OCEAN THERMAL ENERGY CONVERSION [OTEC] POWER FOR SRI LANKA

REPORT OF A STUDY

NATIONAL SCIENCE COUNCIL OF SRI LANKA

DECEMBER 1980

A PRELIMINARY STUDY
ON THE FEASIBILITY
OF
OCEAN THERMAL ENERGY CONVERSION (OTEC) POWER
FOR SRI LANKA

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47/5, MAITLAND PLACE
COLOMBO 7

"Any plan for the utilization of an under-developed area must first ensure an adequate supply of power. An under-planning of the power requirements must be avoided in any case, since this would result in a throttling of the entire industrial development. It is preferable to err on the side of an over production of electrical power since the capital investment in plants for producing power is usually small compared with the capital investment in industries needed to consume the same amount of power."

"Any country which does not wish to depend wholly upon outside aid must have its own research and development organization, not only for investigating the many possibilities which remain unexplored, but also because, even in the fields where general knowledge is available, practical experience and detailed know how have to be obtained."

Dr HOMI J. BHABHA, the late Indian Scientist, in his invited address to the Ceylon Association for the Advancement of Science (presently SLAAS) at its 13th session in December 1957 at Colombo.

Preamble

The steep increase in the price of oil since 1973 has compelled every country to evolve its own energy strategy. Sources of energy alternative to oil are being carefully evaluated and explored. In Sri Lanka the availability of hydro resources has to a large extent inhibited the immediate exploitation of the other alternatives. Nevertheless, electricity generation from non-hydro sources would be needed by the late 1980's to meet the emerging gap between electricity demand and supply. It is therefore necessary to examine the alternatives that may be relevant to Sri Lanka - such as fuel wood, coal, peat, agricultural, industrial and municipal wastes, wind, solar and ocean energy from waves and tides, OTEC, Nuclear energy, etc.

This report is in response to a request made by His Excellency the President of Sri Lanka, J.R. Jayewardene, to the National Science Council to examine and report on the feasibility of an OTEC power station in Sri Lanka.

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Written comments on the preliminary drafts were submitted by the following members of the SEG:- Nihal de Mel, Carlo Fernando, Tudor Gunawardhana, A.N.S. Kulasinghe, R. Mahalingasivam and G.T. Rubaroe.

The drafting committee appointed at the fifth meeting of the SEG on I8 July I980 consisted of the following members of the SEG:

G.B.A. Fernando (Convener)
P.N. Fernando
J.A. Gunawardena
D.B.J. Ranatunga
S. Sivasegaram
H.S. Subasinghe

The Solar Energy Group thanks the staff of the National Science Council for preparing this report. In particular, it wishes to thank Messrs L.C.A. de S. Wijesinghe, M.A.T. de Silva and N. Anbalagan for co-ordinating the activities, Miss. S. Hettiarachchi for typing the manuscripts and Mr. R. Fonseka for collecting the literature for the Committee.

A PRELIMINARY STUDY ON THE FEASIBILITY OF OCEAN THERMAL ENERGY CONVERSION (OTEC) POWER FOR SRI LANKA

1. The OTEC Concept

In the tropical seas, the temperature at the surface is around 20°C more than that at a depth of about one kilometer. It is possible, in principle, to make a heat engine operate between these two temperatures and convert heat to work.

Nature has imposed an upper limit to the efficiency with which useful energy can be extracted from any energy source via a heat engine. This is expressed by the Second Law of Thermodynamics, one of the basic laws of nature, first enunciated by Sadi Carnot as far back as 1824. No violation of this Law has been observed up to date and it is considered as a sacrosanct law of nature by scientists and engineers. By this law the upper limit to the efficiency with which useful energy may be extracted by a heat engine working between temperatures T_1°C and T_2°C (where T_1 is greater than T_2) is

$$\frac{T_1 - T_2}{T_1 + 273} \times 100\%$$

In the case of OTEC this natural limit is about 6.7% when T_1, the temperature at the surface, is 25°C and T_2, the temperature at the depth of about 1 kilometer, is 5°C. Thermal, mechanical and other losses reduce the efficiency to about half of this value in actual practice. Although this efficiency is small, it is still possible to extract useful quantities of energy because a large source of heat is available in the ocean.

Sites for OTEC

OTEC plants can be installed only in the tropical seas. A minimum depth of about 600 m or 2000 ft is required. Problems in mooring systems limit the maximum depth to about 900 m or 3000 ft. The waters at this depth should have access to the deep sea floor. As submarine electricity transmission cables are very expensive, these plants cannot be located too far away from the coast. Owing to these constraints, there are only a few places in the world suitable for the installation of OTEC plants.

An inspection of Ocean Topographic charts suggests that Sri Lanka may be favourably located for OTEC.

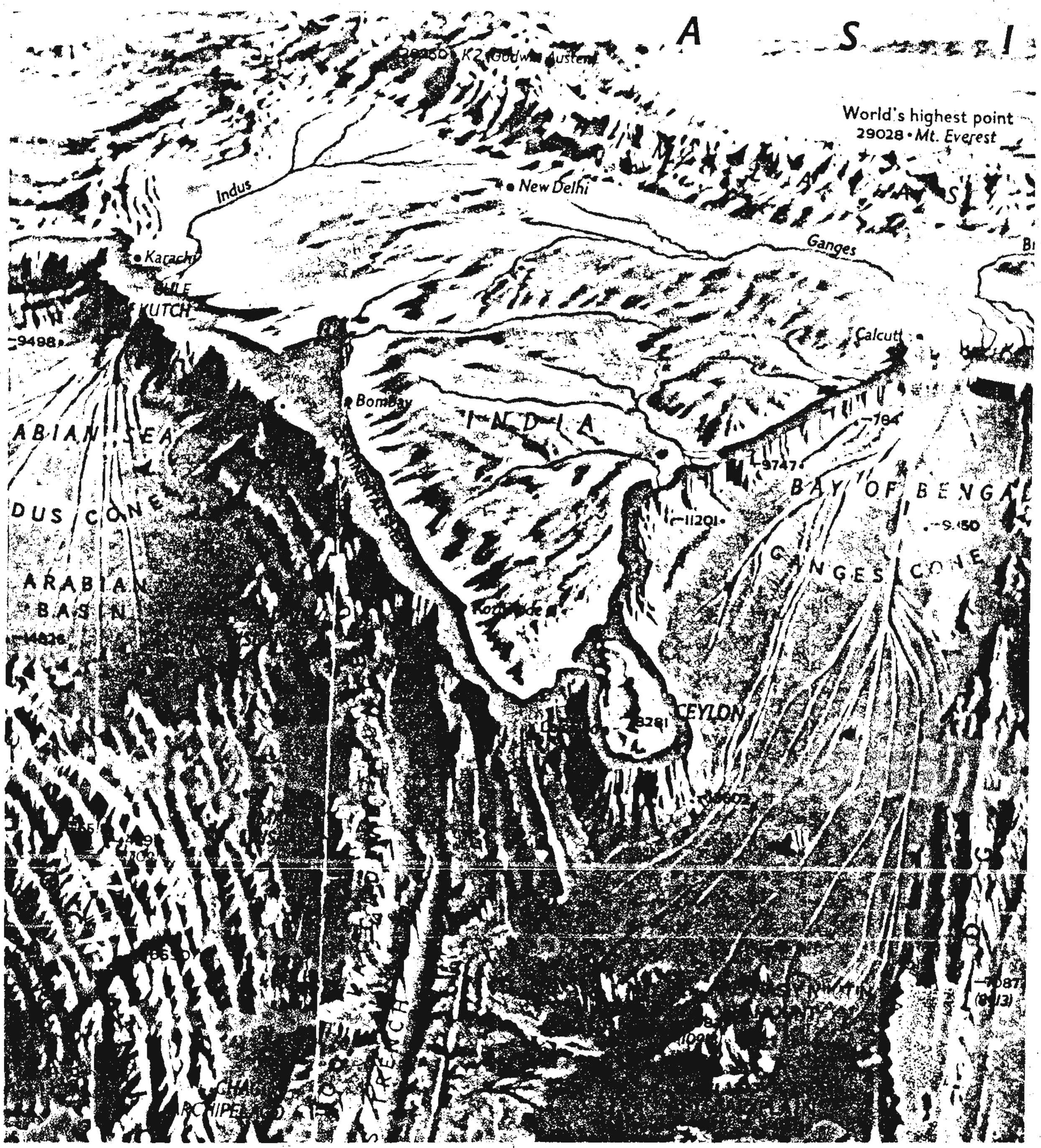


FIGURE I

Map of the National Geographic Society for the National Geographic Magazine,October I967. (I974 reprint).

The ocean floor around the coast of Sri Lanka drops sharply to about 4000 m (I3,000 ft) below sea level

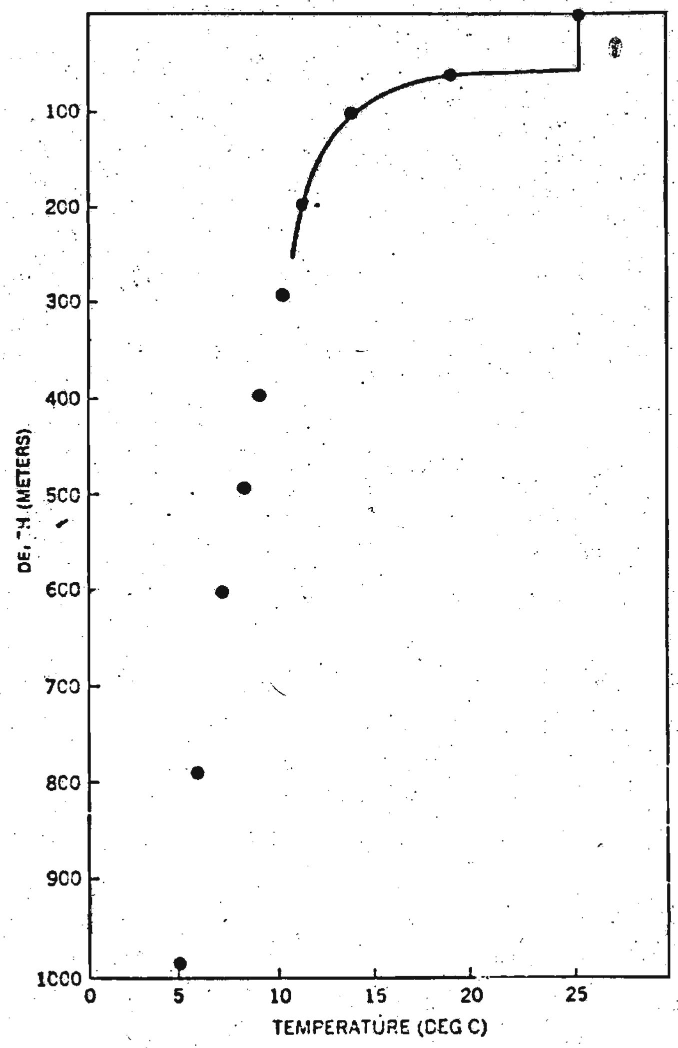


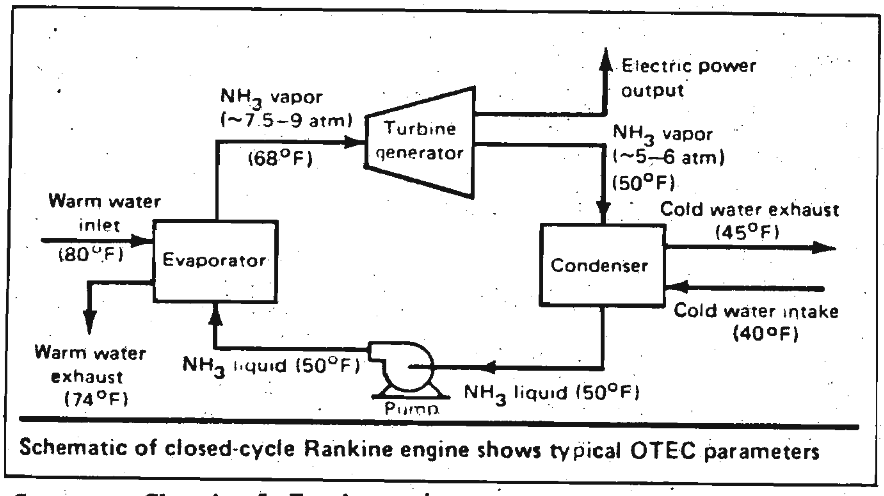
FIGURE 2

Typical temperature profile in the tropical ocean. Taken from F.C. Fuglister, Atlantic Ocean Atlas Woods Hole Oceanographic Institution. (1960).

The black dots are readings at 8°22'N, 27°27'W, and the solid curve is a continuous recording at 8°24'N, 27°27'W.

2. OTEC Plants

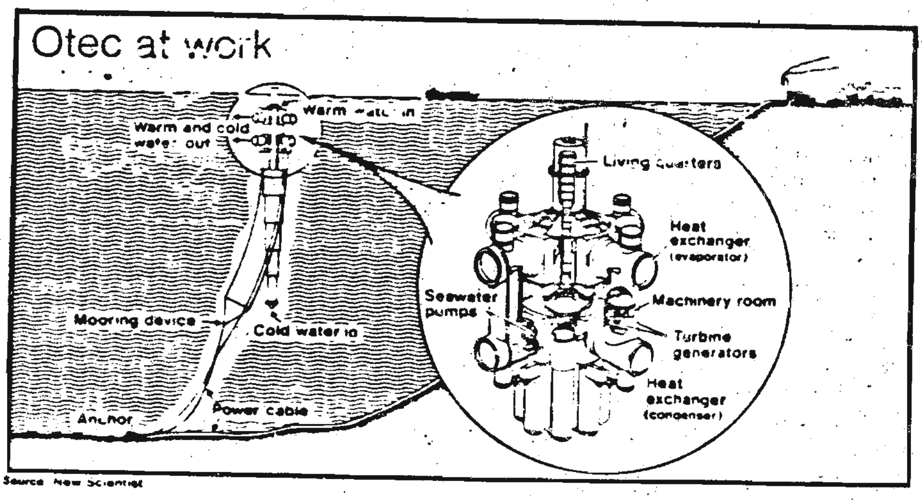
2.I Schematic for OTEC Plants



Schematic of closed-cycle Rankine engine shows typical OTEC parameters

Source: Chemical Engineering

FIGURE 3



Source: New Scientist

FIGURE 4

An OTEC turbine may be driven by water vapour in an open cycle. Warm water at the surface is made to evaporate under low pressure. The vapour drives a turbine and is condensed by cold water at a suitable depth.

Alternatively, a turbine may be driven by a substance such as ammonia or freon-12 in a closed cycle. Warm water vaporises the working fluid and the vapour drives a turbine. The vapour is then condensed by cold water and returned to the evaporator.

2.2 The first attempt

Although the concept was first proposed by the French physicist Arsone D'Arsonval* in 1881, the first successful plant using low pressure vapour in an open cycle was demonstrated by Georges Clude who in 1930 succeeded in producing 22 kW of electrical power in a plant situated off the Cuban coast. However, a greater amount of power was consumed by the vacuum pump in the plant and the result was a nett loss of power.

2.3 The second attempt

A second OTEC plant was attempted in the 1950's by a French Corporation off the Ivory coast near Abidjan. The 7 MW plant based on the open cycle concept, was abandoned because of difficulties in maintaining the cold water pipe.

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* D' Arsonval is best known for the invention of the moving coil galvanometer which is widely used even today in the measurement of electrical quantities.

2.4 Mini-OTEC

Since the escalation of oil prices in 1973, the concept of OTEC has been revived mainly in France, Japan, and the United States. There has been much discussion on this topic since 1973 and the first working model to successfully generate net electric power using the OTEC concept was operated at Keahole Point, Hawaiian Islands, in August 1979.

The Mini OTEC plant, as it is called, is an old service vessel of the United States Navy, subsequently acquired and modified by a consortium of the State of Hawaii, Lockheed Missile and Space Company, and Dillingham Corporation. Alfa-Laval of Sweden provided the heat exchangers. The plant was located 7600 ft (2316 m) off the coast of Keahole Point, Hawaiian Islands where the ocean is 3000 ft (914 m) deep. The barge, measuring 10 m by 35 m and weighing 268 tonnes, housed a 50 kW plant consisting of heat exchangers and a turbine generating system. The working fluid was ammonia operating in a closed cycle. The plant used warm water at 27.2^{o}C and cold water at 6^{o}C, and operated for 620 hours from 3 August 1979 to 16 November 1979 generating 50 kW of power (nett 12 kW (e) after meeting auxiliary requirements). During deployment, on March 19, 1980, owing to yet unexplained causes, the 2150 ft (656 m) long cold water pipe and the mooring system were lost at sea. Nevertheless the Mini-OTEC plant demonstrated conclusively that OTEC power is producible on a small scale.

2.5 OTEC I

The next phase of development was the launching of OTEC I. A World War II Navy Reserve Fleet T_2 oil tanker the USNS CHEPACHET was substantially renovated and modified. Test heat exchangers, pumps, piping, controls and other systems were installed. The vessel was renamed SS OCEAN ENERGY CONVERTER and dedicated in Hawaii on July 5, 1980. The project objectives include ocean testing of components, sub-systems, equipment, and the conduct of self contained experiments. A full assessment will be made of heat exchanger technology, long term biofouling and corrosion effects, techniques of cleaning and testing, power cycle performance and environmental issues.

During these tests, data will be collected for further development of OTEC platforms, cold water pipes and station-keeping sub-systems. The 1 MW(e) [40 MW(Th)] plant is large enough in scale to provide the needed data and engineering experience but still much smaller than the systems which would eventually be used in full scale commercial plants. Since the emphasis during the first test will be on the central heat transfer efficiency and the effects and elimination of biofouling, the conventional turbine-generator is not needed. Hence there will be no electrical output during this phase.

2.6 Other developments

Investigations have also been made into the possibilities of siting OTEC plants off the East Coast of Florida, Western Gulf of Mexico, West Africa and Puerto Rico but they have not proceeded as far as the Hawaiian experience. In Japan, OTEC has been used to produce fresh water. Japan has also tested a 1.2 kW(e) plant very recently. France is investigating the building of a 5MW(e) plant in Tahiti by 1985. Eurocean, a research combine formed by Western European countries, estimates that working OTEC plants will be technically feasible by 1990 with a suggested introduction date of 2010.

2.7 Future Plans of the US GOVT.

In 1980, the Department of Energy of the US Government will call for proposals from firms interested in designing the first OTEC plant of commercially interesting size. The Hawaiian OTEC community expects that a 40 to 50 MW(e) OTEC plant will be built to feed the island of OAHU's electricity grid before 1985. Preliminary estimates are that the cost of this first plant will be in the region of US $ 250 million or more.

In the 1990's the goal is to implement the island commercialization strategy of the US Dept. of Energy of displacing conventionally produced electricity with OTEC power in US islands. The United States funding of OTEC development since 1972 is shown below:

	1972	1973	1974	1975	1976	1977	1978	Total
US $ Million	0.1	0.2	0.7	3.0	8.6	14.5	36.0	63.1

The indications are that in future years there will be a substantial increase in funding for OTEC development. In the United States, two bills supporting OTEC have been passed. The two bills envisage that upto 10,000 MW(e) of OTEC capacity should be built by the end of the century. The bills provide up to $ 2 billion in loan guarantees for construction. (Ref. 4)

3. OBSERVATIONS.

1. OTEC plants are still in an experimental stage. The first commercial plants are expected in the 1990's. These targets are very optimistic. (Ref. 9)

2. OTEC is technically feasible with the investment of considerable financial and technical resources. The cost estimates for OTEC appear to be based on incomplete data and are considered very optimistic. (Ref. 9)

3. The use of higher temperature differences available on land, like the rejected heat from central station power plants, should be the first step for long term evaluation of OTEC components and subsystems.

4. The existing temperature difference which leads to an actual efficiency of around 2 - 3% may not be maintained. If the cold water were to be welled up to the surface in order to extract the nutrients from the deep, the cold water will diffuse into the warm water area of the plant and result in a reduction in the temperature difference, and to a consequent reduction in the efficiency to below 2%. On the other hand it is possible to discharge the cold water at an adequate depth but without the benefit of extracting the nutrients.

5. Titanium requirements for the heat exchangers are very large, and therefore the cost is prohibitive. The feasibility of using aluminium instead, is being investigated.

6. The cold water pipe technology is not well established. The pipe, over 2,000 ft long, is subject to large stresses and may need to be replaced from time to time.

7. The problems associated with marine biofouling are not yet adequately understood.

8. Electricity transmission from sea to shore is very expensive. Hence, these plants cannot be located too far away from the shore.

4. Comparative Costs of OTEC Plants with Conventional Plants

In the United States, a coal fired plant costs US $ 425 per installed kW(e) while the first OTEC plants are expected to cost around US $ 3500 per installed kW(e) for plants of the size of about 250 MW(e).

TABLE I

For 100 MW(e) plant generating 400 GWh energy per annum in the United States.

		Coal	OTEC
1.	Installed Costs ($ M)	42.5	350
2.	Annual interest of installed costs at (10% of 1) US $ M	4.25	35
3.	Fuel costs per kWh in $	0.02	-
4.	Annual cost of Fuel in $ M	8	0
5.	Annual Maintenance costs	not available	?
6.	(2) + (4)	12.25	35

Table indicates that a Coal Plant is cheaper than an OTEC plant. Besides Coal is a Proven Technology while OTEC is not. Studies indicate that in the US, Coal would cost 36 mils per kWh while OTEC is expected to cost anywhere between 39 and 43 mils per kWh. Ref. 14

Assuming that in Sri Lanka a coal fired plant costs US $ 1 million per MW to install and coal costs US $ 0.05 per kWh (this estimate is on the high side) the installation and annual costs of a 100 MW plant generating 400 Gwh per annum are US $ 100 million and US $ 20 million, respectively.

To install an OTEC plant of the same size it would cost US $ 350 million as the lower estimate. Although there are no fuel costs there would be an unknown maintenance cost. A cold water pipe costs US $ 200,000 to replace in the case of a plant generating 0.012 MW nett. The pipe for a 100 MW plant would cost very much more. The annual interest on the difference between the installed costs of proposed OTEC and proven coal fired 100 MW plants (US $ 250 million) at a modest interest rate of 10% per annum (US $ 25 million) is more than the annual fuel costs for the coal fired plant. There are no working OTEC plants to support these estimates and consequently there cannot be any guarantees. A capital cost of over US $ 5000 per kW of capacity is being talked of for OTEC plants.

This indicates that OTEC plants are not economically viable at present although OTEC is from a renewable source of energy. Sri Lanka cannot therefore give priority to the development of OTEC power plants. However, she could advantageously use the developments taking place elsewhere in this field and engage in limited familiarization programmes. The prices of coal and oil are bound to increase in the future. They may also become increasingly difficult to obtain. However, the cost of industrial materials (titanium, aluminium, steel and plastics) also escalate with escalating fuel costs. It is therefore not possible to predict when OTEC would become economically viable.

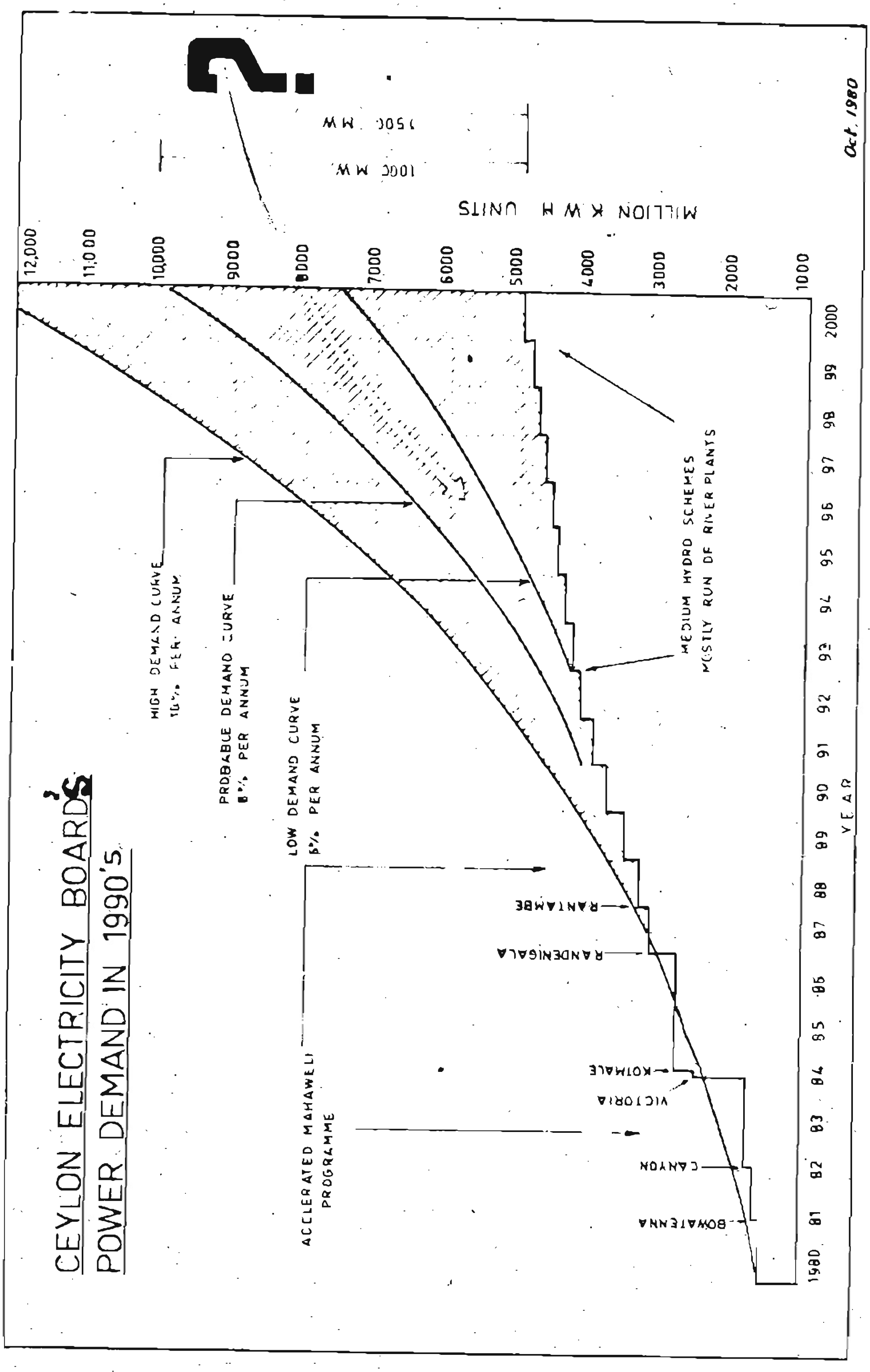
6. Electrical Energy Requirements of Sri Lanka

The total installed hydropower generation capacity of the Ceylon Electricity Board (CEB) is at present 330 MW. This reduces to an effective reliable capacity of 263 MW.

The firm energy capability of these hydro plants is 1400 GWh per year. The total thermal plant capacity in the system at present is 50 MW which reduces to an effective reliable capacity of 30 MW. The energy capability of these thermal plants at present is about 200 GWh per year.

Hydropower additions expected in the short and medium term are Bowatenna (40 MW) in 1981, Canyon (30 MW) in 1982, Kotmale (134 MW) and Victoria (210 MW) in 1984, Randenigala (122 MW) in 1986 and Rantembe (49 MW) in 1987. Expected additional thermal plant is in the form of gas turbines, specifically 60 MW at the end of 1980 and a further 60 MW by late 1981. The CEB generation system if augmented in this manner can even under certain adverse conditions meet the electrical power and energy requirements up to about 1988, at which time they are expected to be around 785 MW and 3855 GWh respectively. The generation requirements anticipated for 1995 are about 1450 MW and 7100 GWh. These requirements are expected to increase to around 2200 MW and 11,000 GWh by the year 2000. Hydropower would continue to be the major source of electricity until the late 1990's with the development of the Samanalawewa project (240 MW, 400 GWh) by 1989/90 followed by projects in the Upper Kotmale Oya, (100 MW, 300 GWh) around 1991, Uma Oya (100 MW, 375 GWh) around 1992 Kalu Ganga (150 MW, 450 GWh) around 1993 and other relatively less attractive projects.

Plate 1


CEYLON ELECTRICITY BOARD'S
POWER DEMAND IN 1990's
MILLION K W H UNITS
12,000
11,000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
1000 M W
1500 M W
HIGH DEMAND CURVE
10% PER ANNUM
PROBABLE DEMAND CURVE
8% PER ANNUM
LOW DEMAND CURVE
6% PER ANNUM
ACCLERATED MAHAWELI
PROGRAMME
BOWATENNA
CANYON
VICTORIA
KOTMALE
RANDENIGALA
RANTAMBE
MEDIUM HYDRO SCHEMES
MOSTLY RUN OF RIVER PLANTS
1980
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
2000
YEAR
Oct. 1980

In order to derive the maximum benefit and reliability from a hydropower system, it is necessary to have a source of bulk energy generation independent of the vagaries of weather. Therefore a bulk non-hydropower plant installation program should also commence around 1990.

Financial resources for the planning, investigation and development of the hydro resources outside the Accelerated Mahaweli Programme have yet to be found.

6. The Relevance of OTEC Development to Sri Lanka

The map of the Indian Ocean Floor (Fig.1) and the Admiralty Charts (Ref.15) indicate that the sea floor drops sharply off the Eastern and Southern coasts of Sri Lanka, to about 13,000 ft or 4000 m below sea level. The belt where the sea floor is between 2000 - 3000 ft. or 600 - 900 m below sea level comes close to the coast (at some places even less than three miles) around Trincomalee, Batticaloa and Dondra. This belt may provide sites for OTEC plants. A speculative geophysical survey conducted by the Western Geophysical Company of America in May 1976 for the Ceylon Petroleum Corporation indicates that on a line running about 10 miles or 16 km away from the coast, the sea floor drops to about 3000 ft or 900 m below sea level, at around six locations between Dondra and Trincomalee. Lines would have to be run towards the coast to determine how close the profile approaches the coast. The Ceylon Petroleum Corporation has instruments to measure temperature profiles. These instruments may be modified to suit this purpose.

If the temperature of the surface waters around the coast is above 27°C, we may not have to go as deep as 2000 ft. or 600 m to extract the cold water. In order to investigate factors like these direct measurements are needed.

The National Science Council should set up the mechanism to coordinate these investigations and to look into problems such as pollution, interference with existing fishing practices, threats to national security, etc. Concurrence of the Ministry of Defence and Ministry of Fisheries is necessary.

We understand that the US has a fund to promote OTEC development in suitable sites in the developing countries. The use of such a fund may be investigated as long as such funding does not effect the regular USAID programme for Sri Lanka.

If an OTEC plant at some stage becomes economically feasible in Sri Lanka, such a plant could be accommodated in the electricity grid. However plans to meet the power requirements beyond the 1990's should, as at present be based on reliable power sources using proven technology. Such plans at present should not include OTEC.

Conclusions

The technical feasibility of OTEC has been established with a 12 kW(e) nett pilot plant in Hawaii. In Sri Lanka, at present, a larger OTEC plant could be considered scientifically feasible, but not economically viable. However, it is possible that OTEC may become a viable source of power in the future. Bearing these in mind we make the following recommendations:-

1. Since OTEC is still in the very initial stages of Research and Development even in the most developed countries, Sri Lanka should, as a first step, carry out a systematic investigation around the coastal regions to map out temperature and depth profiles. This would verify some speculations that certain regions in the Eastern Coast have uniquely favourable basic requirements for setting up of OTEC plants. No reliable information was available to us in the literature. The known depth contour charts indicate that the Eastern coast in particular around Trincomalee, Batticaloa and Dondra could have suitable sites. (Fig. 1)

2. The interest taken by the United States, Japan and France indicates that OTEC is receiving serious consideration as an alternative energy source for the future. Sri Lanka should therefore maintain an interest in the development of OTEC.

3. A large scale OTEC project for Sri Lanka cannot be recommended at the present stage. However, there may be modest funding for any research institutes, universities, corporations or departments that wish to gain familiarization with OTEC.

4. Sri Lankan scientists and engineers should be exposed to development work on OTEC in other parts of the world. This strategy would prepare Sri Lanka for OTEC if and when it becomes a viable proposition.

5. The investigations regarding OTEC require multi-disciplinary skills available under different Ministries. The Ministries likely to be involved are Defence, Power and Energy, Industries and Scientific Affairs, Fisheries and Higher Education. In addition, the organizations likely to be involved are the proposed Central Environmental Authority, the Navy, the Ceylon Petroleum Corporation, the Universities and the Research Institutes. A few individuals may also be interested. As a co-ordinating mechanism is necessary, the National Science Council could initially undertake this task.

6. If these investigations reveal that Sri Lanka possesses features especially favourable for research & development on OTEC power plants, sites could be offered for foreign collaboration with participation by <u>local personnel at all levels</u>. The major funding should come from foreign collaborators. Concurrence of the Ministry of Fisheries and the Ministry of Defence is an essential prerequisite for the location of any OTEC plants in Sri Lanka.

7. Plans to meet the power requirements beyond the 1990's should, as at present, be based on reliable power sources using proven technology. Such plans <u>at present</u> should not include OTEC.

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See also
Admiralty charts - South Coast, East Coast.