h_1

DISTANCE DES OBSTACLES AU NORD ET AU SUD*

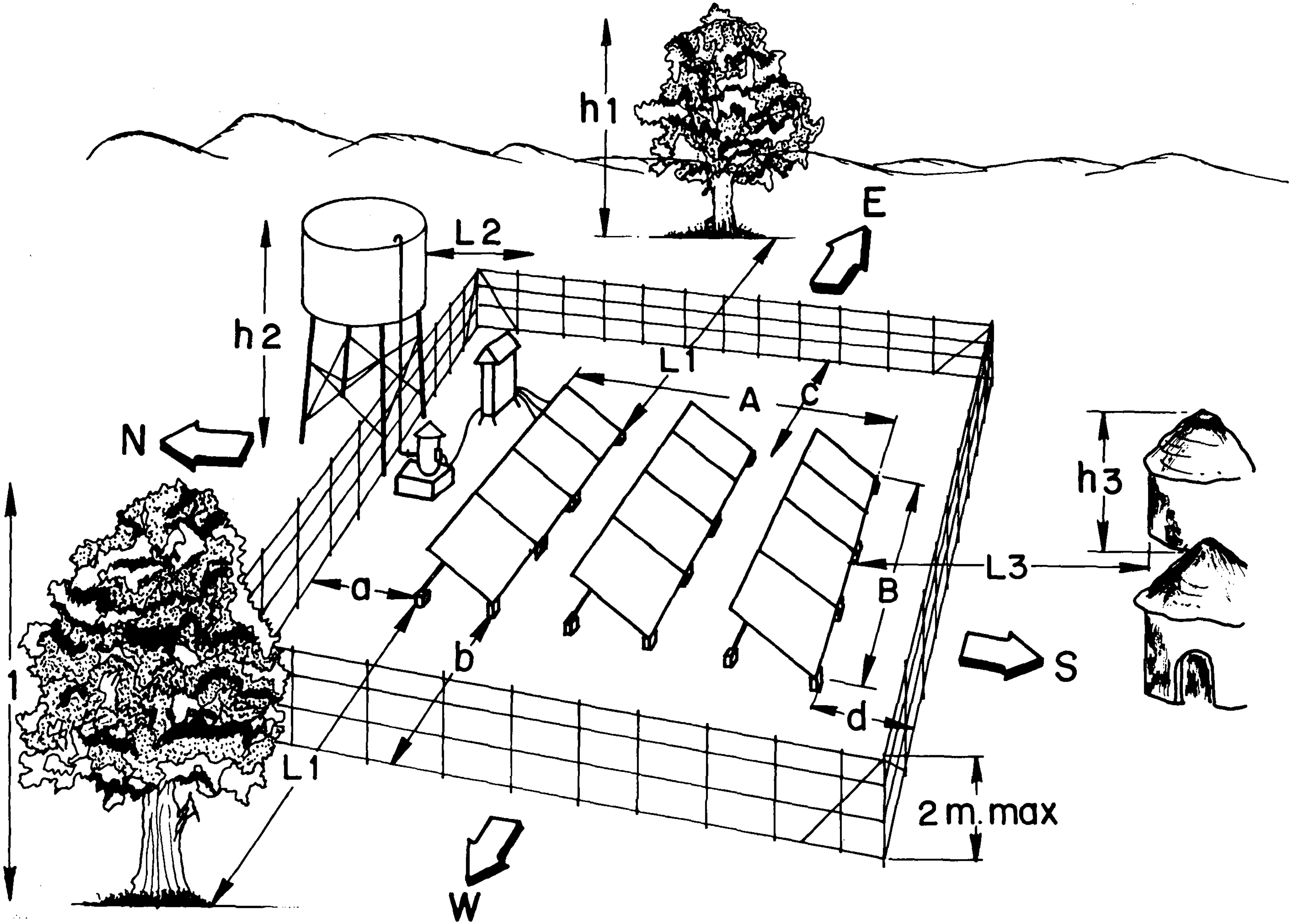
DISTANCES FROM OBSTACLES TO NORTH AND SOUTH*

LATITUDE *LATITUDE*	DISTANCE DES OBSTACLES / DISTANCES FROM OBSTACLES — NORD *NORTH*	SUD *SOUTH*
Equateur à *Equator to* ± 10°	$L_2 \geqslant 0{,}4\ h_2$ ou / or $\geqslant 2$m.	$L_3 = \geqslant 0{,}7\ h_3$
± 10° à *to* ± 20°	$L_2 \geqslant 0{,}25\ h_2$ ou / or $\geqslant 2$m.	$L_3 = 1\ h_3$
± 20° à *to* ± 30°	$L_2 \geqslant 2$ m.	$L_3 = 1{,}4\ h_3$
± 30° à *to* ± 40°	$L_2 \geqslant 2$ m.	$L_3 = 2\ h_3$
± 40° à *to* ± 45°	$L_2 \geqslant 2$ m.	$L_3 = 3{,}3\ h_3$

*Pour hémisphère sud inverser dans le croquis le sud et le nord.

* In the southern hemisphere, reverse the North and South designations on sketches and tables.

DONNEES D'INSTALLATION D'UNE POMPE SOLAIRE
MAIN DATA FOR INSTALLATION OF A SOLAR PUMP



2.3. - INSTALLATION PERFORMANCE

Hauteur manométrique totale	MODELE DE POMPE											
	TYPE 600 W				TYPE 2 600 W				TYPE 6 600 W			
mètres	m3/j	personnes alimentées ou	bovins alimentés ou	m2 cultures maraîchères	m3/j	personnes alimentées ou	bovins alimentés ou	m2 cultures maraîchères	m3/j	personnes alimentées ou	bovins alimentés ou	m2 cultures maraîchères
5	145	4 800	3 600	24200	605	20 150	15 100	100800	1 705	57 000	42 600	284000
15	31	1 050	750	5200	204	6 800	5 100	34000	535	17 800	13 400	89200
25	46	550	400	2700	115	3 850	2 900	19200	330	11 000	8 300	55000
50	-	-	-	-	50	1 650	1 300	8300	156	5 200	3 900	26000
70	-	-	-	-	31	1 050	800	5200	105	3 500	2 600	17500

2.4. - PRACTICAL EXAMPLES

		OUTPUT
ABU DHABI	: organization of nomads	36 m3/day
KONI MALI	: water supply of a training center	40 m3/day
NABASSO MALI	: water for a village of 1000 inhabitants	30 m3/day
CAMPOMORO CORSE	: farm for 250 sheep	16 m3/day

CONCLUSIONS

Beacons, educational television and telecommunications are fields in which photovoltaic technology can be applied economically but they represent a relatively limited market.

The installation of small power stations in isolated areas and the pumpin of water for domestic use in villages and in irrigation have been the object of pilot projects and the results are extremely encouraging. These two types of application represent a considerable marked located chiefly in developing countries.

With the projected decrease in the cost of photovoltaic solar energy, there should be a spectacular development of such applications in the future.

SOLAR AIR CONDITIONING

CLISOTOS HOUSE AT SOPHIA ANTIPOLIS

F. BRUNE

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Compagne Française des Pétroles-PARIS-France *

The CLISOTOS (1) house at SOPHIA ANTIPOLIS represents the results of the research programme (2) carried out by the TOTAL C.F. Group and SOFRETES for building using solar energy :

- heating
- cooling and
- production of domestic hot water.

The purpose of the programme was to produce solar air-conditioning and energy management systems.

The research has not been limited to the application of equipment of hot-water and chilled-water production by includes all the active and passive means that may be used to create comfortable temperature conditions in a building : structural design, window area, insulation, solar protection, etc...

1) CLISOTOS : "Climatisation Solaire TOTAL SOFRETES"
(TOTAL SOFRETES Solar air-conditioning)

2) Sponsored by DGRST and D.E.N.

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5, rue Michel Ange - 75781 PARIS Cédex 16 - FRANCE

.../...

It has indeed been noted that a well-adapted choice of the type of structure and architectural design can considerably reduce the overall cost of the unit.

An important feature of the Clisotos system is that each parameter can be optimized in accordance with the use of the building and the local climatic conditions.

It was also necessary to satisfy the following requirements :

- the use, downstream of the cold production unit, of quite conventional mass-produced air-conditioning equipment ;
- the possibility of using the basic principles and the technology, without substantial modification, in different climates ;
- the suitable management of energy by a microprocessor type unit with an optimizer for each climate ;
- the use of solar panels using a fluid at a maximum temperature of 90° or 95°c.

1. THE CLISOTOS SYSTEM

1. A short description of the pilot house of SOPHIA ANTIPOLIS will be given, emphasizing on the special attention which has been paid to the structure and the insulation.
2. After the description of the space heating and the air conditioning system, we will justify the choice we have made for the chilled water production system and the solar collector .

For this purpose, a computer simulation programme was developped to optimize a solar system with a low-temperature absorption machine, in accordance with different types of collector and for different climatic conditions.

An examination of the computation showed that the best performing collector does not necessarily yield the highest efficiency for every typical day, since the remaining parameters are also very important factors.

It can thus be concluded that the system's best performance is obtained at the lowest activation temperature of the absorption machine and not at the temperature corresponding to the maximum COP. (coefficient of performance).

3. Regarding the hot-water storage, the C. F. P. TOTAL storage tank installed enables priority to be given to quality (controlling temperature) when storing a fluid rather than to quantity in contrast to conventional tanks which function on the quantity principle without quality control.

   The chilled water storage is more conventional in the sense it is a stratification system but with a special improvement.

4. TOTAL C. F. P. has designed and built an automatic control and energy management system to optimize the plant's performance. This system is a microprocessor solid-state (printed circuit) type working in accordance with control programmes.

.../...

5. In order to analyse the behaviour of the solar cooling and heating system under operating conditions, an important measurement programme has been carried out. A programme which as confirmed the results of the theoritical research and has been very useful in developing the ideal energy management and storage system.

2. ADAPTABILITY TO HOT AND WET CLIMATES

Hot and wet seem to be the main characteristics of the South East Asian climates. Among the various solar air conditioning systems using on-the-shelf components, the CLISOTOS system is the most adapted to these climates and has really been chosen for its ability to reach their requirments.

But we must be aware of the difficulties and we will have to solve the following problem : during the wet (and cloudy) season, will the diffuse insolation be sufficient enough for the flat plate collectors to reach the high temperature required by the warm water of the chiller ? This high temperature is in fact necessary to obtain chilled water cold enough to deshumidify the fresh air to the maximum degree of humidity required by the comfort conditions.

This question can be answered easily by a simulation taking into account the following data for a typical day.

- direct and diffuse insolation hour by hour,
- ambiant temperature and degree of humidity hour by hour,
- comfort conditions required,
- physical characteristics of the building.

- o - o - o -

For an installation with vapour compression water chiller, the overall equipment for chilled-water production requires about 0.4/0.55 kW to produce 0.33 tons or 1,2 kW (for hot and wet climates the energy needed is about 40% more).

.../...

The CLISOTOS system should make it possible to reduce the electric power requirement to 0.09/0.13 kW per 0.33 tons or 1.2 kW of cooling, and this for pratically all climates.

An optimized solar system can thus reduce the quantity of mains electric power needed to about 18-20 % of that required with a vapour compression system.

THERMODYNAMIC SOLAR WATER PUMPING SYSTEMS

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and

B.M. DEVIN

Atomic Energy Commissariat - PARIS - France *

SOLAR PUMP PROCESS

The first goal was to develop autonomous water pumping equipment, initially for hydraulic uses in small villages and livestock raising, and then for irrigating crops in arid regions. Since this equipment would have to operate in isolated sites where there are usually no skilled specialists capable of providing maintenance for sophisticated aquipment, the leading features sought after were simplicity, ruggedness and reliability. So, it was initially decided, to use a low temperature thermodynamic cycle.

This cycle operates between a hot source supplied by solar energy and a cold source supplied by water pumped up from the sub-soil.

A solar pumping station includes the following components :

- a battery of flat plate collectors in which water or a heat-carrying liquid circulates in a closed circuit

.../...

* C.E.A.
33, rue de la Fédération - 75015 PARIS - FRANCE

- a heat-exchanger inside which the fluid circulating in the collectors transfers its calories to the fluid circulating in the motor circuit, producing fluid evaporation

- the motor circuit which, in addition to the heat-exchanger, includes the expansion motor, a condenser and a re-injection pump

- the pumping circuit itself, which for low power installations of about 1 kW includes a hydraulic press and a well pump, or for higher powers (25 and 50 kW) an alternator and a motor unit driving one or several pumps.

PRACTICAL APPLICATIONS FOR SMALL UNITS (1 to 5 kW)

HYDRAULIC USES IN VILLAGES

Water supply for isolated villages and oases is a crucial problem. Hand pumping results in considerable waste of time and energy for the inhabitants. Conventional pumping by diesel or explosion engines is conditioned by all uncertainties of fuel supply and requires maintenance which is made difficult under severe climatic conditions, the lack of skilled manpower and stockpiles of spare parts.

The integration of a solar pumping station into a villages is a practical solution. In addition, the installation of the collectors on the roof of a building creates a refrigerated enclosure since a large portion of the calories received is evacuated by the collectors. This building can be used to house a school, a cattle marcket, a dispensary, etc...

HYDRAULIC USES FOR LIVESTOCK

In livestock grazing regions, the uncertainty of the wells along transport routes often means that flocks and herds must depend on a single well, sometimes causing disastruously inadequate conditions.

The multiplication of small volume watering places by means of entirely reliable and autonomous equipment, as the result of using solar energy, makes it possible to supply water rationally to nomad tribes and their herds and flocks.

As things stand now, about 70 solar pump stations as mentioned above are now in operation in twenty countries : United Arab Emirates, Brazil, Cameroons, Upper-Volta, Capo Verde Islands, Mali, Mexico, Mauritania, Niger, Chad, Senegal, The Philippines, Kenya, Sudan...

SOLAR PUMP FOR IRRIGATION PRUPOSES (20 to 100 kW units)

1. SAN LUIS DE LA PAZ

A 30 kW installation delivering electricity for water pumping has been installed in Mexico and has been operating since September 18, 1975. It was researched and developed by the Promethee Association, which includes the French Atomic Energy Commission (CEA) and SOFRETES. It operates according to the same principle as the small stations, except that the expansion motor is replaced by a turbine which drives an alternator. The electric power produced is, of course, used to pump water.

The general characteristics of the installation are as follows :

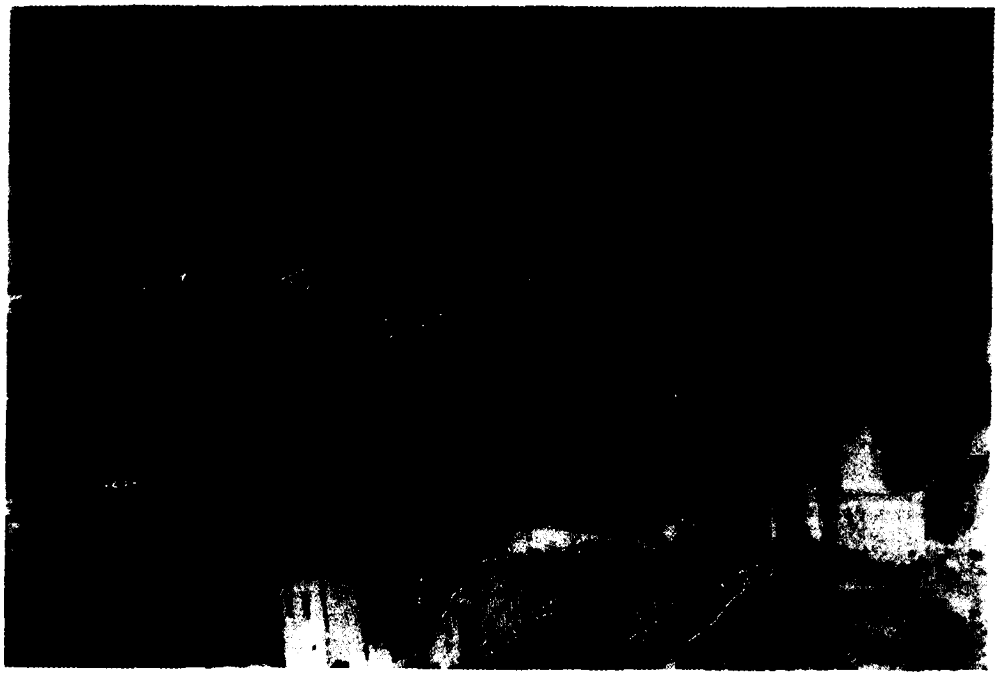
Surface area of collectors	1,500 m2
Working fluid	Freon 11
Turbine rotation speed	7,400 rpm
Pump	Electric centrifugal
Water pumped to 40 m discharge height	153 m3/hr average

This solar power station delivers about 900 m3 of water per day, and it is, to our knowledge, the most powerful solar unit working in the world. Water is tapped at a depth of 40 m in the underground water-table. It delivers water to 15,000 inhabitants of the "pueblo" and will finally irrigate 20-30 hectares of experimental crops. The room available under the 1,500 m2 solar collectors roof will be used for the facilities of an experimental farm.

This first large solar unit devoted to irrigation purposes is located in San Luis de la Paz (Guanajuato State, Mexico) see figure 2. It is part of a long range government programme, run by the environmental improvement agency under the Health Secretariat.

.../...

San Luis de la Paz belongs to the semi-arid climatic zones in Mexico. It has an average mean temperature of about 17°c (62°f), a maximum of 41°c (106°f) and a minimum of about -5°c (23°f). In an average year, rains falls on 39 days and the town has sunny weather on 250 days.



Station d'irrigation solaire
de San Luiz de la Paz (MEXIQUE)

2. DIRE

A 70 kW solar power station for Dire (Mali) on the Niger River. In this project, the power delivered will be simultaneously used to :

- pump water from the Niger River for irrigation at a rate of over 2 m gallons of water/day (to irrigate 150 hectares)

- operate a refrigeration unit at a temperature of + 4°c

- supply the electrical network of the solar village during the evenings.

.../...

3. BAKEL

A joint project between the Government of Senegal, the US Department of State and the French Government is on the way to implement a large solar water pump in Bakel, Senegal, in 1979.

SOFRETES, Thermo Electron from the USA and Sinaes, a National Senegalese company are in charge of this program. The solar pump will lift water from the Senegal river and will deliver an average daily output of 8,000 m3/day for 100 to 150 ha crops irrigation.

4. SAUDI ARABIA

In 1979 the first large solar power station will be implemented in Saudi Arabia. This is a program of the Saudi Ministry of Industry and Electricity, Electrico, and of the Saudi Solar Energy Committee.

From the experience and environmental data supplied by the College of Engineering at Riyadh University, it was decided to use flat plate collectors with black chrome selective coating and double gazing. The designed solar power plant will consist of a system covering the following objectives :

- producing water for electricity and mechanical water pumping
- researching and developing solar thermal power systems
- public demonstration.

Its implementation will take place at a Farm engineering centre in the Riyadh area.

35 kW electrical peak power will be available. The solar plant, associated to the thermal storage facilities will supply energy 24 hours/day.

.../...

The thermal storage system will provide three functions :

- correcting daily solar radiation variations
- night operation
- operating during bad weather periods.

ECONOMICAL CONSIDERATIONS

Cost consideration are of prime importance in solar energy application, mostly because investment in solar systems represents the quasi total investment, at once, for the whole energy to be delivered by the equipment.

First, financing schemes differing from the usual habits have to be set up and solar developments will need either government initiated programs either leasing processes when the technology will be in common use.

Then, since cost is essentially a first capital investment cost, its decomposition in basic elements is of great interest since it shows what cost elements can be affected by local considerations or straight forward technology transfers.

To take an example, a 30 kW thermodynamic unit with a heat storage tank for round the clock operation at minimum power of 10 kw delivering 250 kWh daily average out put, consists of :

Collectors and piping	30 %
Storage reservoir	18 %
Thermodynamic unit	20 %
Control	2 %
Metallic Framework structure	4 %
Civil work	10 %
Erection and start up	9 %
Transport from Europe to Middle East	7 %
	100 %

At least three of the investment items could be transfered very rapidly for local manufacturing. The delivery and transport cost would consequently be directly affected.

These costs do not include the part of investment related to the utilization of generated energy. Which are not "solar energy dependent" and would be similar with diesel engine generators, i. e. :

- for pumping stations : borehole and pumps, water reservoir, irrigation distribution system
- for electrical generators : distribution line, transformer, regulators and safety devices).

In most of the cases, these investments have the same order of magnitude as the generating set.

Finally, comparing solar energy cost with alternative solutions is not straightforward, because the effective expenses associated with energy generation in remote areas, where solar energy is well suited, are generally not known by the operator.

.../...

Case studies made in Africa on electricity generating stations operated by Power Utilities have shown that electrical kWh was not unusually worth 1 to 2 US $, even for generator sizes up to 250 kW depending on the "remoteness" parameter.

In fact, proper terms of comparison are not easy to found for really objective appreciation.

- the "Investment cost per kW" is not adequate due to the specific load pattern of solar units (e.g. : pumping)

- the better figure seems to be the
  Investment cost/installed kWh per day.

Which gives a good basis for comparison between alternative solar energy systems, if not between solar and conventional.

In this units, the realistic observed figures for devices produced in Europe and installed in remote zones of African territory quote as follows :

Daily Energy range	Investment per kWh per day
20 to 100 kW	3000 to 4000 US $
5 to 20 kW	6000 to 7000 US $

Taking into account the price breakdown of upper table, and estimating a significant cost reduction by technology improvement and performance increase, these figures should be considered as able to be reduced by a factor better than 2 or 3, according to the local capabilities of manufacturing, installation and maintenance.

.../...

SOCIO-ECONOMIC FACTORS

It can be understood that usual cost competitivity appreciation of solar energy systems is not a decision factor, but in very remote areas. However, this crude analysis seems to be not realistic since it cannot translate directly into figures what is really "solar energy" I mean a channel for development and growth.

We have seen that its financing conditions were related to government political decisions, and these are supported by the responsability and technology transfer scheme which is to be associated with solar energy :

- creation of local activities for manufacturing and maintenance
- improvement of remote areas growth factor by providing indigenous energy source, not dependent from imports or periodical supply of materials outside the local community
- preparation of a self supporting future when oil costs will be dominated by the market laws (demand above supply)
- after the technology transfer period : saving of hard currencies and reduction of economic dependence from abroad.

CONCLUSION

In conclusion, I would rather say that solar energy devices are worth to be considered as a joint development project between industrialised and developping countries, in order to take into account the whole set of socio-technological parameter and be in a position to set up a comprehensive program. Existing systems are to be considered as probatory models whose reliability and operation experience have shown the benefits which are to be expected from large scale solar energy development. Local demonstrations and testing schemes are to be undertaken with careful control by scientifics, technical, industrial and socio-economic bodies in order to prepare the adapted introduction of these technologies in the stream of the development processes of the less equipped areas.

SOLAR DISTILLATION OF SEA AND BRACKISH WATER

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The problem of fresh water supply on our planet increase progressively with the world population growth. An annual consumption of 800 m3 per capita in the U.S. (1950) and of 500 m3 per capita in Cypre (1966) will attain an average value of 2000 m3 per capita, corresponding to $12 \cdot 10^{12}$ m3 annual consumption for an estimated number of 6 billion people living on our planet in 2000, while the water cycle provides only 60 . 10 m3 of fresh water annually. This situation shows the importance of the researche on the fresh water production.

The water desalination is one of the available methods to provide fresh water, but it demands a great quantity of energy. The use of solar energy for this purpose is promising especially for developping countries which mostly lie in the zones where solar energy is abundant.

Some researches on the solar distillation have been done, especially the utilization of the green house effect, which involves 3 main operations : heating, evaporation and condensation (solar still).

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.../...

Water heating requires a heat source and condensation of vapour a cold surface. For economical reasons, utilization of solar stills (that is based on the principle of "hot-box") to produce fresh water is limited. The operations of collecting solar energy and heating water are realised by a black pan that is the bottom of the basin. Condensation takes place on the internal face of the glass which is also the roof of the hot-box. Then, heat of condensation is to ken off by the ambiant air.

The "hot-box" type solar still is just a little perfectible, and research purpose is mainly to increase productivity by decreasing thermal losses and using new materials (plastic and not glass) which may involve to the reduction of cost price. For such types of still places in sunny regions (5000 Kcal/m2/day 0,3 KW) the mean production of fresh water is 4 l/m2/day. Most of the existing solar stills are units ; only some industrial sets are known, and their mean production is generally less than 100 m3/day.

The basin is often made with concrete metal or plastic film in the small stills. Thermal insulation between saline water and the soil can be made either with on internal sheet (plastic film or glass wool) or by utilization of asbestos ciment. Water tightness at the bottom is obtained by using synthetic rubber sheet or a bitumen glass ; this black sheet absorbs solar radiation ; however absorption of solar radiation may be increased with introducing a black porous wick in the saline water.

Solar still cover is generally made with glass or plastic film. It has two functions : first it acts as a selective filter to solar radiation (sun radiation crosses it and it must be opaque to the radiation reflected by the black pan the temperature of which is low) : secondly it is the condensing surface for vapour.

.../...

A good wettability is necessary to avoid tiny drops condensation ; these drops may fall back into the basin or reflect a great portion of solar radiation. The cover is tilted (generally from 5° to 20°) in order to ensure condensed water flowing to the collecting tank. These conditions are satisfied with glass. Since few years plastic films have been realized (mylar, polyvinyl fluoride) and their optical properties and wettability are suitable ; however in spite of its low cost price, plastic film is not actually superior to glass for its transmissivity decreases with age.

It is also necessary for solar still working to use a mechanical energy source to feed it with saline water.

Low deeped solar stills have a low thermal inertia, they produce water at sunny time only and not during night. On the contrary high deeped basins accumulate the heat of the day and they work during night. It is generally admitted that low deeped basins have better efficiency. Solar stills construction and their working is technically rendered difficult particularly with water tightness (joints and cracks caused by wind lodding) and materials durability (saline water corrosion, fatigue caused by solar radiation), sand and salt deposits, growing of seaweds, breaking of the cover.

Then it has been decided to tilt the black absorbing surface in order to ensure more entring solar energy with keeping a low saline water thickness. This principle is realized in cascade and porous wick solar stills. Relatively, there is only a few industrial realization of these types. They have slightly better productivity than horizontal basin type solar stills but actually that is balanced by their high construction cost. In porous wick stills, it is difficult to solve the problem caused by salt deposit in the pores ; however cascade solar stills could work on the houses roofs and that would be very suitable.

.../...

Many other sophisticated apparatus have been proposed in order to increase solar stills productivity but their equipment cost considerablely increases and finally these stills are not economically advantageous.

The principle of hot box type solar still is simple but the physical processes that follow with distillation are complex and interrelated ; energy transfers between solar still and the ambiant air, and between different elements of the still must be considered. Thermal losses especially are important, not only because they have a decreasing effect on productivity, but they are also responsible of condensation that is fundamental for distillation.

Solar still efficiency (E) totally evaluates the ratio between thermal losses to incident solar energy ; it is defined as the ratio of the real distillated water production to water production that could be attained by converting the whole incident solar radiation into heat of evaporation. The value of E is generally between 0.3 to 0.6 then for an incident solar radiation of 5000 Kcal/m2/day, hot box type solar still productivity is 3.5. Kg/m2/day (if E = 0.4 and λ = 578 Kcal/kg).

High developed mathematical models are directed to investigate the parameters involved and that may make efficiency be maximum. Directly one difficulty is non stationnary working of solar stills. Steady state conditions are practically not attained because of continual solar radiation variation. Some of these models include in the treatment, unsteady state conditions.

Cooper has established that the maximum efficiency of a solar still is 60 % ; that "ideal" solar still is defined as one :

- which has no conductive losses at the bottom and the walls

- where the water depth is sufficiently small so that the sensible heat stored is negligible compared with the energy transfer rates to and from the water.

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As Cooper says there are values of cover inclination and gap distance between water and cover that make efficiency be maximum.

The authors do a comparative study on this kind of solar still by using the electrical analogy of the system and its digital simulation by computer. Some parameters are involved in this study, namely, the design parameters, the meteorological ones and the ones describing the physical properties of the brine. The aim of this study is to choose the best system and to determine the optimal values of the parameters which give the best performance of the solar still. Three principal models and their variations namely water streeming distillator, static distillator and the one with double glasses have been studied. The method consists of dividing the system in a discrete number of small periodes and calculating the parameters describing the performance of the distillation as a function of some input parameters (design, meteorological and physical parameters), and then taking the average values of these parameters. The optimization is done by selecting them as a function of the input parameters.

An experimental study has been done to verify this method, giving good results which prove that this method of simulation is justified.

New researches have traced out 3 promising directions for brackish water desalination.

1) Conception of solar heat-pumping stills in order to use latent heat of evaporation. Then the output and efficiency attain respectively to values of 15 l/m2/day and 58 %

2) Desalination by inverted osmosis where the useful necessary energy is produced by solar energy thermodynamic conversion.

3) Desalination by electrodialysis where the useful electrical energy is also produced by direct solar energy thermodynamic conversion.

HIGH PERFORMANCE FIXED COLLECTORS

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There is a major interest in conceiving and designing solar thermal collectors of higher performance than usual collectors and which could still be used in a fixed position, without the burden of sun tracking, flexible piping and mechanical motive power.

Examination of the basic losses in solar collector physics shows the major terms to be optical losses and convection-conduction losses in the air gap. The latter becoming largely dominant over radiation losses for selective coating absorbers when the collection temperature increases.

In order to deal with a realistic problem, the 130-150°c collector is treated in greater details since it covers two promising fields :

- the cold production with industrial ammonia water-systems
- the thermodynamic engine with conventional fluoro carbon working fluids.

The following assumption are made :

- the operating temperature is to be obtained 6 hours per day with a collecting efficiency superior or equal to 50%

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- the collector is not a single isolated unit, but is interconnected with other similar collectors in a collecting net work, then irreductible piping thermal losses are to be included.

- the total water equivalent thermal inertia is taken into account subsequently in order to define upper acceptable limits for this parameter.

First, a diagram, shows how "vacuum collectors" and "concentrating collectors" do modifiy the basic losses distribution and allows to increase the efficiency at elevated temperature, for the same unit area intercepting the solar radiation :

- vacuum collectors play on loss reduction by governing the loss factors of the unit area,

- concentrating collectors, with conventional absorbers, diminish the size of the absorbing element related with the unit area exposed to sun, thus reducing the total loss without changing the loss factors.

Second, the basic equation for a multi element collector is laid down and signification of the relevant terms is given on various examples. It is shown how, qualitatively, the arrangements proposed in the litterature, and on the market, do behave with respect to the basic physical phenomena involved.

Then, third, calculated performance of several structures able to fulfill deproposed 130-150 requirements are given and comments are made on these solutions.

In particular, attention is paid to selectivity requirements, mirror shape, concentration factor and the question of acceptance angle is considered.

Quite few solution are remaining for a "fixed collector" solution.

Finally, daily energy yield is calculated for these solutions, taking into account the thermal inertia relative to the unit collector area and practical limits are shown.

PRESENT STATUS AND FUTURE PROSPECTS

OF SILICON SOLAR CELL ARRAYS AND SYSTEMS

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The first part of this paper will deal with the present state of the art of the single crystal silicon cell industry : production volume, cost breakdown and main technologies.

In the second section, improvements of the single crystal technologies, due to mass production and automated physical processes, will be described. These developments will be compared, with regard to both cost and performance, with the future polycrystalline (or "semicrystalline") materials, including amorphous silicon films. The various approaches, i.e. vapour or liquid film deposition, or oriented bulk ingot crystallization, will be discussed.

The third part will assume that very low cost goals can be achieved, either through the development of sophisticated single crystal technology, or through a polysilicon breakthrough. Future markets for photovoltaic conversion, including medium-size power generation plants, will then be considered.

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1. INTRODUCTION

Silicon solar cells and arrays are presently the only photovoltaic devices commercially available, and they will most probably keep this dominant situation for many more years. They have been known for 25 years, are widely used for spacecrafts, and in the past 5 years have shown a remarkable growth for terrestrial uses.

However, although improved technology and automated production lines will undoubtedly bring a cost reduction by a factor of 5 or perhaps 10 with respect to present prices within the next 5 to 7 years, singlecrystal cells are hampered by the high cost of the crystal pulling, and by kerf loss of this very valuable material during the wafer slicing operation.

Therefore, great attention is paid to polycrystalline silicon research and development, with an emphasis on thin film deposition methods. Another cost reduction of 5 might be expected in a more remote future from these new technologies, making solar electricity competitive with classical generators.

Another way of cutting prices lies in the use of optical concentration which transfers the major part of the cost from the cell to the optical system.

In spite of this potentiality, one cannot expect that rather complicated tracking mechanisms could eventually beat the low-cost polycristalline technology of flat solar cell arrays.

Great attention is also paid to other materials : single crystals, such as Gallium Arsenide suitable for very high concentration, or cheap thin films (amorphous silicon, cadmium sulfide and other II - IV compounds).

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Thin films have not yet proven their reliability and for the time being present efficiencies much lower than silicon cells. Yet, very cheap technologies can be conceived for their production, and they remain challengers to silicon.

2. PRESENT STATUS OF THE PHOTOVOLTAIC INDUSTRY

The world production of silicon cell panels (encapsulated solar cells) is estimated in 1978 at about 1 MW (peak).

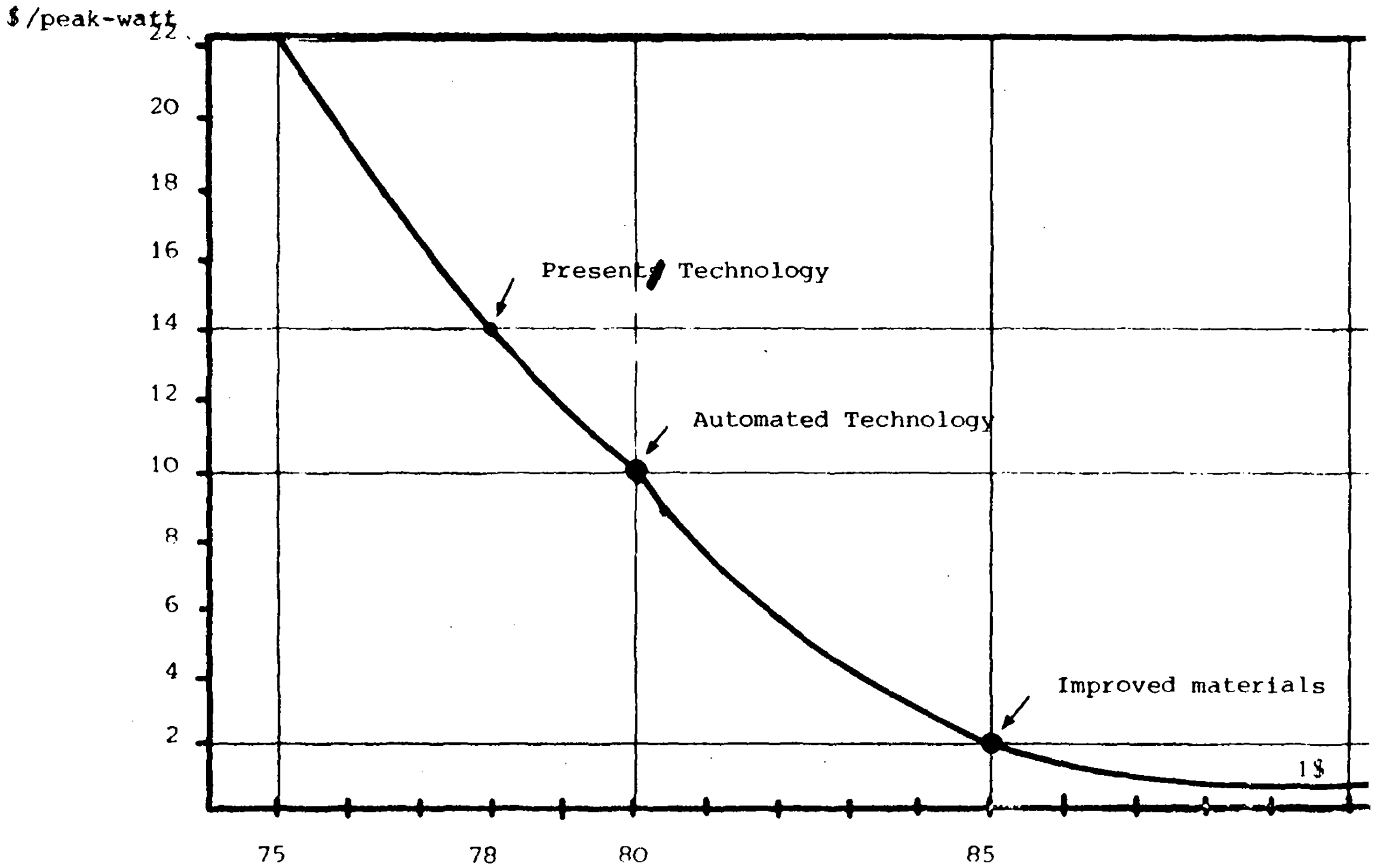
About three quaters of this amount are manufactured by half a dozen American Companies. The non-U.S. production is dominated by a French manufacturer, with a yearly production of 200 KW. The rest comes from Japan, with pilot-scale production in Germany and the U.K..

The rate of growth of this industry is very high, doubling every year. At an estimated average price of US$ 16-20 per peak-watt, this industry has a world-wide turnover of about US$ 20 Million, which roughly doubles with the associated system hardware. Prices have dropped steadily by 20% per year in the past 4 years. However, the market demand seems to-day to be larger than the production. But this phenomenon is rather temporary, as new and large production units are being built.

Figure 1 shows the long term trend of photovoltaic panel costs : this personal analysis is somewhat less optimistic than the values predicted by the U.S. Department of Energy, which forecasts prices as low as 1.00 $/peak-watt around 1986 or 1987. In my opinion, two facts are overlooked :

Fig. 1

Expected Price Trend for photovoltaic Panels (Bulk Price)



- the cost of encapsulation, which is independent of the value of the active photovoltaic material, cannot decrease as fast and as much, especially because of the present tendency to use glass windows instead of plastic coatings which are less reliable ;

- cheaper materials, such as "polysilicon" are still in a research stage and might not become industrially available before 1985.

3. COST REDUCTION PROGRAMMES

The strongest effort, by far, is made by the U.S. Department of Energy. The very recent (October 1978) "Photovoltaic Act" passed by the Congress is a mobilization of gigantic efforts in order to cut prices of photovoltaic devices : 1,5 Billion Dollars are to be spent within the 1978/1988 period, with an immediate appropriation of 125 Million Dollars. 75 % of this total is to be spent for R and D, the rest for demonstrations (1).

The production is expected to double every year and reach 2 GW in 1988, while prices are said to be as low as 1 US$ per watt-peak, thus bringing the cost of energy down to about 5 US cents per kWh (assuming that, in a sunny country, a peak-KW installed produces 20,000 kWh in its life-time).

The Government of the Federal Republic of Germany has launched last year an 8-year programme within the industry, which will receive during that period a total of 160 Million DM (about US$ 80 Million). However, this programme differs from the American counterpart, because it is entirely devoted to a non-conventional polycrystalline silicon technology which will be described later on.

In France, the total yearly Government subsidies to photovoltaic development amount to about 25 million US$. The great majority of these funds goes to silicon (single or polycrystal) projects.

Japan is known to make a strong effort on polysilicon, but few results have as yet been published. U.K. is not very active in terrestrial silicon cells. There is, however, a small-scale pilot production line in operation.

One should also mention the EEC programme, which has spent on photovoltaics, during the past 3 years, 17 Million Units of Account, (about 80 % of the appropriation being engaged in silicon R and D or demonstration projects.

TABLE 1

Major photovoltaic programmes

U. S.	1977 - 78 1978 - 79	51 M $ 125 M $
France	1978	20 M FF (US$ 4)
F.R.G.	1978	6 M DM (US$ 3)
E E C	1978	5,5 M UC (US$ 6.5)

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4 - COST REDUCTION FACTORS (single crystal technology)

One of the major factors will obviously lie in the large volume of production which is expected, together with the introduction of fully automated lines. However, the technology will have to adapt itself to mass production and cheap manufacturing processes . Here are the main improvements that can be expected.

- Silicon Starting Material :

  The electronic grade ultra-pure silicon costs about US$ 60/kg. Experimental results lead to the definition of a new "solar-grade" silicon, with a much higher level of impurities (this is at least true for some of the impurities). Costs of the material are expected to drop by a factor of 5 to 6. However, many people believe that relatively impure silicon may lead to difficulties during the growth of large silicon single-crystal, and therefore this material is perhaps more suited for poly-crystalline cells.

- Size of the crystals :

  The major part of the world production is made with 2" to 3" diameter Czochalsky crystals. The present generation starts or uses 4" wafers, but 5, 6 or even 8" crystals are considered. The increase of the diameter is of great importance, since the handling of the wafers remains almost constant. Figure 2 illustrates this increase of cell size from 1970 to 1975 (French production).

- Wafer slicing :

  Kerf and etching losses represent half of the single-crystal used. The present technologies use generally 300 µm thick wafer, thickness which is quite redundant (100 µm represent an optimum for the photovoltaic effect). One hopes to bring the Kerf loss down to 100 µm and the thickness down to 200 µm, thus using half the quantity of crystal presently needed.

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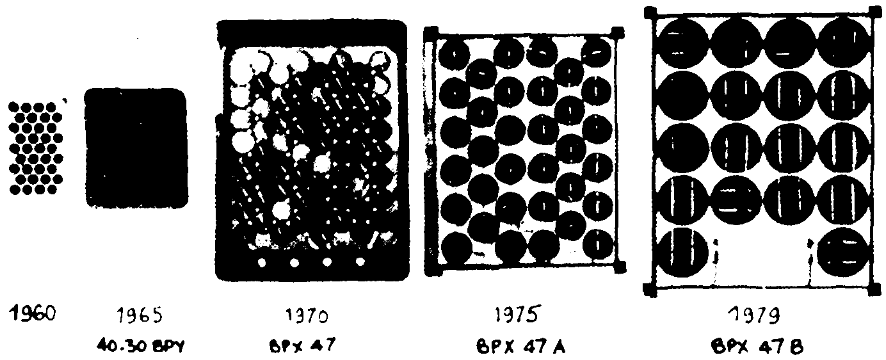
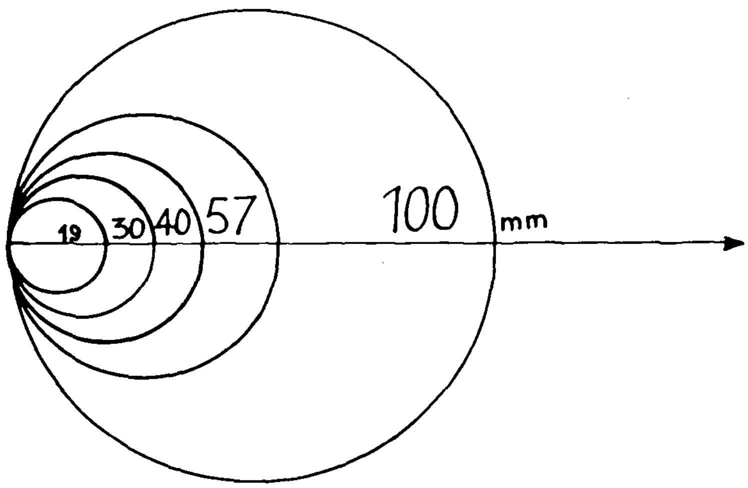
Fig. 2

The area of cells has increased ten-hold
between 1960 and 1975





		40.30 BPY	BPX 47	BPX 47 A	BPX 47 B/18	BPX 47 B/20
Ø cellules Ø cells (mm)	19	30	40	57	100	100
Puissance Power (W)	0,65	2,5	8	11	16,5	18
Tension Voltage (V)	3	16	12-24	15,5	8,2	9,1
Nombre de cellules par module Number of cells / module	36	40	64	34	18	20

- Cell Technology :

  Many improvements are at the R and D stage. Schottky diodes have been definitively abandoned despite their simplicity (the efficiency remains low, around 10-12 % at most). Diffusion is the preferred way to make the junction.

  However, new solid-solid diffusion methods are very promising, and may push the traditional gaseous diffusion out. Ion implantation, laser annealing, laser induced solid-solid diffusion are amongst the newcomers. The effective efficiency achieved on a production line, which was barely 10 % 5 years ago, reaches nowadays 13 to 15 % and is expected to be boosted up to 18%.

- Contacts :

  Silk-screen contacts are widely studied in order to replace the expensive vacuum or photolithographic deposition. However, the durability of these new cheap contacts is not yet as good as the former ones, but becomes acceptable if a high-quality hermetic encapsulation is used.

- Encapsulation :

  Here, the price drop tendency is not yet as sharp as it is with the other items. More and more producers abandon the cheap plastic coating for a tempered glass window which is much more expensive but gives far superior reliability. Progress can be expected from larger panels (up to one square meter, for instance), requiring less handling. The packing factor of the cells within the panel is quite important in view of the expected high cost of the encapsulation per unit area : there is a tendency towards square cells, as used in space generators, instead of round ones, with the packing factor increasing from 0.7 to 0.9.

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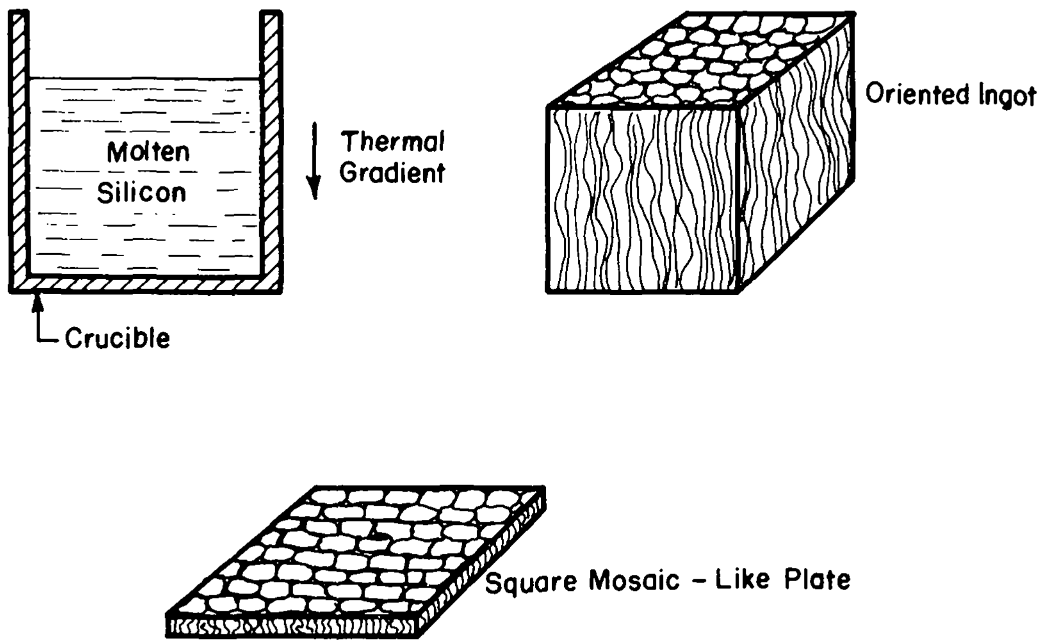

Fig. 3 "SEMI CRYSTAL"
THE CRYSTALLISATION UNDER A THERMAL GRADIENT
GIVES RISE TO A "COLUMNAR" STRUCTURE

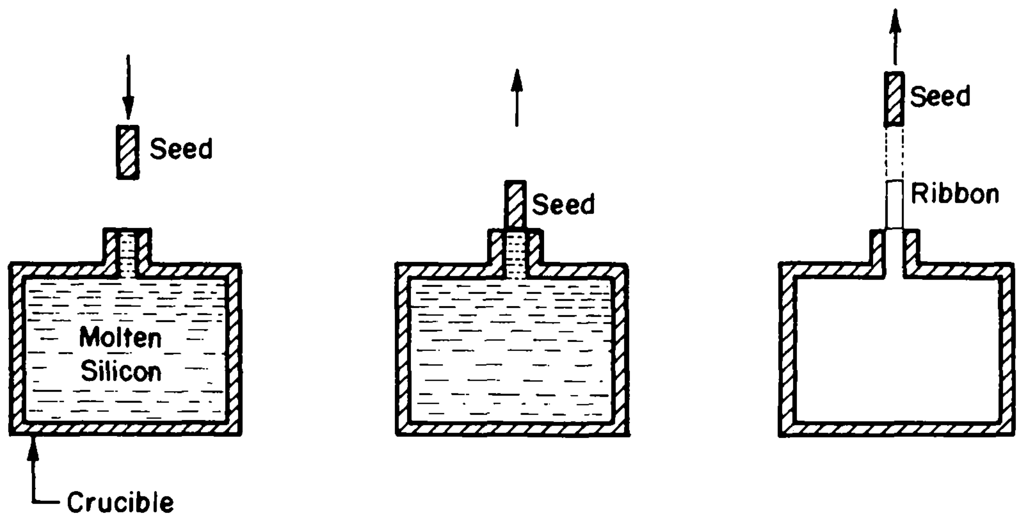

Fig. 4 EFG RIBBON GROWTH METHOD
THE MOLTEN SILICON CREEPS BY CAPILLARITY INTO THE VERTICAL DIE. THE SINGLE CRYSTAL FLAT SEED ENTERS IN CONTACT WITH THE MOLTEN SILICON, AND IS THEN PULLED

5. THE NEW TECHNOLOGIES OF SILICON GROWTH

A great ingenuity exists in this field, and many dozens of methods have been investigated. Only the most promising ones are mentioned here :

- The so-called "semi-crystal" :
  This method, contrary to all others, consists in a bulk but oriented crystallization of a silicon ingot. It requires therefore a slicing, perpendicular to the direction of preferred crystallization, with the unavoidable Kerf loss. Figure 3 shows schematically the method, which is actively studied in Germany (Wacker) and in the U.S. (Solarex). Efficiencies of 10 % are easily achievable on large (10 x 10 cm2) areas, and recently 14 % (and even 16 % on selected small samples) have been reported (2).
  The size of the grains is typically of the order of the square millimeter, or more in the center of the mosaic.

- The "epitaxial" films :
  Vapour phase decomposition of chlorosilane is applied on a large-grain metallurgical grade cheap silicon substrate. Efficiencies are nevertheless poor, a few per cent, because of contamination by the substrate (3). Thick epitaxial layers (50 μm) are rather expensive. Attempts have been also made to use vapour phase deposition on other materials, such as stainless steel : grains are very small, and require a recrystallization.

- The "ribbons" :
  The idea here is to grow directly a single crystal ribbon, directly usable for the cell production without any further slicing. The vertical ribbon pulling, so-called Edge Defined Growth (EDG) of Mobil-Tyco is the most advanced method and schematically shown on Figure 4. However, if rather long (few meters) relatively wide (7 cm), but unfortunately very thick ribbons have actually been obtained, the single crystal

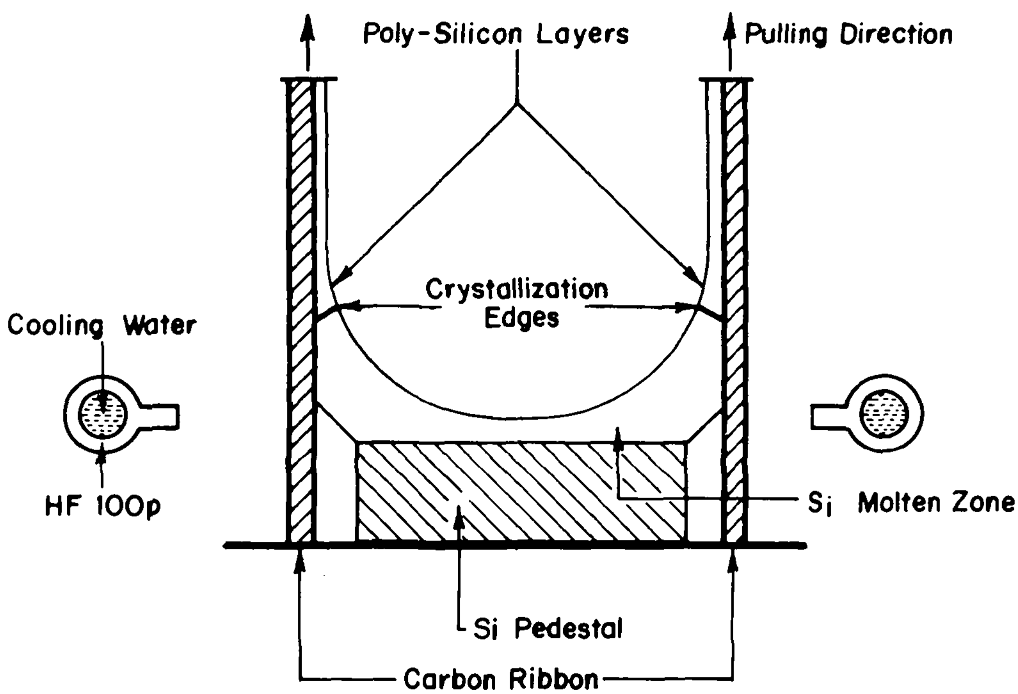

Fig. 5 SILICON COATING

Two or more flexible carbon ribbons are in contact with a silicon molten zone. By pulling upwards the ribbons, a controllable film of silicon is deposited on the carbon substrates becomes very rapidly twinned, dislocated and, after a few feet of pulling through the die, the structure resembles more an oriented (along the pulling direction) poly-crystal than a true single-crystal. Efficiencies up to 12 % have been reported with the best samples (4). Other "ribbon" pulling methods have been designed : horizontal pulling is studied mainly in Japan ; the laser heated floating zone "ribbon against ribbon" (i.e. poly-ribbon against single-crystal ribbon) technology has been imagined by Motorola in the U.S..

- The "silicon coating from the melt" :
These technologies require a careful handling and control of molten silicon, which is deposited as an oriented thin film on e suitable substrate. Honeywell in the U.S. uses a dipping method, the substrate being a ceramic (mullite). In France, a more sophisticated technology is under development at Laboratoires d'Electronique et de Physique Appliquée, which may allow for a true continuous fabrication : Figure 5 describes the process, where flexible graphite coated carbon ribbons come in contact with a "drop" of molten silicon and are then pulled, thus allowing for the deposition of thin and controllable (from a few to 100 μm) film. Efficiencies of about 8 % are presently achieved, with grain sizes of about a square millimeter (5).

- The "dentritic" growth :
This rather old method, which works rather well with germanium, has never been abandoned for silicon at Westinghous Laboratories. Webs several feet long 3 cm wide have been reported (6). The efficiency of the cells is excellent (up to 16 %), but the reproducibility of this technique seems difficult to control, and the growth rate is slow.

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Aside from this sampling of the polysilicon growing methods, many others are under testing ; many others will probably be imagined. Except for the first one, which is rather straightforward but potentially not as cheap as the others, the winner, if any, is still unknown.

From a scientific point of view, it is quite remarkable to think that the grain boundaries of polysilicon are not as harmful as expected. A few years ago, no expert would have guessed that 14 or even 16 % conversion efficiencies could have been achieved with such materials : one had imagined that grain boundaries would have trapped the carriers, or even worse, would have produced low resistivity short-circuits through the layer. All the interesting polysilicon technologies yield truly "monograin" structures, where there is a single crystalline grain within the thickness of the sample, and grain boundaries are perpendicular to the layer : in practice, one gets hundreds or thousands of little cells in parallel, with a mosaic structure.

6. AMORPHOUS SILICON

This material has been "rediscovered" recently in Great-Britain, as being a potential thin film photovoltaic material. The novelty consists in a strong hydrogenation of the silicon free valences, thanks to a decomposition of silane or a cathodic sputtering in a hydrogen low pressure atmosphere. Very soon, efficiencies of 5 % were reported (7), using Schottky diode technology. However, little practical progress has been made since. But the understanding of the semiconductor mechanism of this "alloy" has been extensively carried out in many countries. It seems that several types of "a - Si (H)", - amorphous silicon-hydrogen compound -, exist, and amongst these , at least one behaves like a true semiconductor. We are facing here a new category, the IV - I semiconductor.

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Potentially very cheap, because of its extremely low thickness (micrometer), fundamental research can perhaps bring this material up to a decent efficiency (10 % or, according to some authors, up to a theorictical value of about 15 %). The field is still wide open.

7. AN ALTERNATIVE SOLUTION : THE OPTICAL CONCENTRATION

Optical concentration is attractive : the amount of photovoltaic material is reduced by a factor which, depending on the system, can lie between a few units to 100 or even 1,000 (with gallium arsenide). However, this is somewhat compensated by the cost of the tracking device (if any) and of the mirrors or lenses used. Furthermore, concentrating photovoltaic systems can only be used in clear-sky climates, and are unsuitable for Northern countries.

Refined technologies allow the use of special silicon cells up to a concentration ratio of 20 to 30 with natural air cooling around radiators, and up to 100 with water cooling (the water, which can be maintained around 70°c, can be used for heating purposes). Due to this higher temperature, cell efficiencies lie at most around 12 %, and optical losses bring this figure closer to 9 or 10 %.

For a very low - a factor of 3 to 5 - concentration ratio, seasonnally tilted systems are recommended : they consist generally in E - W oriented through, either with flat mirrors, or cylindro-parabolic mirrors. Linear Fresnel lenses are also in use.

For medium concentration (up to 30), one-axis tracking system and linear focusing are preferred. For higher values, a true qun-tracking two-axis mechanism is required with a point focusing. This last system seems to-day the most promising one, in spite of a more complicated mechanical device. Plastic Fresnel lenses are generally used, and are fabricated to-day in rather large sizes (up to half a square meter).

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One expects that, if such systems are industrially developed (and they are not to-day), a figure of 5 $ per watt-peak could be achieved, with a possible added value for hot water. However, if this technology is not exploited very soon, the progress expected in the flat arrays technology will beat the concentration method. Furthermore, the operating costs of concentrating systems are expected to be higher : for instance, nobody really knows how reliable the mechanical parts are, and whether such generators can be left unattended for a long period of time.

8. THE INFLUENCE OF THE ENERGY CONVERSION EFFICIENCY

Until a few years ago, there was a widely spread opinion according to which the efficiency of the conversion was relatively unimportant if very low cost materials were to be achieved : more refined value analysis shows that, for a complete photovoltaic generator, the fixed cost per unit area (i.e. costs which are independent of the nature of the active material) are far from negligible. These fixed costs comprise, on one hand the price of the encapsulation on the other hand, the cost of the land, the metallic supporting structure, possibly the electrical wiring. For a given power, they become smaller when the intrinsic efficiency of the material and the packing factor within the panel increase.

On a medium term basis, the encapsulation materials may cost at least US$ 40 per square meter : a simple structure, as mass-produced for greenhouses, costs about US$ 20. Installation and wiring may bring the total up to US$ 80 per sauare meter. Figure 6 plots the overall "panel efficiency" (cell efficiency multiplied by the packing factor) against the cost of the active photovoltaic material for different energy prices (assuming 20,000 hours equivalent peak-power lifetime and 10 % capital depreciation per year). It shows how efficiency materials, even if they cost nothing, penalize the final price of energy.

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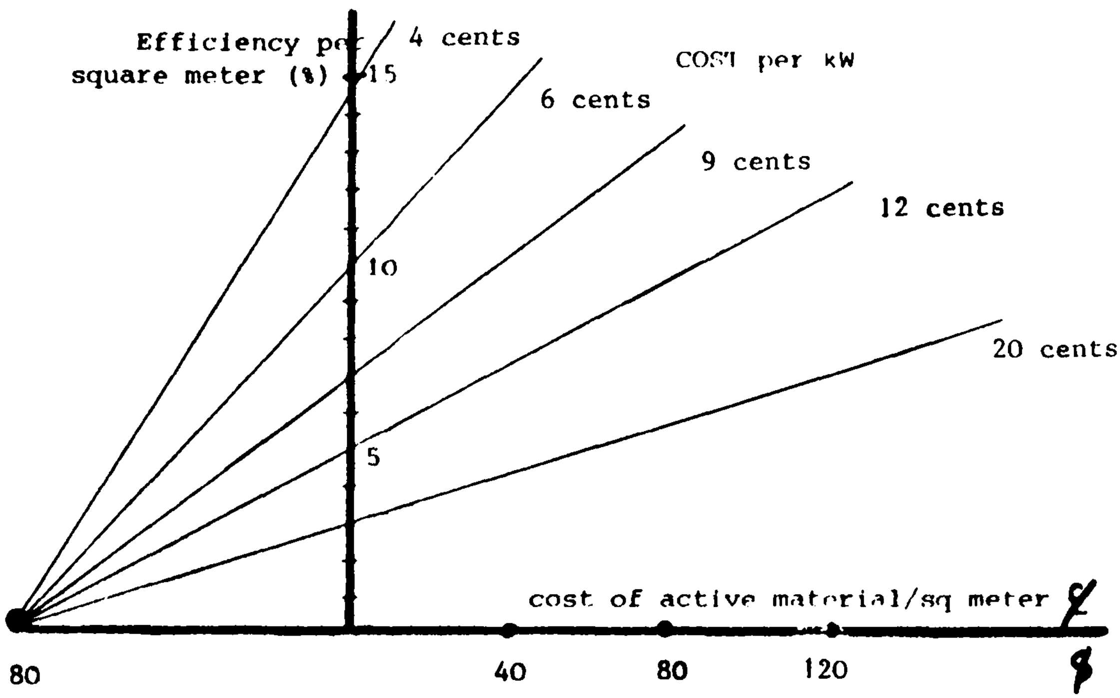
Fig. 6



INFLUENCE OF FIXED COSTS ON PANEL EFFICIENCY

9. THE PROSPECTS FOR PHOTOVOLTAIC GENERATORS

Photovoltaic electricity is to-day unbeatable for small power stations, up to 1 kW, in remote areas : beacons, telecommunication links, television sets, even small pumping units, represent the major part of the commercial market. At such a small level, the storage problems with lead batteries, can easily by solved.

As prices go down, the upper limit of the generator power will go up. Between 3 to 5 $ per peak-watt, Diesel engines of 100 kW or more will certainly be beaten by photovoltaics, in remote villages and cities of developing countries, where electricity costs to-day anything between 40 cents and $ 1, reaching 2 US$ per kWh in some places. The storage problem becomes serious at this level, and may represent an important part of the investment (about US$ 100 per kWh stored).

If prices still continue to decrease, down to US$ 1 (or even US$ 0.5) per peak-watt, real power generating plants can be envisaged. Electrical storage becomes practically impossible (one can think of an indicrect hydrogen storage). Electricity would then be produced at competitive price, if the electrical grids can cope with the random fluctuation of the solar production. Hydroelectricity complements very well the poor reliability of solar electricity : for instance, the South-West American electrical network is said to accept at least 15 % of solar electricity without storage, the dams acting as buffers : solar electricity then becomes a kind of "water conservation" system for hydro-electrical plants. Not all the countries have such favourable conditions ; nor enjoy the sunny climate of Arizona. These factors can probably explain the exceptional enthusiasm of the U.S. Government for photovoltaics.

Nevertheless, even if such ambitious goals are not to be achieved, the more limited and more conventional markets for photovoltaic systems, especially in the developing countries, already offer a very large interest, which justifies the efforts and hopes of the scientific and industrial communities.

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SOLAR CELLS FOR CONCENTRATION GENERATORS

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INTRODUCTION

It is commonly admitted that from an economic point of view, the concentration branch of the photovoltaic field is of great interest. In short the cost of the solar kilowatt hour can in the near future be divided by 5. This will save 10 years while we wait for cheap solar cells to be available.

With this in mind, we have undertaken to examine the aspects of and limits to the design of photovoltaic concentration generators. In this article we distinguish between problems related to cells and those related to systems. We will also present a model developed in Toulouse, France which has been in operation for a year .

A. THE CELLS

As soon as work began on photovoltaic concentration generators, it was clear that cell design would depend on the method of cooling which was chosen.

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With forced convection cooling, there is practically no limit to cell surface. It requires, however, the use of complicated techniques which can compromise the simplicity and dependability of the entire system. That is why it is preferable to stick to natural convection cooling at the outset. For this we demonstrate that there is a link between radiator structure, the surface S of the cells and the level of concentration K. Thus for a standard aluminium structure, the maximum rise in temperature over ambiant temperature $\Delta T = 30°c$ leads to a relationship of the following sort : $K \times S = 0{,}03$.

The chief difficulty which arises in the design of solar cells comes from series resistance which limits efficiency at high concentrations of light. It is the result of contact resistance and material resistivity ; it also comes from the shape of the metal current collection grill on the illuminated face of the cell. As figure 1 illustrates, the resulting drop in tension is due to the current which circulates sideways along the emitter. The following equations govern this phenomenon :

$$\begin{cases} \dfrac{d\,V_{EB}\ (y)}{} = \dfrac{P}{Z\,W_E} \cdot I_T\ (y) \\[2ex] \dfrac{d\,I_T\ (y)}{dy} = Z\,(J_L - J_D\ (y)) \\[2ex] J_D\ (y) = \dfrac{I_{EO} \cdot V_{EB}\ (O)}{2\,L\,U_T} \left[x \exp - \dfrac{\Delta V_{EB}\ (Y)}{U_T} \right] \end{cases}$$

The results of this analysis applied to a silicium solar cell are presented in figure 2 as curves. The form factor is the distance separating the elements of the metal grill. These curves show that it is possible to design cells capable of operating under a light intensity of 200 suns.

We resume below presently available choices in semiconductor materials.

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MATERIAL OR COMPONENT	CONCENTRATION RANGE	CONVERSION EFFICIENCY
Si	1 - 500	15 %
GaAs	1 - 1000	25 %
"Additional" solar cells		30 %

B. CONCENTRATION SYSTEMS

Table one resumes the different lines to be studies. Our 1 Kw generator project began two years ago. A model using 4 cm2 of silicium cells operating under 40 suns and cooled by natural convection has been built. It is at present at the pilot stage. All components have been designed and elaborated individually and in relation to the system to give the system a homogenous character. Many tests have been run with this model to evaluate performance and dependability. These tests are described below. We also give an estimate of installation costs which give rise to major conclusions concerning the development of the photovoltaic branch.

1. MODEL

1.1. - HELIOSTAT

He consists of a double-axed frame set in motion by two 30 W triple-phased asynchronous motors. Two controls make it possible to follow the sun :

- a four quadrant sensor ensures fine monitoring. It emits two error signals (site and azimuth) corrected by the appropriate electronic order given to the motors. Its precision is $\pm$ mrds.

.../...

- logical circuits control general direction when clouds pass ; this control system also points the heliostat east in the morning and cuts in to protect the heliostat if winds are stronger than 75 km/hour.

One day's power consumption for the control circuits is 200 Wh for a 12 m2 heliostat. The panel equiping the heliostat is a rigid triangular structure.

1.2. - MODULES

Each module comprises six solar cells and their concentrators. They are placed on an aluminium frame with heat dissipation vanes. Concentrator props are fixed to this frame. The module structure was designed in such a way that cell temperature would not go more than 30° over ambient temperature. Modules are equiped with a apparatus which prevents condensation and keeps out polluting agents allowing the whole module to breathe with variations in temperature.

1.3. - CONCENTRATORS

Concentrators are Fresnel lenses made of methacrylate. They are designed to concentrate 40 times the sun's radiation on 4 cm2 cells. Their efficiency is about 75 % and they are treated to resist abrasion an ultra-violet rays.

1.4. - SOLAR CELLS

These cells come from two different manufacturers : R.T.C. in Caen (France) and Solarex (USA). Their efficiency at 40°c under 40 suns is 10 %. They are glued directly onto the module's frame and are connected in series.

2. EXPERIMENTS

We have developed specific measuring, recording and analyzing equipment for the model installed in TOULOUSE. Measurements concern weather conditions, cell temperature and electric power produced by the pannel.

Overall model efficiency is 7 % and in the pilot stage it can be increased to 9 % as table II illustrates.

3. ECONOMIC EVALUATION

Table III combines figures for each of the generators components. These figures were chosen in view of large-scale industrial production and yield a peak watt cost of around 25F. This means that our tests have confirmed the fact that the photovoltaic concentrator line has the advantage over flat systems which cost about 100F/watt peak.

These results, however, must be built upon. The use of forced convection, in particular will open the way to high concentration levels and new generations of solar cells.

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The authors would like to than Mr. LANCELLE, Mr. MATHIEU, Mr. SUAU, and Mr. THEREZ for their generous scientific assistance.

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Photovoltaic Conversion
1 kW generator
Sunlight Concentration

Cooling	Passive		Active	
Concentr. Range	Low 15 X	Medium 100 X	Medium 400 X	High 1000 X
Cells	Si	Si	Si	As Ga
Accepted Radiation	diffuse and direct	direct	direct	direct
Heliostat Control	One axe	Two axes	Two axes	Two axes
Utilization	Photo-electricity	Photo-electricity	Photo-el. and Domestics	Photo-el and Thermodyn.
Implementation	Sub-tropica and Northerm	Sub-tropical and tropical	Tropical Equatorial	Tropical Equatorial
Overall Efficiency	10 %	10 %	15 %	25 %

TABLE I :

Different approaches of photovoltaic conversion with concentration.

Efficiency of	Prototype		Pre-industrial stage	
Lenses	75 %		80 %	
Cells	10 % (RTC)	13 % (SOLAREX)	13 %	
Fill Factor on the panel	70 %		85 % (passive cooling)	90 % (active cooling)
Overall	7 %		9 %	

ANALYSIS OF EFFICIENCIES ON THE SYSTEM LEVEL

TABLE II

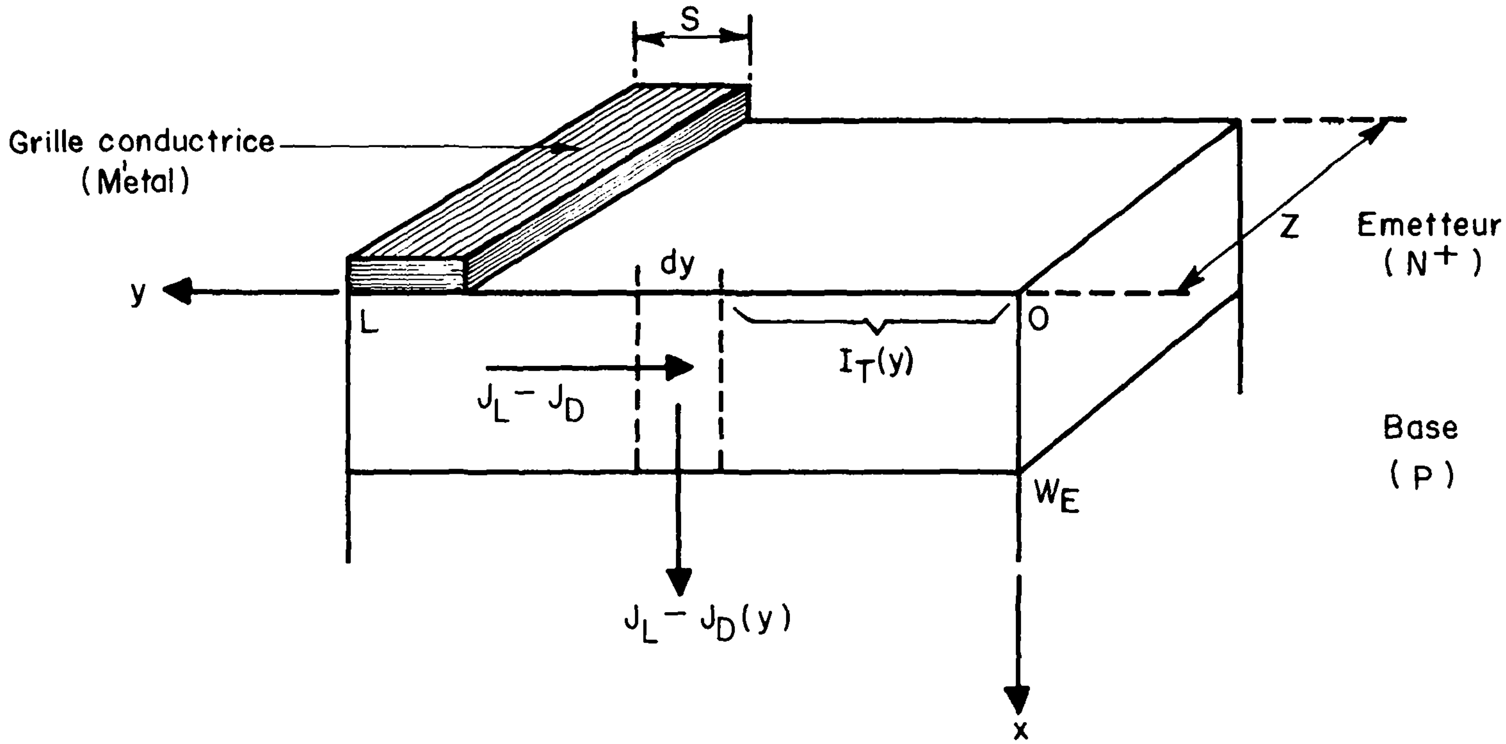


Fig. 1 Cross sectional view of a diffused solar cell

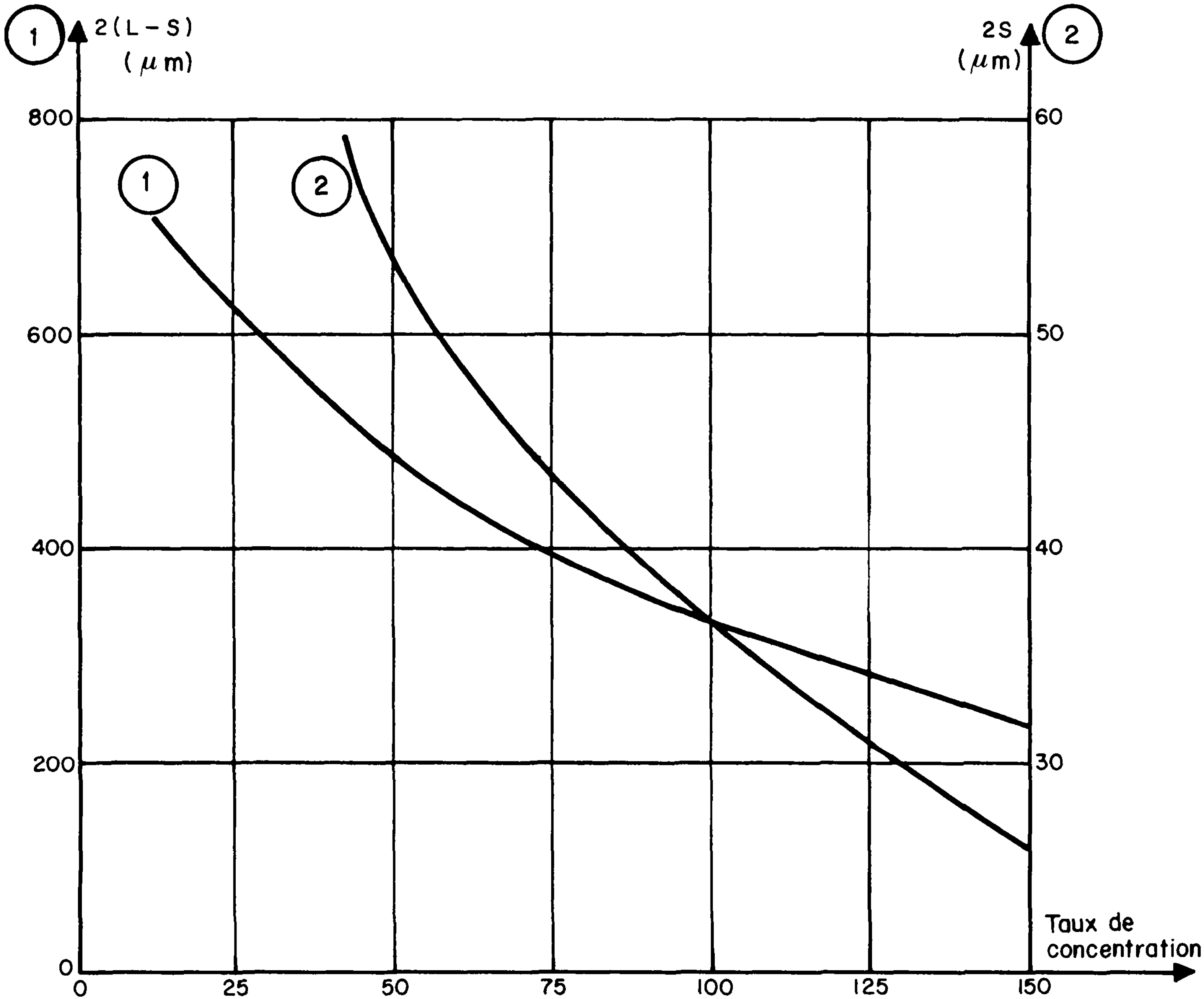
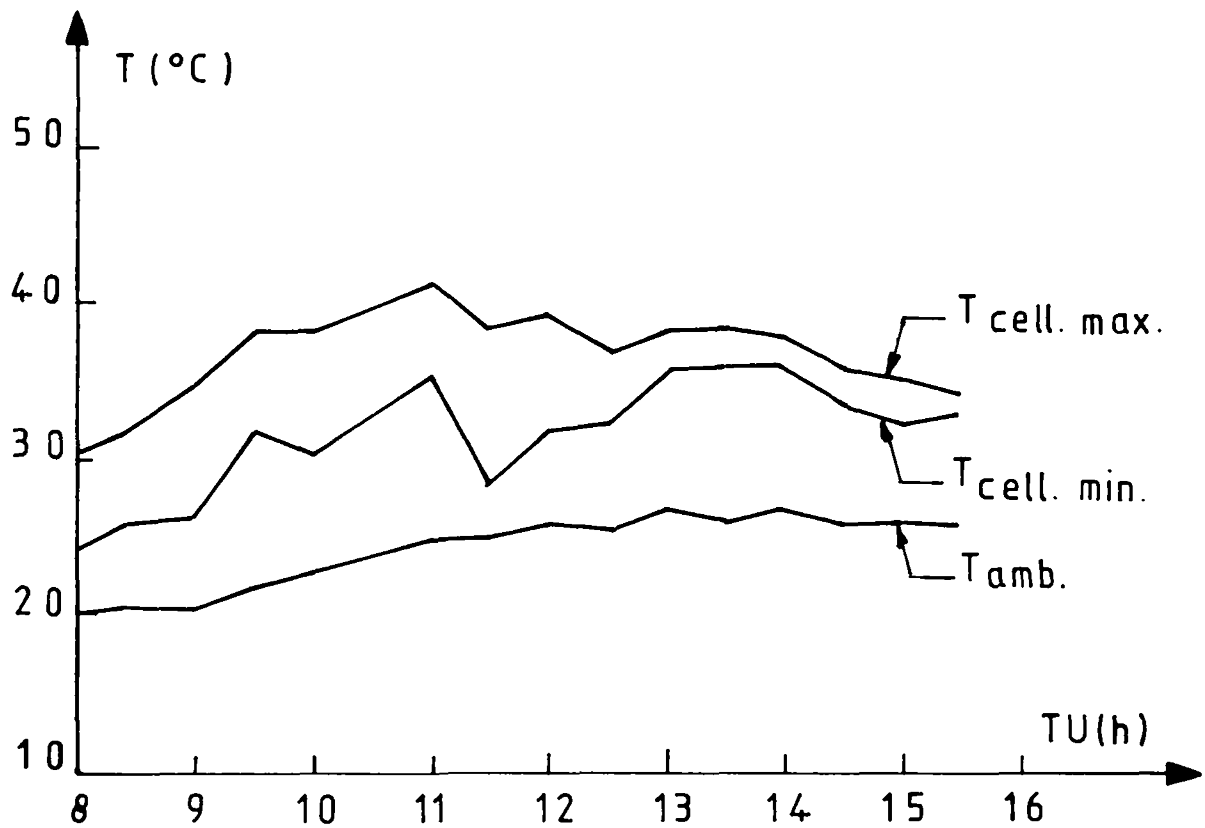


Fig. 2 Optimized values of the inter-line distance and grid-line width versus the concentration ratio

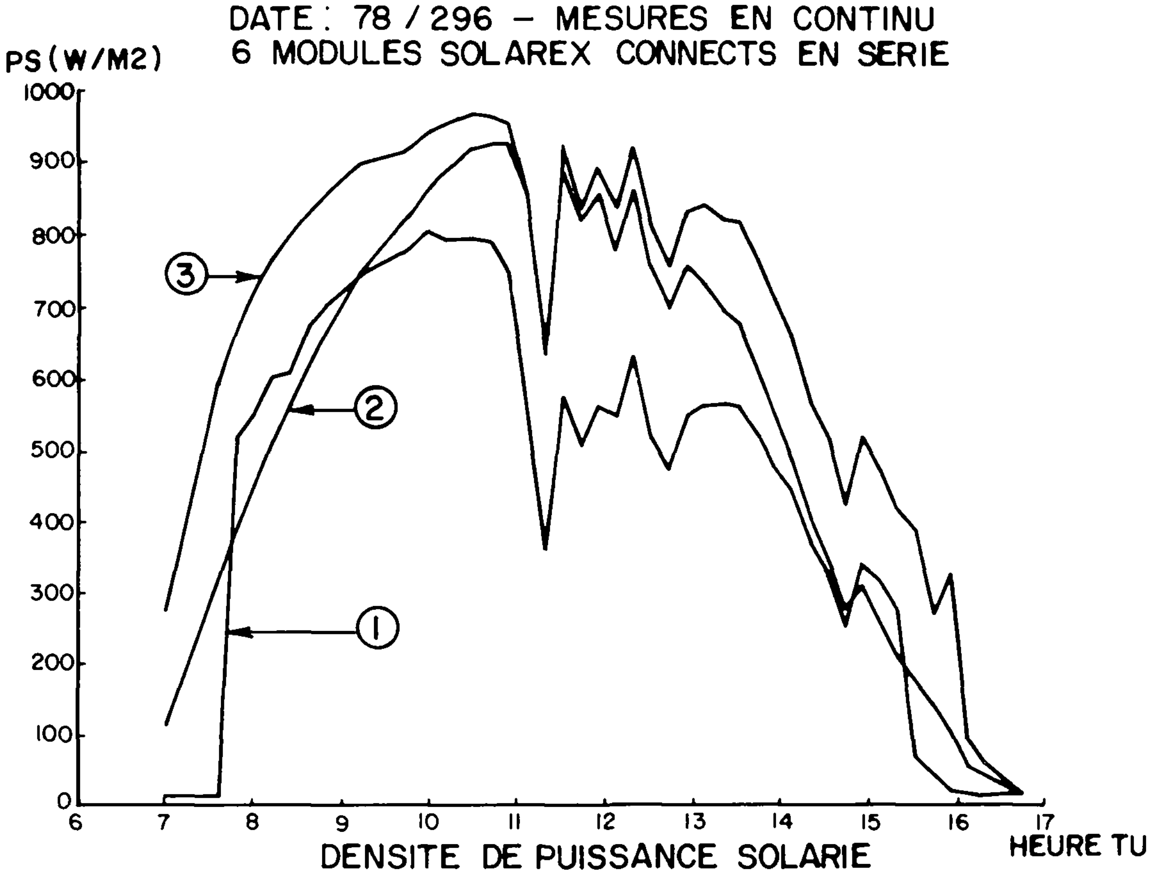
	POSTE	OBSERVATIONS	PROTO 50 m2	SERIE X1000 50 m2 unité	F/m2	% PARTIEL	%
HELIOSTAT (M.O. incluse)	Electronique Commande	1500 F de composants	3.000 F	2.000 F	40	8	28
	Monture Altazimut	Actionneurs inclus	200.000 F	12.000 F	240	48	
	Panneau		100.000 F	9.000 F	180	36	
	Génie Civil		10.000 F	2.000 F	40	8	
CONCENTRATEURS	Lentilles	Matrice + Matière + Formage	60.000 F	7.500 F	150	48	17
	Assemblage	Collage	15.000 F	8.000 F	160	52	
MODULES	Radiateurs	Profilé Alu + Filière 2,1 kg/bac	25.000 F	6.500 F	130	35	21
	Toles-supports	Alu 10/10 mm 1,3 kg/bac	20.000 F	4.000 F	80	22	
	Assemblage	Outillage Découpe + Pliage + Rivetage Joints d'étanchéité Peinture	15.000 F	8.000 F	160	43	
CELLULES	Cellules	Si 4 cm^2 2 Fois cellules convent. actuelles		22.500 F	450	74	34
	Assemblage	Caractérisation + Appairage Positionnement Collage Connexions	16.000 F	8.000 F	160	26	
	Assemblage Panneau	10 mm/bac	500 F	400 F	10		1
	TOTAL	Hors Cond. de Puissance			1800		100

Rendement 8,3 % ⟹ 22 F/W_C (dont Assemblage : 6 F/W_C, dans l'état actuel des techniques déjà implantées)

TABLE III

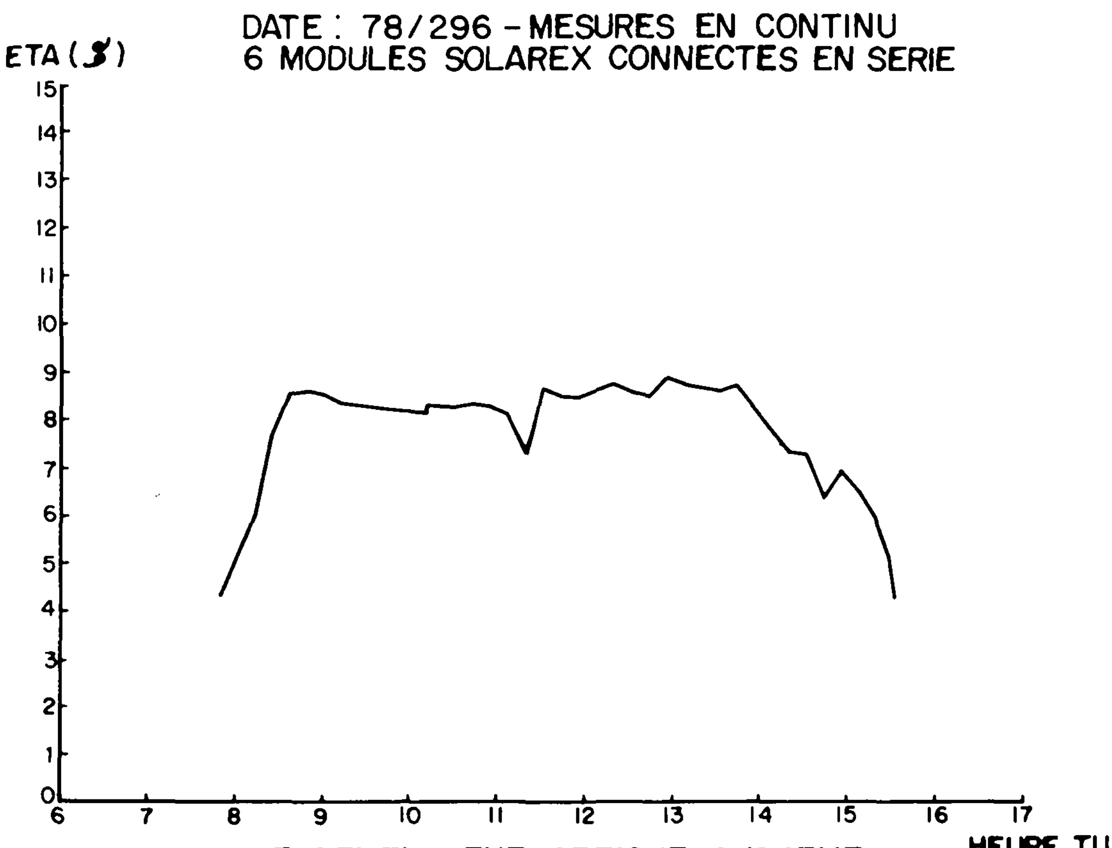


T (°C)
50
40
30
20
10
T cell. max.
T cell. min.
T amb.
TU(h)
8
9
10
11
12
13
14
15
16



DENSITE DE PUISSANCE SOLARIE

1 : DIRECTE 2 : GLOBALE (CAPTEUR FIXE)
3 : GLOBALE (CAPTEUR ORIENTE)



RENDEMENT ENERGETIQUE-SYSTEME

System Efficiency

SOLAR TECHNOLOGIES IN RURAL AREAS

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The fundamental ideas of this program of research projects and technological demonstrations are :

- The combination of the photosynthetic part of the spectrum and the thermal flux of solar radiation accelerates the introduction of modern techniques in agricultural zones.

- In temperate climates, domestic heating and crop drying complement one another through the seasons. The extensive use of air or water solar heating increases the profit on investments.

- Because of the dispersed nature of solar energy, it is probable that many of its applications will be on the farm or village level. For this reason, the technologies applied must be adaptable to the layman.

The aim is to improve protein production for the animals to produce primary energy on the farm to reduce pollution and to introduce new technologies. Examples taken from a farm in the south-west of France are given as illustrations. We are also looking for technologies compatible with traditional agricultural techniques and innovations introduced in the last few decades.

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Three frames of analysis determine the course of this study :

- The first, energy accounting, or the analysis of energy inputs and outputs (following parallel methodologies we would like to be able to make a protein accounting as well as carbohydrate accounting).

- The second, space analysis takes into account the cultivatable surface on the average farm, water availability and use ; the degree to which the farm is in conflict with or is integrated into the surrounding countryside, its influence on ecological chains and its resulting role as a purifying or polluting agent.

- The third, frame of reference, economic analysis determines which of the technologies contained in this program can be profitably applied by the farmer in a given time and place. This implies full-scale experiments carried out over a number of years. Choices of technologies are made on the following criteria : market value of inputs and outputs ; feasibility as determined by the level of technological competence in the area, which conditions the acceptance of new technologies ; and the existence of supplier and client industries.

It will be of great interest to compare this program with similar ones carried out elsewhere. The stress laid on the integration of local technologies increases the value of comparisons made with countries of different traditions and climates.

The organisations involved have now completed the research phase of the seven points listed on the chart on fig. 3. Size and technological choice are discussed and most of the system will be operational at the end of the year.

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PROJECT'S TECHNOLOGICAL FOUNDATIONS

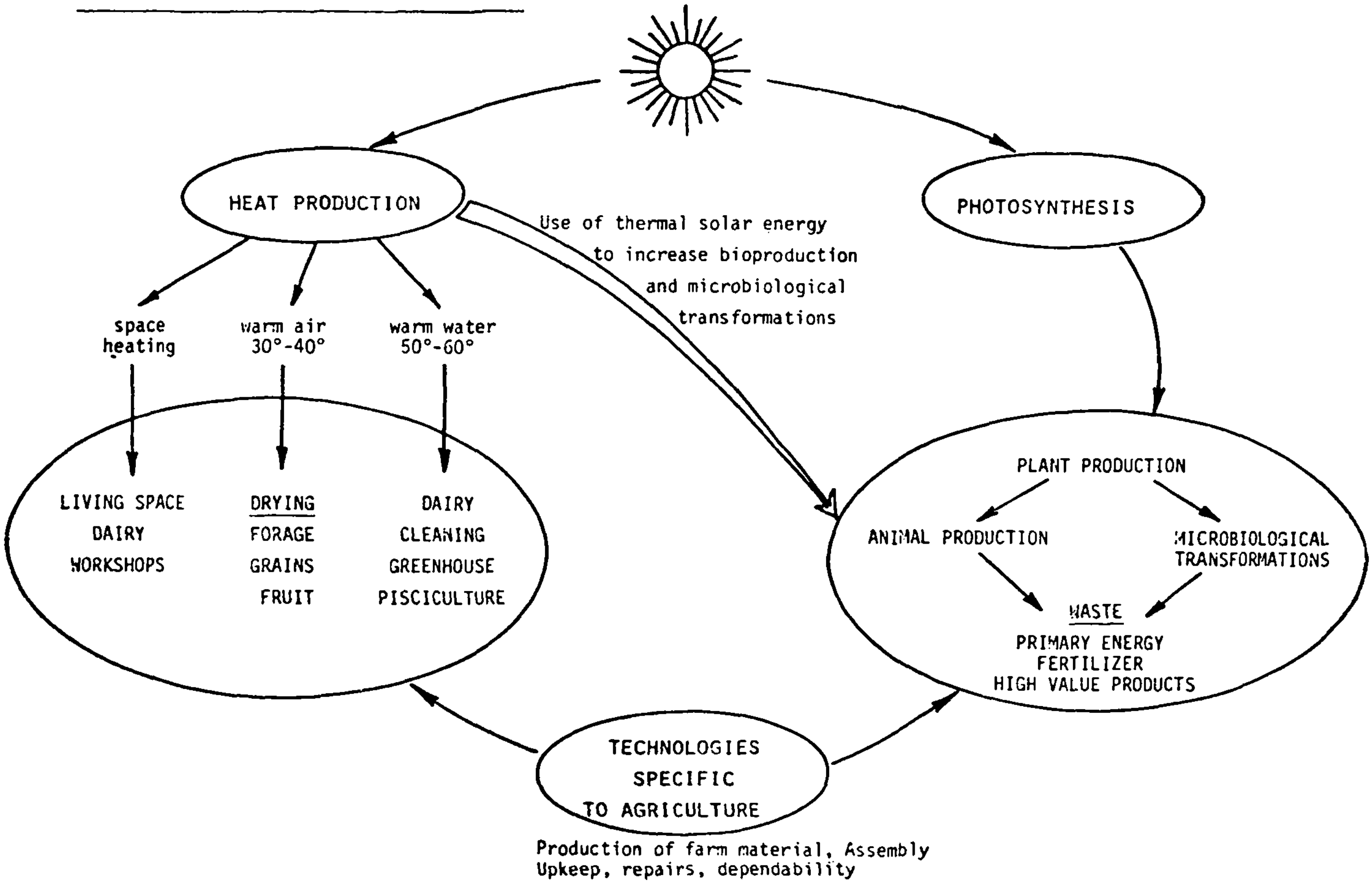

Fig. 1

PROJECTS'S COMMON REFERENCE POINTS

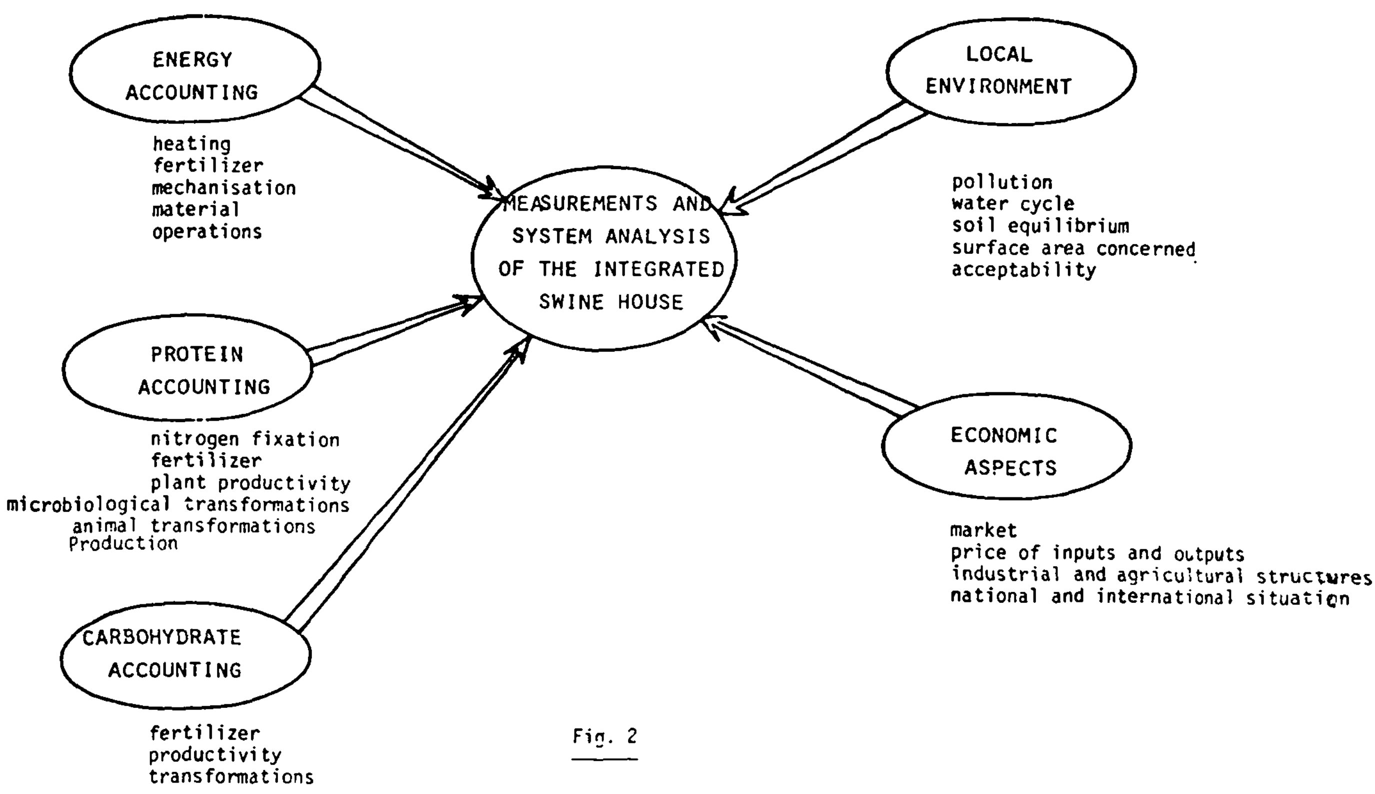

Fig. 2

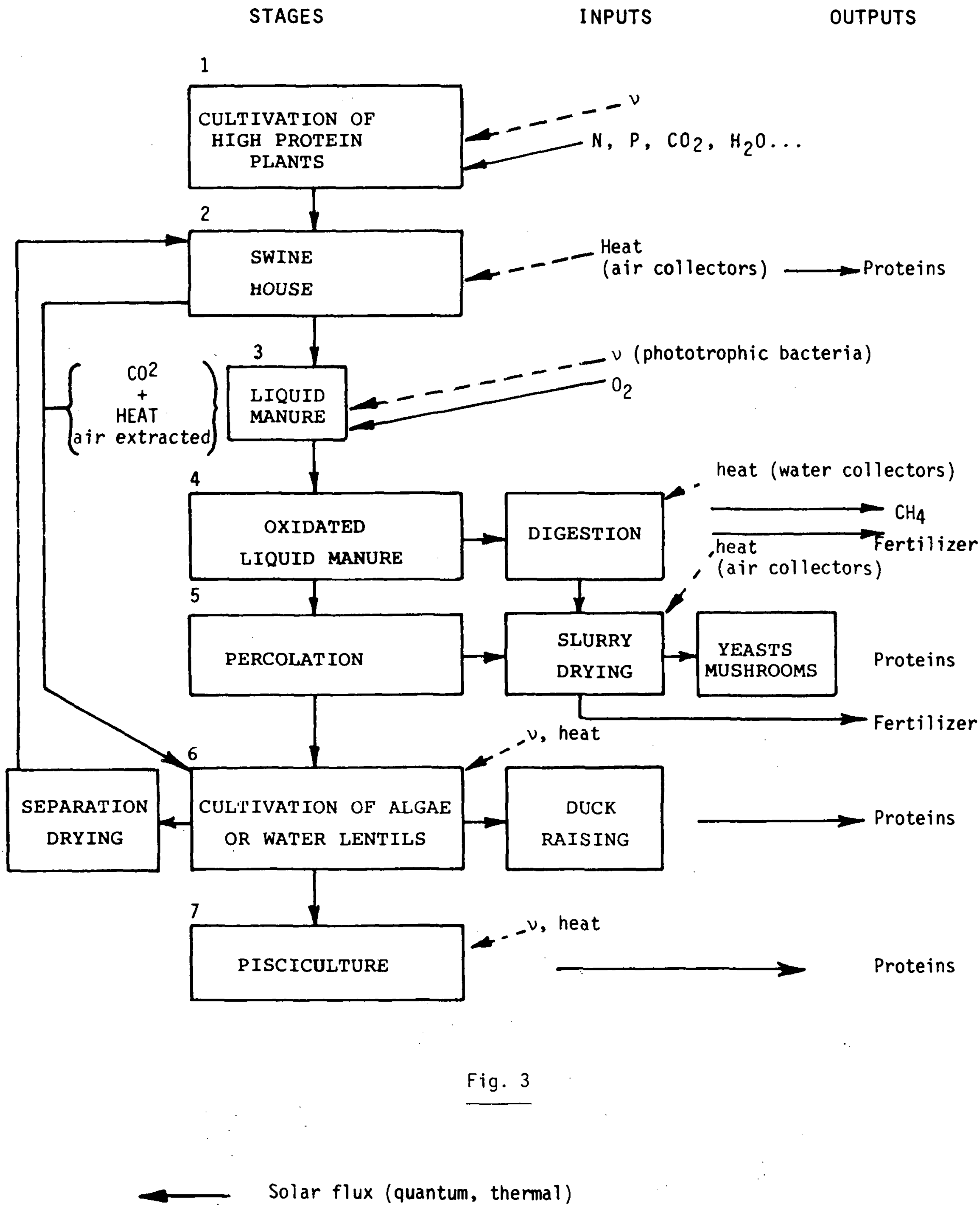

Fig. 3

(*biotechnologies solaires JFM/ 05/78*)

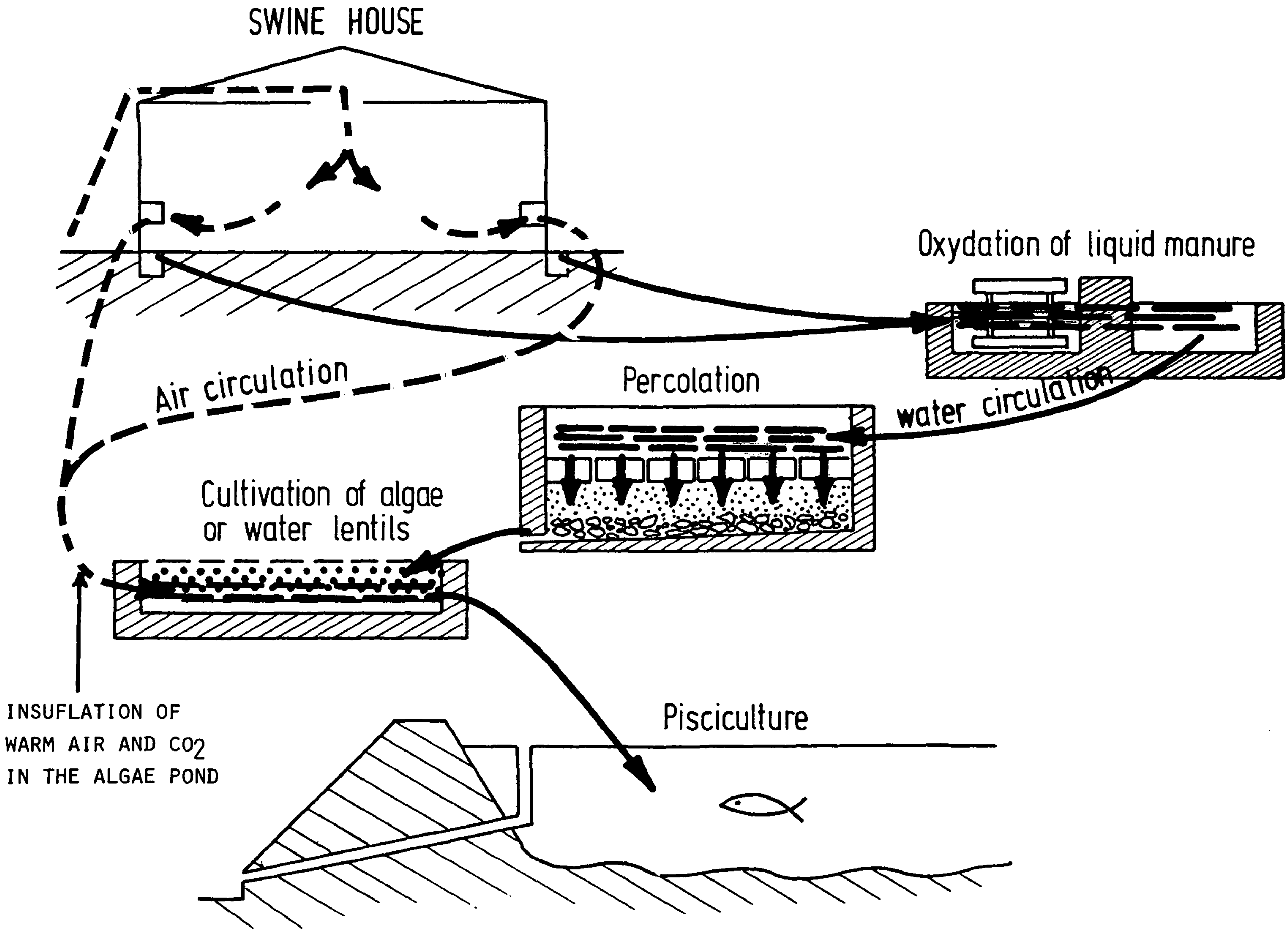
SWINE HOUSE
Oxydation of liquid manure
Air circulation
Percolation
water circulation
Cultivation of algae
or water lentils
INSUFLATION OF
WARM AIR AND CO2
IN THE ALGAE POND
Pisciculture

Fig. 4

1. THE SWINE HOUSE

An attempt to integrate solar techniques into the swine house is currently underway. The model pigsty takes advantage of low and middle temperature solar technologies at different levels of operation.

Air and water solar collectors can bring heat into the operation of the pigsty on diverse levels. The following list is a resume of suggested techniques and current research projects.

- The cultivation of plants rich in protein, protein enrichment and drying
- The heating of the swine house, the thermal balance sheet and the solar contribution
- Aerobic oxidation of liquid manure (the aim is to reduce the mechanical energy to a minimum by use of biological process)
- Anaerobic fermentation of mud and wastes (straw)
- The percolation of mud through strainers and its drying
- The cultivation of monocellular algae and plants on ponds
- Pisciculture as a human food source or as a means of producing protein for animals.

.../...

2. HOT WATER USE IN AGRICULTURE

In addition to domestic needs, a farm consumes large quantities of hot water. Liquid or semi-liquid feed techniques require the heating of large amounts of water to between 50°C and 60°C. Hot water at slightly lower temperatures are required for hosing down dairy, calving and cattle raising facilities in general.

This water can be heated in simple flat plate collectors and stored for a supply of several days the dimensions being determined by the local climate.

On a farm where methane fermentation of solid and liquid manure is exploited, output can be increased and the length of the production cycle reduce if a part of the hot water obtained is run through a coil in the methane digester.

Warm water from solar collectors can also be run through flat plastic water ducts into a greenhouse.

After running through the greenhouse, water is still warm enough to raise the temperature of a grasscarp pond a few degrees.

.../...

3. THE GREENHOUSE

The greenhouse is a good example of the first point mentioned above. Three factors can be mastered : temperature - through the storing of excess heat during the day and its use at night ; hygrometric regulation ; and the photosynthetic fraction of the solar flux (with curtains or blinds). Global greenhouse energy assessments have stimulated the creation of models in which a partial or complete control of these factors is established.

Many systems for controlling temperatures have been described by various authors. One example is the use of water to store heat with air serving as the transfert medium. It has been also suggested that a solution with 1% $Cu\ Cl_2$ be used both to collect and to store heat. Pebbles have also been used for storage with air as the transfer medium.

These systems enable to control to a certain extent the difference between greenhouse temperature and the temperature outside. Numerous studies have dealt with the use of water in the greenhouse and the control of hygrometry.

Excess light has in the past been eliminated with curtains. A new greenhouse technique introducing a double wall makes it possible to recuperate heat absorbed by venetian blinds. This heat can be stored in a gravel or a change of phase storage system. Temperature, hygrometry, luminosity and photoperiod can be controlled by the opening or closing of the blinds.

TRENDS IN THE PROCESS DESIGN FOR ETHANOL PRODUCTION AS ENERGY SOURCE

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1. INTRODUCTION

Biomass plantation for conversion into fuel is soon to be investigated in numerous countries, and, Brazil make the highest effort to reduce its bill for imported oil by including ethanol as a constituent of motor fuel up to a level of 20 %. The ethanol is produced by fermentation of many different raw materials, for example grain, molasses, sulphite waste liquor, wood waste, sugarcane, cassava, beets, fruits and whey. The overall reaction of the fermentation is expressed by the Gay-Lussac equation :

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2\ CO_2$$

Under optimum fermentation conditions , the maximum alcohol yield is 0,45 g/g of carbohydrate, the maximum alcohol concentration than can be obtained is, in a reasonable time, in the fermentation medium approximately 10 to 15 % by volume.

In western countries, with actual structure of the agroindustry the Energetic yield E.Y. (energy input to obtain 1 unity of energy of distillated ethanol) is shown in next table.

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	Beets	Molasses	Potatoes	Corn
E.Y.	1.29	0.78*	1.6	1.74

* without consideration of energy input for the production of molasses

The problems of the alcoholic fermentation are :

- to decrease the needs in energy to produce ethanol during fermentation and extraction,

- to become competitive from the economical point of vue with the ethanol product by synthetic route which now supply more than 80 % of domestics needs.

The key of success needs to :

- improve the yields

- improve the productivity by finding new strains and new technology of ethanol production

- increase the ethanol concentration in the fermentation broth (research of new strains)

- find new technologies of ethanol separation

- valorisation of the by products : biomass, CO_2, ...

II - PROBLEMS FOUND IN ETHANOL PRODUCTION

II-1. - YIELDS IN ALCOHOLIC FERMENTATION

The practical yields are :

.../...

	$\frac{\text{kg biomass}}{\text{100 kg sugar}}$	$\frac{\text{kg ethanol}}{\text{100 kg sugar}}$
Batch culture	10	40
continuous culture	5	45

In our laboratory during the growth of Saccharomyces cerevisiae on glucose, in strict anaerobiosis, we evaluated in bath culture the substrate consumption by maintenance and the yields. The values of the maintenance coefficient m changes during the growth cycle. The highest value is reached during the rapid cell growth when the fermentation starts. The m values is related to the cell growth inhibition and we obtain a good correlation between m and the initial substrate concentration. The yields of glucose conversion in ethanol decrease when S_O increases as shown in the next table.

S_0 gl^{-1}	20	50	80	100	190	250
m_{S_0} h^{-1}	0,066	0,07	0,078	0,11	0,15	0,2
r $\frac{\text{g. eth.}}{\text{g. cell.}}$	0,45	0,45	0,44	0,425	0,40	0,27

The decrease of the yield is due to inhibitory effects.

II-2. - BOTTLE-NECKS IN METABOLISM AS GROWTH RATE CONTROLLING FACTORS

Ethanol production is controld for inhibition phenomenas by :

- ethanol produced (product inhibition)

- substrat (substrate inhibition)

.../...

In anaerobiosis (in batch culture) we show that we get an irreversible inhibition due to ethanol production (figure 1) at any initial concentration of sugar. In no case the initial substrate inhibition is removed and we can consider than cells are biocatalyst limited by intraparticular diffusion for desorption of the metabolite produced.

Due to the inhibitions, the cells mass concentration in the reactor is low because yeast growth and fermentation is slowed down and stopped in the presence of amounts in ethanol in the range of 10 - 15 % by volume. It is therefore necessary to find new strains more resistant to inhibition of to remove ethanol when it is produced and to recycle, or entrapped cells to increase their concentration.

II-3. - THE IDEAL TECHNOLOGY

If we consider the more realiste situation, the better technology will be a continuous technology :

- to decrease inhibition by ethanol we must use a plug flow reactor
- to eliminate inhibition by sugar we must add carbon source at the optimal feed rate (distributed feeding)
- to eliminate inhibition by ethanol it is possible to to remove it by both distillation and fermentation.

III - PRACTICAL APPROACH

III-1. - MAXIMISATION OF THE PRODUCTIVITY BY CONTINUOUS MULTISTAGE FERMENTATION

Yarovenko and Russian use this technique. In our laboratory we demonstrated using 8 well mixed reactors in series than the productivity is multiplied by 2,2 related to batch culture. This technology is not optimal and we must optimise the feed of inhibitory substrate at any stage to obtain the optimal concentration in sugar in the reactor.

.../...

The population can be increased by cells recycle, biofiltrations on the cells or immobilized yeast.

III-2. - EXTRACTION OF THE ETHANOL COUPLED WITH FERMENTATION

Some authors propose to increase the productivity of the ethanol production by coupling both fermentation and ethanol extraction by vacuum distillation. If the productivity is increased, the energetic yield became drastically high.

III-3. - FERMENTATION OF RAW MATERIAL

For beets or sugar cane, the new process can be summarized by

Crops → Direct fermentation on cellulose and sugars in solution → Separation liquid/solid → Ethanol separation

This situation avoid the extraction of sucrose.

III-4. - RECYCLING THE SOLID RESIDU AS FUEL

The energy required for the extraction of 1 energy unit from ethanol is, considering the ethanol content of 9 % in volume, summarised on the next table.

Raw material	beet	molasse	potatoes	corn
distillation	0,78	0,78	0,94	0,92

New technique of ethanol extraction -different of distillation- must be found.

Efficient heat recovery systems must be found and the maximum use of bagasse or lignocellulosic materials as a fuel must be performed. Biomass as feed animal or fertilizer, carbon dioxide utilisation must be improved.

.../...

IV - CONCLUSION

The concept of biomass conversion to readly usuable energy source is appropriate to the time. The discussions of this paper have been based on systems which require significant energy consumming input.

For the future, new technology and new strains for ethanol production must be found. Biologist and engineers have to cooperate to find more performant ways of ethanol production.

ORGANIC ACID PRODUCTION IN ANAEROBIC FERMENTATION

The anaerobic digestion has traditionaly methane as a product. This complexe process involves an acidogenie fermentation that, after hydrolysis of biological substrates conduct to volatil fatty acids, CO_2, hydrogen and methane. A great number of investigation have been concerned with the optimisation of this reaction in which organics acids (acetic, butyric, propionic, ...) are inhibitor of their own production during acidogenesis and of their assimilation during methanogenesis.

We have study the technology to isolate the acidogenesis and to produce organic acids has product of anaerobic fermentation.

An acidogenie population has been isolated after 3 months on continuous plug flow culture (C.P.F.C.) without any pH regulation and 6 month with pH regulation. The change in kinetics data at pH 6 and θ = 30°c have given in the next table :

.../...

	Organic acid tolerance g/l	Yield g/g	Productivity $gl^{-1}\ h^{-1}$	K_i^P * g/l
Kinetics data before culture in C.P.F.C.	18.9	0.378	0.5	0.38
Kinetics data after culture in C.P.C.F.	40.0	0.75	1.5	15

*K_i^P inhibition constant from $\mu = \mu_m\ (K_i^P/(K_i^P + P))$

Temperature have an effect on organic acid profile. The amount in propionic acid increase at low temperature. At 40°c the mixture of organic acids contains mainly acetic and butyric acid (65 % and 36 %)

Substrat exert a weak inhibition effect, but organic acids are strongly inhibitors. The optimal technology of production is : or the continuous plug flow fermentor with cell recycle, or the use of series of well mixed reactors. We study the use of 8 continuous stirred fermentors in series and we can study the behaviour of the population in long continuous culture. The stability of the system is high and the productivity can reach 2 $gl^{-1}h^{-1}$ at a yield of 0.75 g/g with 99 % of the substrate removal.

Obviously the interest of plug flow continuous culture appeared in the production of inhibitory product. The methanic fermentation have interest not only for methane production but for organic acid production which have an high interest has basic product for the industrial chemistry.

Similitude between kinetic behaviour of the alcoholic fermentation and organic acid production appears. All the conclusion on the trends in fermentation technology for alcoholic fermentation are useful for acid production.

PHOTOVOLTAIC SOLAR CELLS : DESCRIPTION OF DEVICES IN USE AND LONG-TERM EVOLUTION

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INTRODUCTION

Solar cells are semiconductor devices which perform a direct conversion of light into electricity, by way of the photovoltaic effect.

Silicon solar cells for terrestrial applications are now become industrial products and are commercially available. Their structure and performances, their arrangement in panels are described and the actual output specifications are given.

A strong research and development effort is made in industrialized countries in order to reduce the cost of present solar cells. Besides this short and mid-term effort essentially devoted to silicon a long term investigation has to be conducted for finding out cheaper materials and technologies such as thin film cells. The participation of all countries to this long-term effort is desirable.

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1. CELLS AND PANELS

Present solar cells are made from thin wafers, usually circular, of single crystal silicon. Fig. 1 presents the cross section of a cell. Light is incident on the top. The photon-electron conversion takes place at the junction between two regions doped with specific impurities. For collecting the generated current two metallic electrodes are soldered on the cell : one covers entirely the back side, the other one has the form of a grid.

A solar cell panel consists of a number of elementary cells, usually connected in series in order to increase the output voltage. A typical model of panel (BPX 47 A from RTC company) comprises 34 cells, 57 mm in diameter. The cells are disposed between two glass plates and embedded in a resin. The output characteristics under AM1 illumination (100 mW/cm2) depend upon the working temperature as indicated below :

	25°c	60°c
Optimum current	690 mA	690 mA
Optimum voltage	15.5 V	13 V
Maximum electric power	10.7 W	9 W
External efficiency	6.3 %	5.3 %

The external efficiency accounts for the packing factor of the panel ratio between active area and total area (36 x 47 cm2). For this panel the packing factor is 0.5..

The present trend in the panel realizations is to increase both the size of the cells and the packing factor of the panels. Large cells are obtained by growing large diameter single crystal ingots and this leads to a smaller silicon cost per unit area. Fig. 2 presents an example of the past evolution in panel realization. The more recent module consists of 100 mm diameter cells. The current delivered by such cells is greater than 2 amperes. .../...

2. LONG TERM PROSPECTS

A basic tendency in the present technological development is to ensure a continuous coverage of the panel. This is the way taken with polycrystalline silicon : ribbons, thick films or plates can be arranged side by side to a flat continuous collector.

The ultimate objective could be the realization of large area thin film cells. The combination of a large area per elementary cell and of thin film materials is an attractive system because of the expected reduction in material and labour costs. However, as already stated, the conversion efficiency must remain above a threshold value of the order of 10%.

Crystalline or polycrystalline silicon is not an appropriate material to be used in thin film form. The minimum required thickness is 50µm and the minimum grain diameter is a few hundred microns. Among the other possible materials two categories of materials are worth mentionning here.

- Amorphous silicon
  This material is one hundred times more absorbing than crystalline Si so that one micron thick films can be used (1). Indeed here is a new class of materials requiring intensive fundamental and applied research. As an example the Ge-Si alloys also exist in amorphous form and allow one to set the limit sensitivity wavelength at any value between 0.8 ans 1.3 µm (2). This offers a great flexibility in cell design.

- Polycrystalline and highly absorbing materials
  Because of high absorption a thickness of 2 - 3 µm is sufficient. Furthermore the requirements on grain size are the less severe as thickness decreases. This is exemplified on Fig. 3 which shows in which way the theoretical efficiency depends on grain diameter for two materials : Si and GaAs, one of these highly

.../...

absorbing materials (3). Other materials falling in this category are InP, CdTe and Cu_2S.

The most advanced realization makes use of the heterojunction CdS/Cu_2S. A cross section of the structure is seen on Fig. 4. Photon absorption takes place in Cu_2S and photon-electron conversion occurs at the Cu_2S /CdS interface. The maximum efficiency reported for this type of cell is 9 % (4), while values of 12 % have been measured for short periods of time by an Indian group (5). Panels have been realized at a pre-industrial level. A panel made by the compagny Photon Power comprises 60 elementary cells of 40 cm2 area. The thin film cells are protected by a tempered glass cover on one side and a soft metal film on the other side.

The power generated under AM1 illumination is 9.6 watts. The efficiency is 4 % referred to active area and 3 % refferred to total area (3096 cm2). Fabrication cost is claimed to be low and uses a low temperature chemical spraying process. Long term stability has yet to be investigated.

The achievement of these long term objectives requires intensive and extensive research. This research effort has not to be confined in well industrialized countries, contrary to the new silicon growth technologies. Because the perspectives are much more remote all countries can find here an accessible and fruitful field of research.

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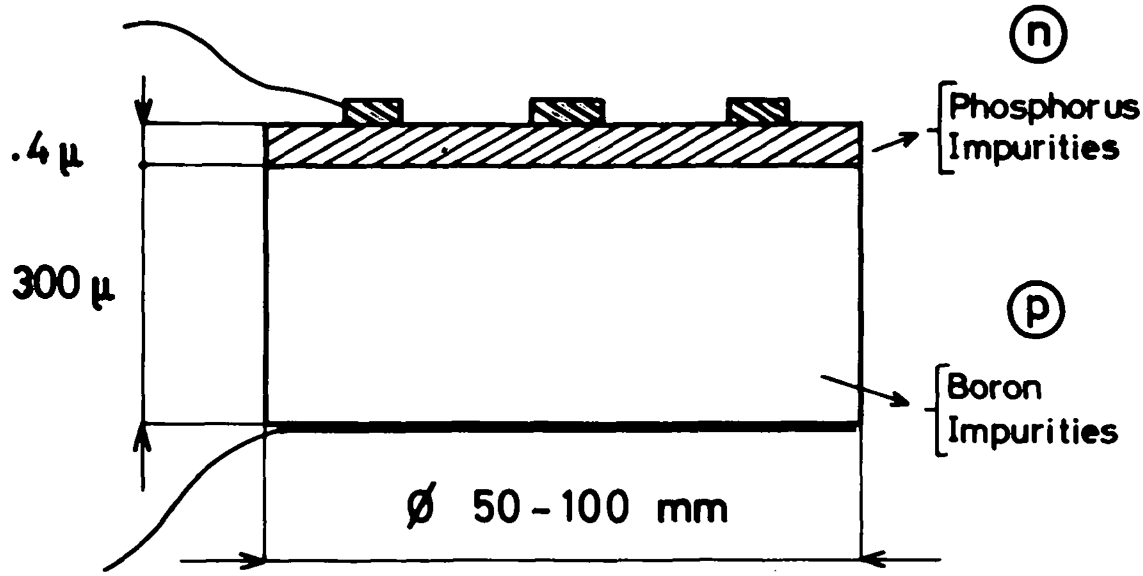
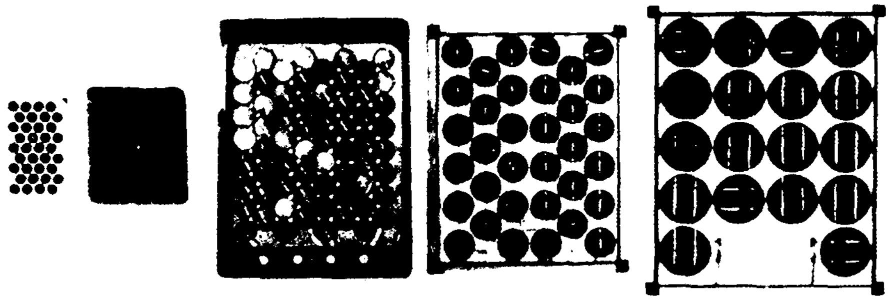
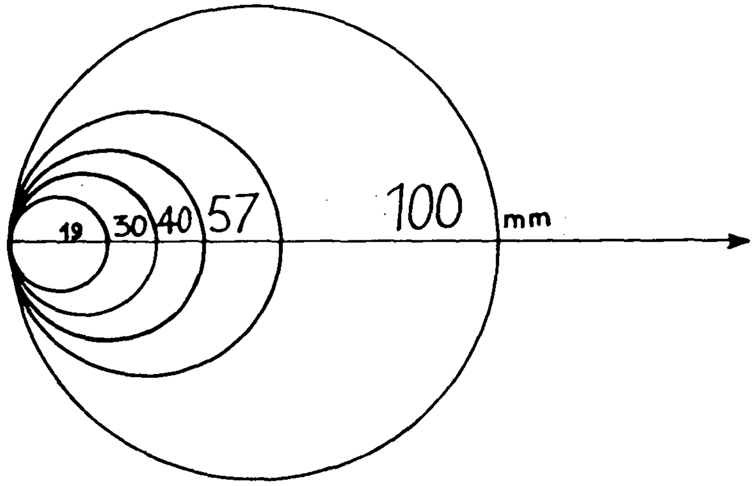


Figure 1

Cross-section of a silicon solar cell



1960	1965	1970	1975	1979
	40.30 BPY	BPX 47	BPX 47 A	BPX 47 B



		40.30 BPY	BPX 47	BPX 47 A	BPX 47 B/18	BPX 47 B/20
Ø cellules Ø cells (mm)	19	30	40	57	100	100
Puissance Power (W)	0,65	2,5	8	11	16,5	18
Tension Voltage (V)	3	16	12.24	15,5	9,2	9,1
Nombre de cellules par module Number of cells / module	36	40	64	34	18	20

Figure 2

Time evolution in panel characteristics (from RTC company)

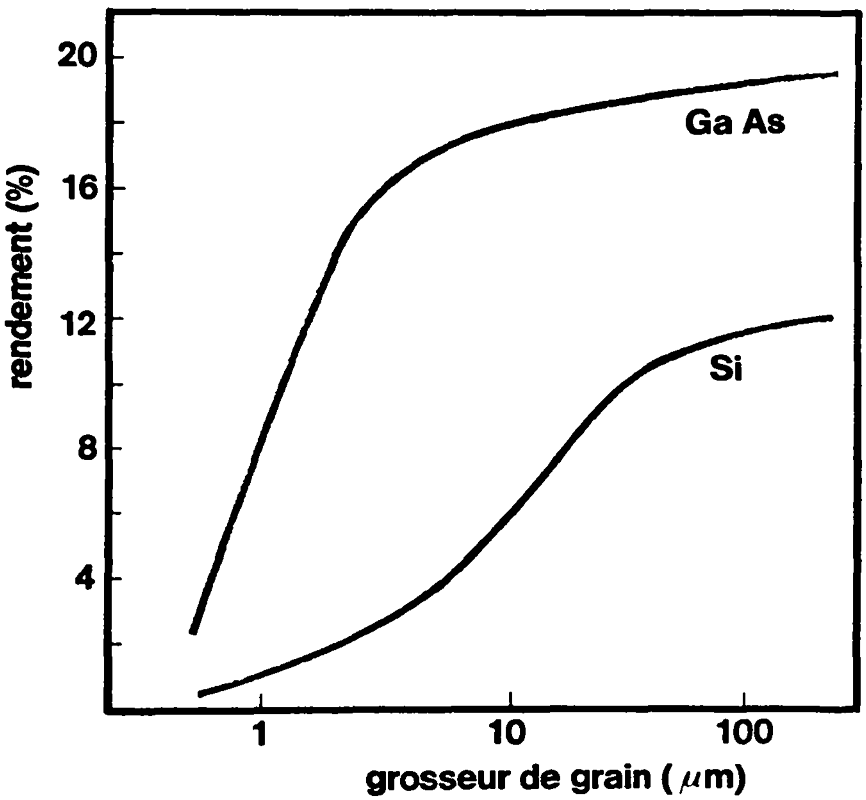


Fig. 3

Figure 3

Variation of theoretical efficiency as a function of grain diameter of two polycrystalline materials.

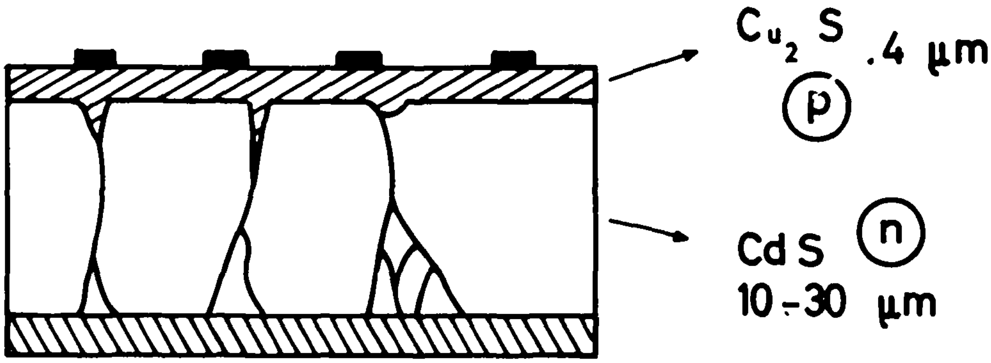


Figure 4

Cross-section of a Cu_2S-CdS solar cell

SOLAR ENERGY AND WATER DESALINATION

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1. SOLAR ENERGY APPLIED TO DESALINATION

The desalination techniques are using energy under various forms which all may be originated from solar energy.

The energy consumption per cubic meter of soft water produced varies substantially with the process involved.

Distillation processes are extracting soft water vapor from salinated water. Their energy demand is independent of the salinity of the water, in first approximation.

Membrane processes do behave differently and energy required is strongly dependent upon salt content. They will be prefered for brackish or low salinity water. They have limitations due to compatibility problems of the membranes with water temperature and with sludge content.

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.../...

In an ideal reversible process, extraction energy of salts would require a theoretical energy varying between 0,7 and 1,8 kWh/m3 from sea water according to the conversion rate. The practical situation due to irreversible losses is somehow different and will be understood after a brief description of the various processes.

1.1. DISTILLATION PROCESSES

As a principle, distillation has to perform three successive operations: heating, evaporation and condensation.

1.1.1. DIRECT DISTILLATION : SOLAR STILLS

Well known, since a century at least, solar stills are performing the three functions in the same apparatus. Condensation latent heat is evacuated to atmosphere and not recycled. Then daily yield is low (4 to 6 liters per square meter) of basin, but not far from the upper limit allowed by a daily insolation of 6,5 kWh/m2. This energy would be capable of evaporating grossly 12 liters of water, the usual yield of 4 to 6 corresponds to a collection efficiency between 35 and 50 % which is a very reasonable figure for simple devices and no breakthrough can be expected from this process.

Simple and cheaps, its technology is well suited for capacities up to some cubic meters per day.

1.1.2. INDUSTRIAL PROCESSES

Vapor compression

This process is extracting the evaporation product and compressing it in order to induce condensation at a temperature slightly above the evaporation temperature.

.../...

The latent vaporization energy is then recycled and energy consumption reduced. The compressor is acting as a heat pump and the potential performance of the principle is high.

Many installations of this kind are in operation and their usual capacity is of the order of 500 m3 per day. Energy is required in mechanical or electrical form.

Multiple effect units on vertical tube evaporators

The latent heat of vaporization removed by the soft water steam is recycled, without recompression to a second unit operating several degrees below the firstone. The arrangement consists of several (3 to 15° units in a temperature cascade. A careful disposition of heat exchangers and recuperators provides a very good efficiency to the process which is used for large units (1000 to 100.000 m3/day).

Reaching a steady state operation requires several hours and continuous operation is a necessity. It imposes heat storage for utilization with solar heat and requires significant amount of mechanical energy for turbulent water flow in heat exhangers.

Multiflash system

Designed and used for big units (30.000 to 40.000 m3/day) this process has been, to day, used for up to 75 % of all distillation capacity installed in the world.

Sea water, pressurized and pre-heated is introduced in a chamber where pressure is below saturation pressure of incoming water : instantaneous vaporization occurs, caused by depression. A succession of pressure drops occuning in a suite of consecutive chambers, in a thermal cascade, leads to efficient utilization of thermal energy which is recycled by the feeding pipe.

.../...

In the same way as in the proceeding system, heat stabilization is long and mechanical energy significant.

1. 2. MEMBRANE PROCESSES

1. 2. 1. ELECTRODIALYSIS

The salt cations and anions are removed of the water to be treated by selective migration through a permeable membranes, under the motive power of an electric field.

By principle, electricity consumption is proportional to the salinity of the water.

Application of this technique has been made in France for effluent processing in chemical industries and also for water desalination powered by a wind turbine.

Capacity can range from 10 to 10.000 m3/day. This process is directly applicable to solar cells and requires no "heating time". Discontinuous operation raises no special difficulty.

1. 2 2. REVERSE OSMOSIS

Salt water is "filtrated" through a semi-permeable membrane which has the property of retaining bulky salt molecules. It has a limitation due to temperature sensitivity of present day membranes and works on mechanical energy. A high pressure hydraulic pump is needed to overcome osmotic pressure between salinated and soft water and force water diffusion through the membrane.

The system can be designed to work in a range of pressure and conversion rate combinations in order to optimise either membrane investment of energy consumption this latter case beeing of utmost interest when mechanical energy is originating from a solar engine.

.../...

A test model is operating in the C.E.A. test center of Cadarache, based on the coupling of a 3 kW solar engine SOFRETES with a reverse osmosis unit devised by CEA/Applied Chemistry Division. This prototype is to produce 15 m3/day of fresh water from brackish water containing 2000 mg/liter of dissolved salt.

This unit is to operate during 6 hours a day, that is to say without energy storage.

If it is admitted that 50 m2 solar collectors are necessary to produce 1 kWatt (mechanical) the production of 1 m3/day of fresh water necessitates 11,3 m2 of solar collectors that is to say a performance of about 100 liters/day/m2 (to compare with 4 liters/day/m2 of standard solar stills).

2. DESALINATION PROCESSES, ENERGY SUMMARY FOR TODAY PRACTICAL UNITS

It is to be kept in mind that an operating desalination system will require its own energy supply for the salt separation process, and also auxiliary energy to provide the needed saline water at the entrance of the system. This will be often brackish water from deep wells (60 m as a standard example in Middle East "Badia"). Then, dissociating the energy needs could be misleading. Solar heat will distillate but not pump the water, unless thermodynamic engine is also provided.

This constraints stongly supports the membrane processes, since they are minimally energy consuming and in the same form as needed for pumping.

This short review had not the intention to study the detailed comparative merits of the various combined pumping-desalination units, but only to expose the principles and constraints and provide grounds for reflexion.

Figure 1 summarizes the combined energy needs for the described systems. It requires no detailed comments.

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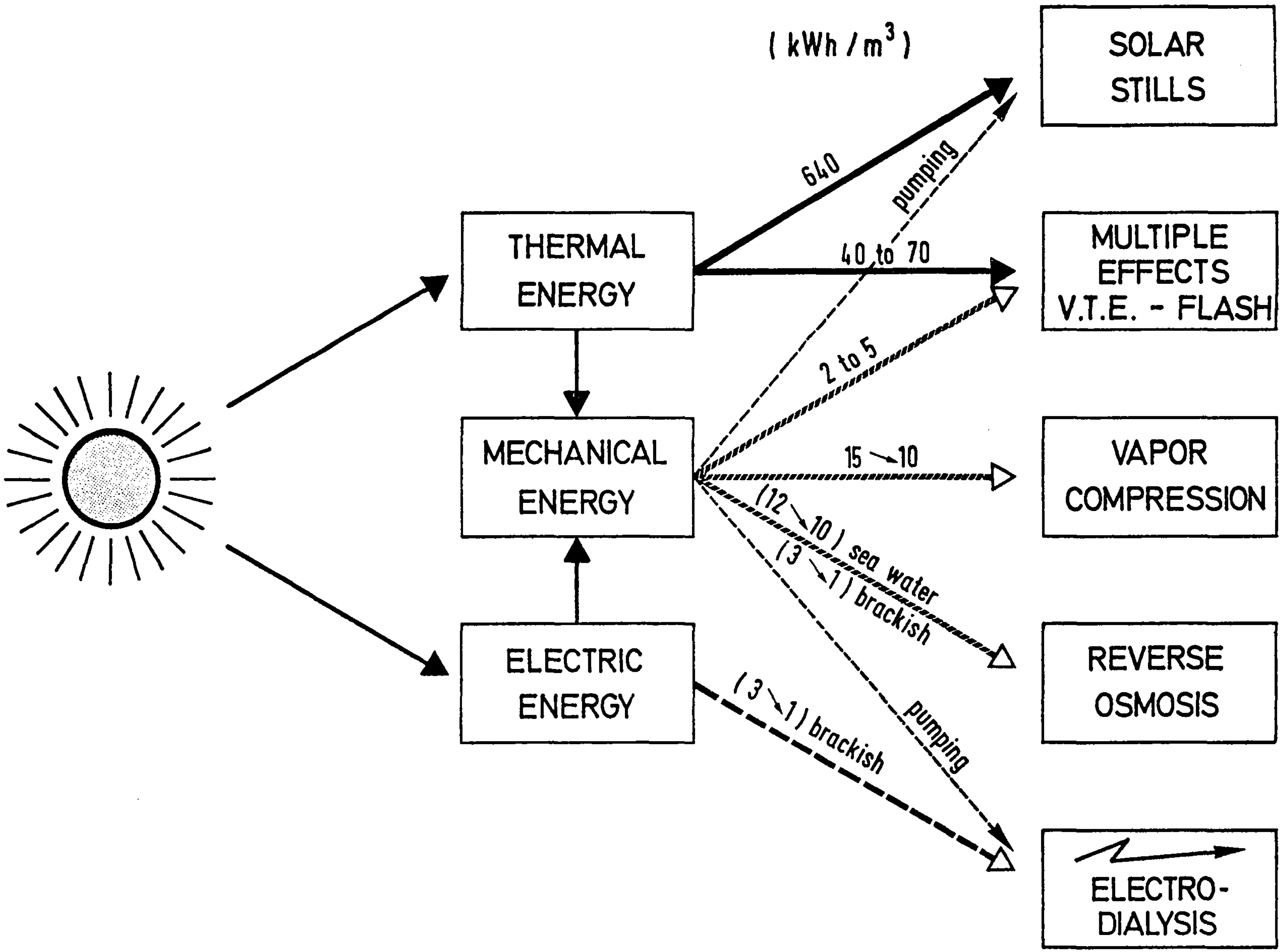

Fig 1 – SOLAR DESALINATION – ENERGY SUMMARY

C.E.A./C.P.E.S.

SOLAR COOLING

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1. PASSIVE COOLING

Passive cooling has been extensively used in the past in traditional houses. A reactualisation of these techniques based on a scientific approach of the problem is currently underway in various countries. Three directions (and the coupling between them) are being studied : humidification, ventilation and radiation.

1.1. - The psychometric chart

A description of the psychometric chart will be presented leading to a classification of the climates depending on the heat content of the humid air. We shall present three typical climates and discuss the possibilities as well as the limits of passive cooling using humidification.

An example of cooling by humidification will be given showing the water consumption and the ventilation needed.

A coupling, as studied in Odeillo laboratory, between humidifiers and a solar chimney will then be presented.

1.2. - Radiative cooling

The existence of the so-called atmospheric window allows for cooling of a surface as soon as it emits in the range 8.5. to 13 µm.

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After TROMBE et al, nocturnal cooling through this radiative effect was studied in various laboratories. Recently, P. GRENIER in France proposed to use radiative cooling during sunshine as well as during the night. For that purpose, a filter transparent to the infrared but opaque to the solar radiation has been realised.

2. SORPTION CYCLES

Amongst the machines using sorption cycles we shall distinguish :

- liquid absorption (NH_3-H_2O, H_2O-BrLi, etc...)
- solid absorption ($CaCl_2$-NH_3, etc...)
- solid adsorption (zeolithe-H_2O, etc...)

Two of these cycles (NH_3-H_2O-BrLi) are very well known and have been extensively commercialised. Recently, machines using H_2O-BrLi cycle have been adapted to solar energy.

The thermodynamics of these cycles will be rapidly discussed, this will allow us to introduce two important quantities :

- the threshold temperature
- the relative circulation of the refrigerant.

As a conclusion, we shall insist on the fact that the H_2O-BrLi cycle is very well adapted for solar powered (using flate plate collectors) climatisation as soon as a water cooled condenser is used.

In the event of the necessity to use an air cooled condenser, another cycle has to be selected for climatisation. The NH_3-H_2O cycle has been proposed and various firms are intending to adapt such machines to solar energy. These machines need a rectifier which implies a sophisticated technology.

.../...

The possibility of the application of other cycles to solar energy will then be discussed. Some simple physical arguments will be given in favour of solid adsorption.

We shall describe an intermittent cycle using the zeolithe 13X-H_2O combination. It will be shown that such a cycle is well adapted for solar climatisation with an air cooled condenser.

The influence of the various temperatures of the system on the coefficient of performance of the cycle will be discussed. As a consequence it will be shown that high performance collectors are necessary for some applications of solar cooling.

We shall then discuss briefly the technology that has to be developped and :

- the choice of the combination (liquid absorption or solid adsorption for example)
- the type of cycle (intermittent or continuous leading to cold or hot storage)
- the temperature of the condenser.

As a conclusion, the technological simplicity of intermittent cycles using solid adsorbents will be exposed.

The possible coupling between sorption machines and the heat sink of a solar powered electricity plant will be presented. We shall insist on the fact that the choice of the cycle will greatly depend on the temperature of the heat sink and on the desired temperature of the evaporator.

3. THE RESEARCH ON SOLAR COOLING IN EUROPE

The French programm on solar cooling includes projects on :

- passive cooling
- research for new cycles
- study of selective surfaces for high performance collectors
- development of selective surface vacuum collectors
- adaptation of machines working with liquid absorption cycles to solar energy.

Furthermore, the CEC program includes projects on :

- Rankine cycles
- Combination of solar energy and heat pump.

It is generally expected that within a few years, the optimisation of the cycles for the various applications in solar cooling (from climatisation to congelation) will have been found and that systematic economical studies based on comparison of actual units will allow an important development of solar cooling in the same manner as for solar heating. Moreover as shown in part I, passive cooling will develop in the regions where the climate is well adapted.

ABOUT UTILIZATION OF SOLAR ENERGY

FOR AGRICULTURAL DRYING

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Drying of crops or any other agricultural products is a problem in temperate as well as in semi-tropical climate. Crops recently harvested are more or less gorged of humidity. But one knows that part of the water inside the product must be immediatly eliminated otherwise unfavourable enzymatic reactions or microorganismus proliferation will take place both aiming to spoil the product in terms of nutritive value as well as tasting value. Once this water taken off, one can usually proceed to a slower drying till an humidity level in agreement with a good preservation of the product.

Crop drying may often be looked as a quick pre drying then a slow drying.

In many countries, crops are partially lost because meteorological conditions do not permit at the good time this quick predrying nor the end of the drving (we are meaning natural drying).

To prevent this damage, one is tempted to use energy supply in order to speed up this processus. The purpose of this work was to prospect the availibility of solar energy technologies which could be applied to this field.

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We consider it like that : for each given problem, we try to find the best appropriate technology and if possible, to replace that one in an integrated unit (look as well J.F. MIQUEL's paper) so as to diminish as much as possible the whole investment costs.

We studied the following items.

1. SUM UP OF THE INFORMATION NECESSARY TO STUDY A DRYING OPERATION

The evaporation of water out of a product starts off as soon as the partial pressure of water vapour in the product P^{p}_{vp} is superior to the partial pressure of water vapour in the ambient atmosphere P^{a}_{vp}

$$P^{p}_{vp} > P^{a}_{vp}$$

But this operation proceeds more or less rapidly, depending on the way of water migration out of the product, the surrounding conditions, the system of heating being used, and the <u>dimension of the product</u>.

Let us imagine a <u>batch drying</u> as represented on Fig. 1. The air moving from the bottom to the top gets altered, colder and colder, more and more humid. If the eight is sufficient, the air gets out saturated of water. This is called drying on <u>variable conditions</u>.

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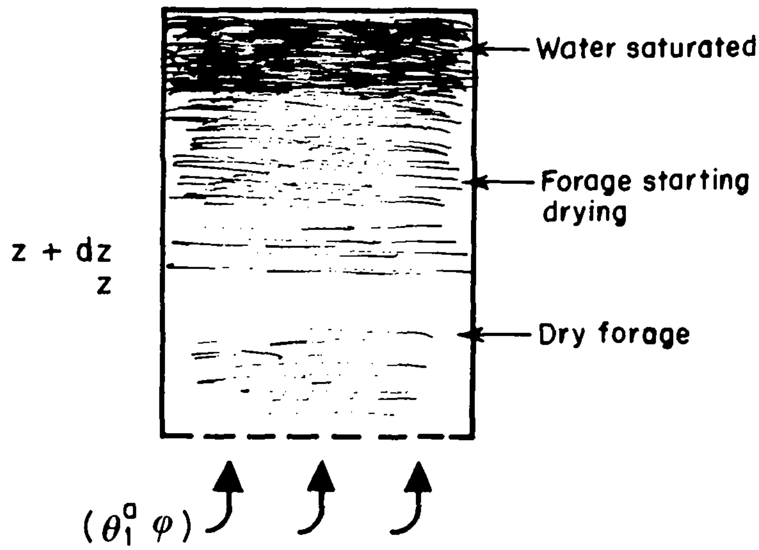

Fig. 1

To investigate such a drying, it is necessary to know first how a thin larger of product (between z and z + dz) does behave.

We have then summed up the more important features to know on the drying of a thin layer (that is under constant conditions)

A. Phase of constant evaporation velocity (methods to increase the evaporation velocity ; drying by convection ; drying by convection and conduction)

B. Phase of decreasing velocity
(superposition of sorption curves on the psychrometric chart ; evolution of the temperature of the product during the drying ; methods to increase the drying velocity ; calculation of the drying time).

We have then seen how to use all these informations for the batch-in-bin drying or deep bed drying (variable conditions)

.../...

A. Evolution of the point characteristic of air (during the constant velocity phase)

B. Relation between distance covered and the air characteristics (constant velocity phase)

C. Batch-in-bin drying
(generalities ; exemples of drying curves when air gets out unsaturated ; same, when air gets out saturated ; influence of air velocity on the drying velocity ; rough energy balance)

D. Methods of simulation.

2. SOME IDEAS ON THE WAY TO APPROACH A STUDY OF DRYING IN AGRICULTURE BY USING RENEWABLE SOURCES OF ENERGY

As soon as drying operation is intended, one has to choose the more appropriate source of energy, to dispose of it in sufficient quantity, to work with it correctly regard to the foreseen utilisation.

SETTING THE PROBLEM is then necessary. For that, it is good to

2.1. STATE ALL THE OPERATION CONSTRAINTS :

- maximum product temperature
- constraints in temperature and in the choice of the techniques appropriate to the predrying
- required moister content
- duration of drying
- recommended leading of drying
- harvest dates and their spreading in time
- economical, ecological, geographical ... political constraints

.../...

2.2. GATHER INFORMATIONS ON THE PRODUCTS

- sorption curves
- drying curves

measured on samples

- influence of the air velocity on the drying velocity
- pressure-drop through the product versus air velocity
- drying-time versus thickness of the layer

2.3. DRAW UP AN INVENTORY OF THE RENEWABLE ENERGY SUPPLIES LOCALLY

- solar,wind or hydraulic energy ... ; possibilities of storing these energies.
- choose the more appropriate technique of captation for the situation taking into account the performances of the energy collector possible.

2.4. SEARCH INTO POSSIBILITIES OF EXTENDING THE USE OF DRYING COLLECTORS TO OTHER OPERATIONS, AGRICULTURAL OR ELSE, MEANING TO REDUCE TO A MINIMUM THE INVESTMENT COST.

2.5. TRY AND FIND OUT ALL THE PRACTICAL TECHNICS POSSIBLE, NEEDING NO ENERGY AND ENABLING TO REDUCE THE MOISTER CONTENT BEFORE THE DRYING OPERATION OR DURING IT? AND TO INCREASE THE DRYING VELOCITY

2.6. SEARCH THE APPROPRIATE LEADING OF THE DRYING CONSISTING IN MAKING THE BEST USE OF THE DRYING INFLUENT FACTORS DURING ONE AND THE OTHER PHASE SO AS TO INCREASE THE GLOBAL VELOCITY WHILE DIMINISHING THE CONSUMTION OF ENERGY.

2.7. GOING FROM THE MOST SIMPLE TO THE MOST COMPLICATED AND TRYING TO TAKE THE BEST OUT OF THE OLD TRADITIONS...

3. WHAT IS IMPORTANT TO KNOW ABOUT THE PLANE SOLAR COLLECTOR

to use it as well as possible, eventually in a drying operation

4. APPLICATION : STUDY OF SLURRY-DRYING FROM A SWINE HOUSE IN TEMPERATE CLIMATE WITH THE HELP OF AIR AND WATER SOLAR COLLECTORS

One of the important problems in swine-breeding farms turns out to be the elimination of manure. As manure is progressively taken out of the swine-house, destruction of its smell must proceed and storage problem has to be solved. An average breeding farm of 40 sows corresponds roughly to a total of 560 present animals producing about 3 m3 of manure per day (2).

Varied technics are being used but, up to now it seems that all of them still present a few disavantages either of ecologic type (bad smells, destruction of the ground pores by repeated spreadings, rising of the DBO - Biological Oxygen Demand -, or of economical type (high cost of some of the equipments...)

Upon J.F. Miquel's initiative, and inserting itself in a wider study on "Integrated swine house" (1), a collaboration with the Technical Pork Institute (2) has been established, in order to study the way of drying.

The immediate care is to realize a device :

- that dries up the percolated muds the quickest way possible and all over the year,
- of easy use for the breeder,
- so that the extra-cost is as low as possible.

This study is carried out in Villefranche-de-Rouergue, in latitude 44° North, in South-West of France.

Figure 2 shows how, after a few tests with air collectors, we go on one study, by using simultaneously air and water collectors.

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We also point out the problem of energy storage by rock and water, as well as the increase of the exchange area between air and slurry by fragmentation with the aid of a mechanical system.

NOTE : *for more informations, see (3) and (4)*

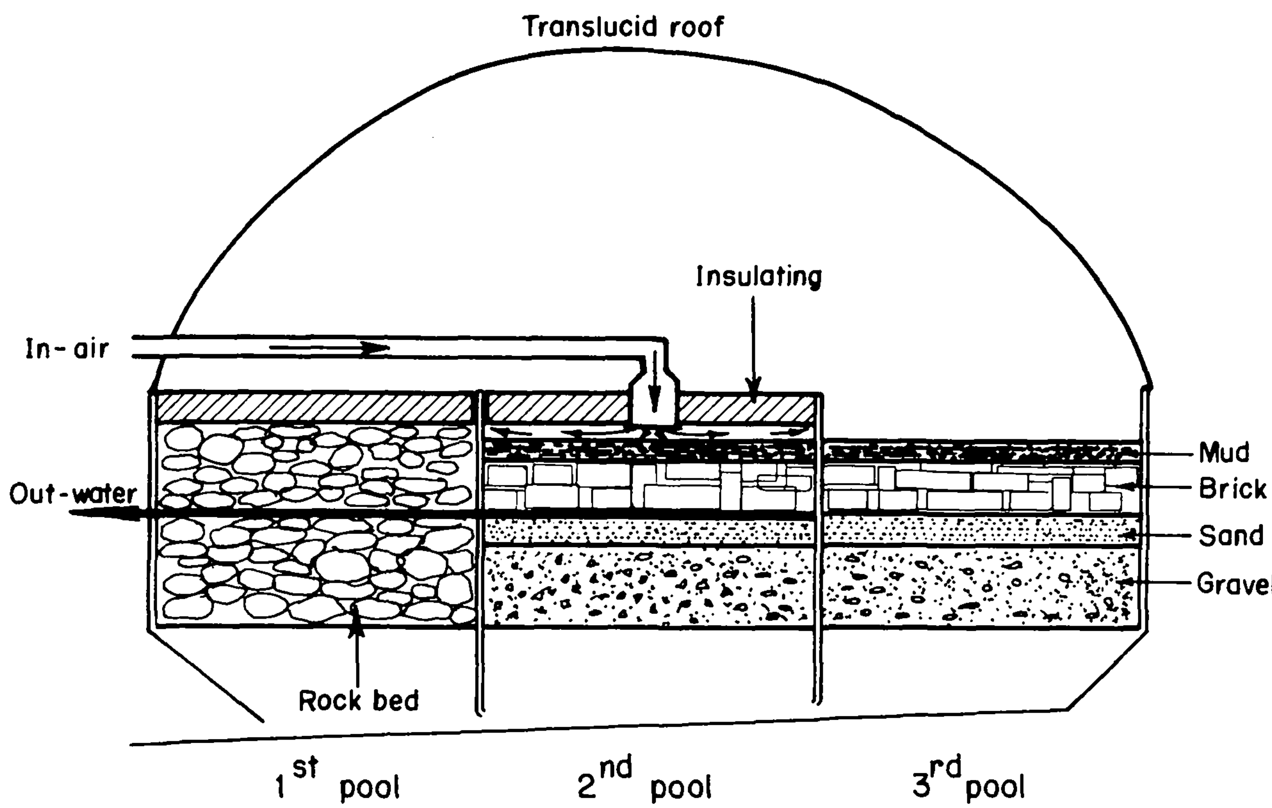

Fig. 2 Part of the whole drying system

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TRANSFERRING TECHNOLOGIES OF RENEWABLE ENERGIES

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Using renewable energies in order to meet at least a part of energy needs is now an official target in D.C.'s (1). In France, a few years ago, renewable energies were estimated as accounting for 5% of the total energy consumption in the year 2000. Today the estimated figures are about 10 to 15 %. In L.D.C.'s, knowing that :

a) the growth of energy consumption connected with general economic growth will take place in the 80's in a context of exhaustible energies being more expansive than they were in the 60's.

b) the energy systems, being less developped, may adapt themselves to other sources of energy faster than they do in the D.C.'s it can be thought that the role of renewable energies should perhaps grow fast.

Some technologies and some productions in the field of renewable energies are developped in L.D.C.'s as well as in D.C.'s. However, the industrial potential of the D.C.'s will allow a quicker industrial development for some technologies, than it will do in L.D.C.'s. Then it is obvious that if the south and south east Asian countries decide to promote renewable energies, they would desire to make themselves the "renewable energy devices" they need.

1) D.C.'s means Developed Countries ; L.D.C.'s means Less Developed Countries Though they mean little concerning the development problems, these expressions are used in this paper in order to simplify the text. This does not mean that we agree in any way upon the economic analysis which these words refer to.

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For that purpose, they should :

a) develop to an industrial stage the technologies they possess

b) acquire other technologies through a process of "Technology Transfer".

The governments and industrial corporations of the D.C.'s should play an important role, mainly in the second direction.

1. TECHNICAL PRODUCTION ROUTES IN RENEWABLE ENERGIES

The main technical production routes concerned in this paper are :

a) heating of air or gas,

b) heating of water or calorific fluid,

c) heating of solids,

d) direct producing of electricity,

e) conversion of wind or water energy,

f) using biological processes to produce energy.

It might be difficult to describe all the parts of each of these routes. For instance, in an apparatus based on heating of water for the production of mechanical energy, panels of glass, pipes, heat exchanges, boilers, gas motor, condenser, circulating pump, are found. The technology of each component is sometimes very simple, sometimes rather sophisticated.

Every technical production route can lead to various applications. From the heating of water, it is possible to : heat a room, cook different products, produce steam for industry, produce cold, produce electricity...

.../...

The needs that can be met by renewable energies in L.D.C.'s are not necessary the same as they are in D.C.'s. In the tropical zones, heating private houses or offices, producing warm water should not be considered as a basic need. On the other hand, drying agricultural productions quickly is often more important in the "South" than in the "North". So, the technologies to be developed for L.D.C.'s will not be the same as those developed for D.C.'s (1).

The interest for renewable energies in D.C.'s became great just after the rise in oil prices a few years ago. Il shall not be forgotten that this is a short period concerning the structuration of an industrial branch. In fact we can hardly speak of a renewable energy branch in the D.C.'s like we speak of a nuclear branch. The relationship between industrial plants for building renewable energy devices are still insignificant. Only a few corporation are trying to produce such devices on an industrial scale. Most of the applications are still experimental or produced on a small scale.

Howerver, before it really exists, this branch will be asked to transfer its technology.

2. ABOUT TECHNOLOGY TRANSFER : DIFFERENT POINTS OF VIEW

Concerning Technology Transfer, the demands of L.D.C.'s, generally speaking, are mainly summarized in the project of "code of Technology Transfer" proposed by the "Group of 77" of U.N.. The most important points concern : access to scientific and technical information, financing the projects, quality of equipments, training, using national productions, no-export contracts... For all these points L.D.C.'s ask for an equality with their partners : not only formal (in the contracts) but real (in the industrial relationship).

The reactions in the D.C.'s are various. The governments and the industrial corporations - mostly the multinationals - have not always the same interests. Some governments officially wish to promote cooperation with L.D.C.'s and then encourage restrictive practices

(1) Except those developed in the D.C.'s for the L.D.C.'s markets.

because of the growing unemployment in their countries. Industrial corporations wish to keep the control on the world market that they have through monopoles or oligopolies.

However Thechnology Transfer can take place. Sometimes a corporation transfers its technology, knowing that an other is ready to do it. Otherwise the corporation transfers a nearly obsolete technology : so it hopes that the technological gap can last. Sometimes, the corporation wants to limit some production activities in its area - in order to develop other activities - and accept to transfer even its most up-to-date technologies.

So it can be possible, mainly because of the bargaining power of L.D.C.'s, in some cases to devedop industrial cooperation between L.D.C.'s and D.C.'s . Is such cooperation possible in the field of renewable energy transfer ? the analysis is rather different than what just has been described.

Difficulties should come from the fact than in D.C.'s, technologies have not been improved in industrial process. L.D.C.'s may have to buy technologies that can fail. On the other hand, two facts can make the transfer easier :

a) the technology is mainly in the hands of research laboratories. Those which belong to the public sector in Europe will more easily accept the idea of cooperation than private ones.

b) The industry being not yet important, the development of a renewable energy industry in the L.D.C.'s cannot affect directly employment in D.C.'s. One of the main obstacles to the transfer of technologies - from the point of view of D.C.'s - does not exist.

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3. TECHNOLOGY AND ECONOMIC ORGANIZATION

The consequences of the development of renewable energies both in D.C.'s and L.D.C.'s on the economic organization of these countries are worth - even briefly analysing.

At a general level it can be asserted that transferring technology is not neutral. When a country buys technology, it does not concern only systems of machines and their technical organization. It concerns also the economic organization that have created this technical organization and not an other one.

In the field of energy, most of the existing systems transferred to the L.D.C.'s are based on a centralized organization : scaling up of growing plant sizes, interconnection of distribution networks, and so on.

On the contrary the renewable energies appear to be linked with decentralized choices (1) :

- in most applications, scaling up does not reduce costs
- many applications, can satisfy a precise energy need in - or near - the place where it appears.

Thanks to that, it can be hoped that renewable energies can contribute to lower the "human cost" of economic development.

(1) But it shall be noticed that this tendency is often inverted when a technical production route reaches large scale industrial state. It should also happen in the field of renewable energies.

.../...

RENEWABLE FORMS OF ENERGIE AND INDUSTRIAL DEVELOPMENT : ELEMENTS TO CONSIDER

LINE	APPLICATION	MATERIEL	MODE OF PRODUCTION	INTEREST FOR DEVELOPMENT COUNTRIES	REMARKS
1) Hot water or other heat transfer medium without concentration (or with low concentration)	1) Space heating (individual or collective)	Flat-plate collectors (glass, tubing, insulator, plastic or metal frame) Regulation (by relay or electronic) Heating Installation (traditional)	craftsmen : simple large companies : complicated common in industrialized countries common in industrialized countries	Almost for D.C. in the intertropical zone Variable elsewhere	
	2) Domestic hot water production	Flat plat collectors (same as above) circulation of water to be heated or of another medium) pipes, regulation Storage tank (with or without exchanger)	same as above plumbing electricity common (electric water heater)	same as above (except for social service buildings (hospital)	
	3) Cooling (refrigeration *air conditioning*)	Flat plat collectors (same as above) *Exchanger* Cold producing apparatus (same as for butane refrigeration)	Same as above *common* common (camping refrigerators but production difficult)	Perspectives for *refrigeration* (private use) and for air-conditioning (private or in buildings)	Use of linear concentration collectors possibl possible
	4) Production of mechanical energy	Flat plate collectors (same as above) Thermal motor (evaporator, motor, condenser)	same as above precision necessary No previous application of this kind of product	Pumping underground water, production requires precision	Other solutions appear more attractive
	5) Production of electric energy	same as above + alternator or generator	same as above + common in the electro-technics industry	complicated solution No market with small companies or in D.C. over time	
2) Heating of water or other medium with concentration	1) Industrial uses (O = 100°c)	Medium concentration collectors (cylandro-parabolic for example) exchangers or direct use of heat and steam	precision machining of materials common boiler	I.A.A. textiles (drying) + diverse industries	clear skies necessary
	2) Production of electricity	Field of heliostats Boiler Turbo alternator	civil engineering materials and above all more or less complicated servo-control for positioning Precision boiler Electrotechnics industry (precision technology exists)	Does not seem justified if D.C. does not have previously developed metallurgy and electric industries	Profitability doubtful Dependability unproven

3) Distillation of salt water	1) Fresh water production	A) Medium concentration collectors *Cascade type exchangers (multiflash)* B) Pool with glass roof (many possible configurations) C) Pool with metal roof (latent heat removed by evaporation) connected to flat plate collectors.	same as Z.1. *boiler systems piping rather* complex simple rater simple	*solution not yet tested* very low productivity Use limited to hospital garages *productivity a little better*	would make it possible to recycle existing dessali-nation plan Installations would have to be too large if they were to satisfy fresh water needs.
	2) Watering in green houses	Slight modification of a standard greenhouse	simple	should be studied seriously where there are green houses and briny water	
4) Heating of air or solids	1) Greenhouse (a reminder)				
	2) Space heating	Flat plate collectors (air) air circulation system storage - by heating solids or liquids - by physical-chemical transformation of a substance within storage area	varying difficulty in technical aspect Necessary to work with architect	or almost no interest in the intertropical zone	Does not exclude an approach in which housing is adapted to local conditions and experience
	3) Drying conservation	Flat plate collectors (air)	most often easy to integrate into design of light structures	of great interest (crop drying and conservation above all)	
	4) Middle and high temperature ovens (household ovens or ovens for industrial purposes)	concentrator systems (mirors) possible servo-control of position (electronic) oven (possibly using heat resistant materials)	more or less complex more or less complex simple	limited handling difficult and results variable	family solar oven poorly accepted
5) Direct conversion into electricity	* all uses of electricity are at low or middle vottages	panels (silicium chips, assembly, connections) equipment run on electricity storage of electricity (battery, others ?)	semi-conductor product is still difficult. The rest can be simple and dependable electric and electronic industries. rather complex	very promising perspectives in rural electrification if semi-conductor production becomes similar and a good market develops local electric and electronic industries	considerable price reduction are expected in this field (a great deal of research is being done in the U.S.A.)

6) Water powered	1) Major installations	- dams - high pressure pipes - hydroelectric power stations	hihg technology B. T. P. electrotechnics	Engineering and production high power electric equipment in few developping countries attractive if sites exist	competition with agriculture uses (major irrigation activities) sometimes complementary
	2) Small installations (powered by current of streams, rivers or irrigation canals	- small dams turbines coupled with alternators - direct use of mechanical energy	B.T.P. part simpler electrotechnics remain rather complex but common in industrialized countries mechanics can be simple	very attractive for rural electrification combined with irrigation works but turboalternators are still rather complex	
7) Wind powered	1) Pumping	- frame + blade system - pump of more or less simple design - wells of varying depths	methal constructions with some parts of wood occasionally Mechanics can be simple	In arid zones simple technical solutions	windly sites required
	2) Production of mechanical energy	same as above except that equipment uses mechanical energy directly	same as above	possible	windmill
	3) Production of electricity	wind mill (propeller and alternator on frame) possibility of mechanical and/or electronic regulation possibility of storage (batteries)	precision necessary in machining of propeller alternator rather sophisticated simple electronics or complicated mechanics rather complex	alternative to photovoltaïc cells but perspective of its coming into everyday use are smaller	winds must be regular and quite strong
8) and 9) Tide - Waves thermal gradient in the sea	* Production of heat, then of electricity	Not developed yet (as fas as we know)	very sophisticated technological solutions	of almost no interest for the moment	

10) Geothermal energy	1) Production (chiefly space heating)	Deep drilling Pumping installations (2 if cold water injection) Equipment using hot water	Equipment similar to that used in the petroleum industry complicated mechanics	Of little interest except if water arrives at a temperature at which it can be exploited by industry (200-300°) difficult	Does not exlude the possibility of low temperature geothermal energy (40-60°c) for heating
	2) Production of electricity	Same as above + traditional power station	complex	attractive for countries with considerable geothermal ressources (Phillipines for example)	
11) Biomass	1) Production of wood, combustable	Rational exploitation of forest			(as a reminder)
	2) Use of waste products production of gas and compost	Digesters, grinders, storage, pipes, ... (animals wastes and even dry plan)	all equipment relatively simple	Interest = immediate fertilizer supply with that of the energy (gas)	uses competing with that of wood as a raw material
	3) Erops with high energy yield	Agricultural equipment Processing equipment (example distilleries)	can be kept simple	of interest but less of a priority the agricultural self-sufficiency	- energy line (methanol) - chemical line (ethanol)
	3bis) Other special biological cycles		Technologies often complex		to be developed

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