OCEAN THERMAL ENERGY CONVERSION AND THE PACIFIC ISLANDS

March 2001 **SOPAC Miscellaneous Report 417**

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Cover: An imaginary illustration of an OTEC Plant – OTEC Laboratory, Faculty of Science and Engineering, Saga University, Japan.

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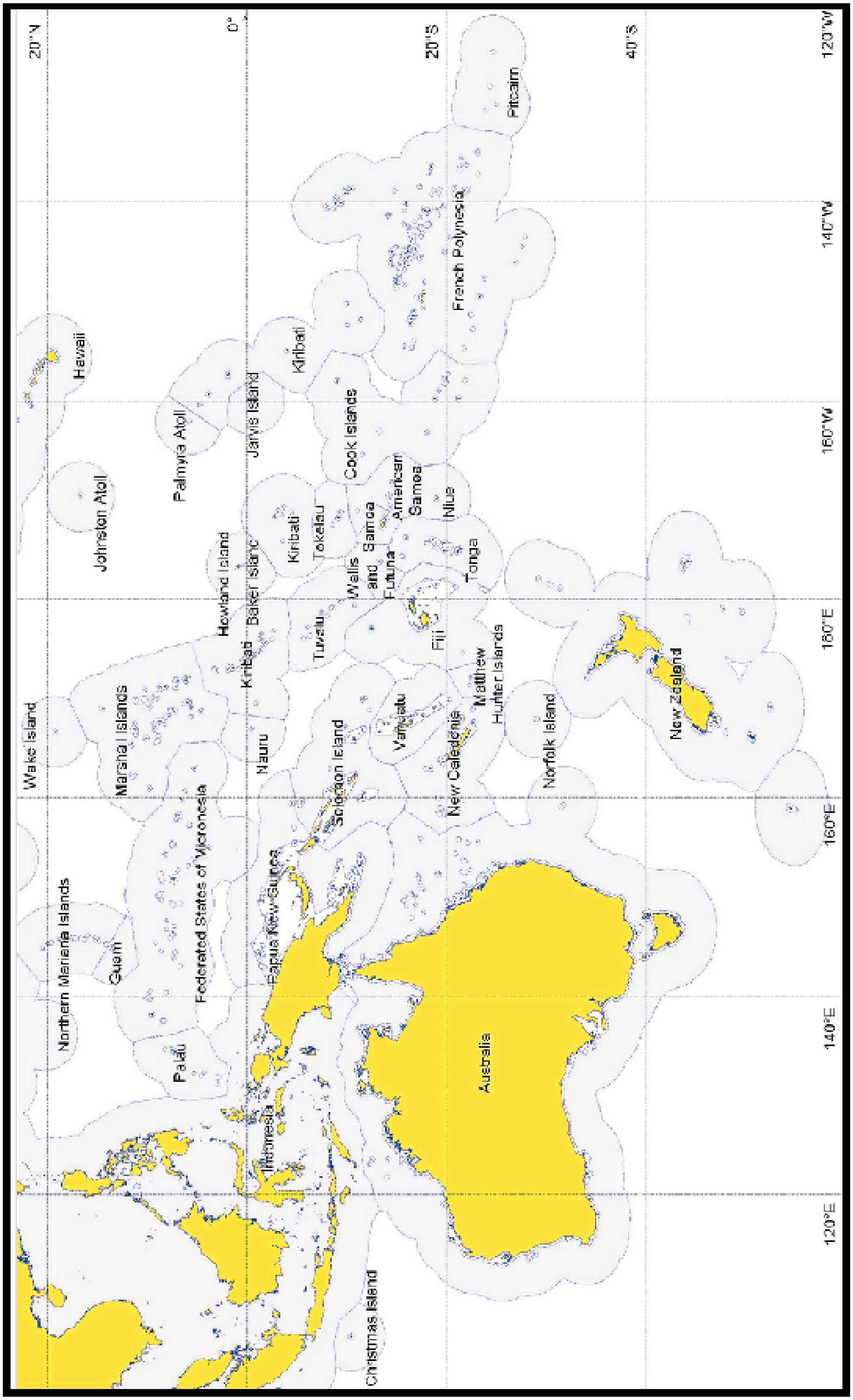
ACKNOWLEDGEMENT

Comments and suggestions provided by Mr Paul Fairbairn, Energy Manager, SOPAC, Mr Jean-Michel Durand and Mr Solomone Fifita of SPC (PREFACE), and other members of the CROP[1] Energy Working Group are gratefully acknowledged.

[1] Council of Regional Organisations of the Pacific

THE PACIFIC REGION



EXECUTIVE SUMMARY

The idea of using thermal energy from the ocean is not new. A French scientist, J. D'Arsonval first thought about the idea more than a century ago but it was only in early 1970 when research on this technology started to take shape.

The Pacific island countries are heavily dependent on fossil fuels to meet their increasing energy needs for economic development. The high costs associated with fossil fuels are placing an increasing strain on the economies in the region.

A significant factor in energy usage patterns in Pacific island countries has been attributed to the availability of energy sources as early as the fifteenth century where pollution control was not an issue. People have used what they have been able to get, be it coal, oil, natural gas, wood, etc. However, within the last two decades warnings of global destruction and climate change have become major issues. The growth of environmental awareness and the rising demand for energy has urged researchers to identify other sources of renewable energy.

The heat stored in the ocean can be converted into electricity by means of a process called Ocean Thermal Energy Conversion (OTEC), which uses the ocean's natural temperature gradient to drive a turbine connected to a generator which produces electricity. Apart from electricity, there are other useful by-products from the OTEC process like fresh water, chilled water and nutrient-rich water. To date there are basically three types of OTEC systems developed to harness the ocean heat – a closed-cycle, an open-cycle and a hybrid-cycle.

The economics of energy production have delayed the financing of permanent OTEC plants. At present, the cost per kWh from OTEC is more than that of the electricity generated from fossil fuels and decreases with increasing capacity of the power plant.

The environmental impact of the introduction of OTEC plants to the Pacific region is a significant concern to our small island countries. The laying of pipes and discharging of cold water at huge volumes in the coastal waters may cause damage to the marine ecosystem.

INTRODUCTION AND BACKGROUND

This paper is the result of discussions held during the Regional Energy Meeting (REM) 2000 and the SOPAC STAR Energy Working Group 2000 meeting which noted the need to provide technical information on "New Energy Technologies", in particular, hydrogen fuel, ocean thermal energy conversion (OTEC) and space solar power generation.

As Pacific island countries vary widely in terms of natural resource endowment and energy use patterns, they still remain heavily dependent on fossil fuels to meet their increasing energy needs. The relatively high costs associated with fossil fuels have encouraged research into indigenous resources as an alternative source of energy. However, the potential of indigenous resources is yet to be fully realised and exploited.

The excessive use of fossil fuels by industrialised countries[2] has not only increased the carbon dioxide and other ozone-depleting gases in the atmosphere, but has also contributed to global warming, sea-level rise and climate change, all of which the Pacific island countries are vulnerable to. The Pacific islands view this as a major disaster and have openly criticised the industrialised nations for not taking serious measures to reduce the pollution of the atmosphere and their greenhouse gas emissions.

Not withstanding the above, there are a number of changes afoot unfortunately not driven by past neglect but by opportunities to realise economic gain. This has lead to the sudden overwhelming interest in the region for funding renewable energy projects as the result of industrialised countries' commitment towards the Kyoto Protocol[3], this resulting in the introduction and increase of new and renewable energy technologies into the Pacific region.

The Pacific Regional Energy Assessment (PREA) conducted in 1992 highlighted the failures in using unconventional approaches (wind power, wave power, ocean thermal energy conversion (OTEC), biogas digesters, biogas gasifiers and solar power). Further unsuccessful introduction of renewable energy technologies, except for solar photovoltaics, were highlighted in the European Community's Lomé II Pacific Regional Energy Programme Final Report, August 1994. Both reports stressed the lack of technical, economic or financial viability of the options in the Pacific context and their unsustainable institutional support requirements. This led to the Pacific island countries remaining very much dependent on imported petroleum products to cater for their day to day energy requirements.

[2] China, Japan, Russia, United States

[3] It is noteworthy that the Kyoto Protocol has not been ratified by the industrialised countries - as at June 2001.

A significant factor influencing energy usage patterns has been attributed to availability and affordability. People have traditionally used what they have been able to get, be it coal, oil or natural gas. As early as the fifteenth century pollution control was not an issue but within the last two decades there have been numerous warnings of global destruction due to increase in greenhouse gases resulting in changing climate conditions. The growth of environmental awareness to address these issues and the rising demand for energy has urged researchers to develop and adopt new sources of renewable energy.

The idea of using thermal energy from the oceans was first thought of by a French scientist, J. D'Arsonval, more than a century ago. It was only since early 1970 when research on this technology started to take shape.

The Oceans cover more than 70% of the earth's surface. This makes them the largest solar energy collector and energy storage system on this planet. The 60 million square kilometres (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 29 billion kilolitres (250 billion barrels) of oil.

The heat stored in the vast expanses of water can be converted into electricity by means of a process called Ocean Thermal Energy Conversion (OTEC). However, the temperature differential required for this process is not achievable in all parts of the ocean. Research work has identified potential sites which are considered suitable for developing OTEC plants, see Annex 1.

The OTEC system operates on a thermodynamic cycle, which uses the temperature differential between warm surface water (at 26^0C or 79^0F) and substantially colder water (at 4^0C or 39^0F) from the ocean depths. Apart from being able to use the differential to generate electricity, other useful by-products from the OTEC plant are fresh water, chilled water and nutrient-rich water.

OBJECTIVES

The primary objectives of this paper are as follows:

1. Provide information on the history, operation, application and current development on the ocean thermal energy conversion technology; and
2. Provide information to assist decision makers in making appropriate decisions on the introduction of the technology into the Pacific region.

HOW OTEC WORKS?

What is OTEC?

OTEC or Ocean Thermal Energy Conversion is an energy technology, which uses the ocean's natural temperature gradient to drive a turbine, which is connected to a generator. It is desirable that the temperature difference between the warm surface water and the cold deep water be at least 20^0C (68^0F).

The Basic Process

OTEC systems rely on the basic relationship between pressure (P), temperature (T) and volume (V) of a fluid, which can be expressed by the following equation:

$$\frac{PV}{T} = \text{a } constant$$

where pressure, temperature and the volume of a fluid can be closely controlled by manipulating the other two variables.

Hence the differential in temperature of the fluid can be used to create an increase in pressure in another. The increase in pressure is utilised to generate mechanical work.

There are basically three types of OTEC systems developed that can utilise sea water temperature differentials – they are: a closed-cycle, an open-cycle and a hybrid-cycle.

Closed-cycle OTEC System

The closed-cycle system uses a working fluid, such as ammonia, pumped around a closed loop, which has three components: a pump, turbine and heat exchanger (evaporator and condenser). Warm seawater passing through the evaporator converting the ammonia[1] liquid ④ into high-pressure ammonia vapour at ⑤.

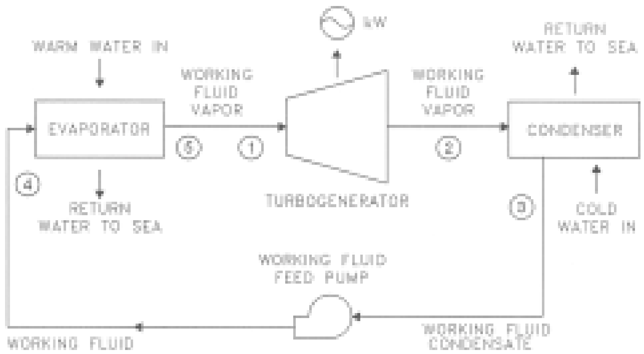


Diagram: courtesy of Luis Vega, Hawaii.

Schematic of a closed-cycle OTEC system

The high-pressure vapour at ① is then fed into an expander where it passes through and rotates a turbine connected to a generator. Low-pressure ammonia vapour leaving the turbine ② is passed through a condenser, where the cold seawater cools the ammonia, returning the ammonia back into a liquid ③.

Open-Cycle OTEC System

The open-cycle system is generally similar to the closed-cycle system and uses the same basic components. The open-cycle system uses the warm seawater as the working fluid. The warm seawater passing through the evaporator ② is converted to steam ③, which drives the turbine/generator. After leaving the turbine ⑤, the steam is cooled by the cold seawater to form desalinated water. The desalinated water is pure fresh water for domestic and commercial use.

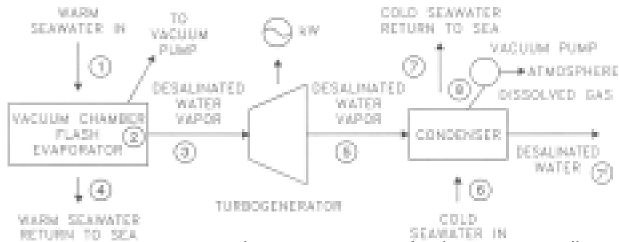


Diagram: courtesy of Luis Vega, Hawaii.

Schematic of an open-cycle OTEC system

Hybrid OTEC System

The hybrid system uses parts of both open-cycle and closed-cycle systems to produce electricity and desalinated water. In this arrangement, electricity is generated in the closed-cycle system and the warm and cold seawater discharges are passed through the flash evaporator and condenser of the open-cycle system[4] to produce fresh water.

PLANT DESIGN AND LOCATION

The location of a commercial OTEC plant has to be in an environment that is stable enough for an efficient system operation. The temperature differential at the site has to be at least 20^{0}C (68^{0}F). Generally the natural ocean thermal gradient necessary for OTEC operation is found between latitudes 20 degrees north and 20 degrees south.

Land-based OTEC plants do not require a sophisticated mooring system, lengthy power cables and more extensive maintenance as required with open ocean environment. In addition, the land-based sites allow OTEC to be associated with industries such as agriculture and those needing cooling and desalinated water.

The offshore or floating OTEC plant is another option. There are a number of difficulties associated with such a facility as it is difficult to stabilise the platform. The need for lengthy cables to deliver power and extra transportation to access the plant are added expenses. The plant is also more susceptible to damage especially during storms.

[4] That is, the original open-cycle system with the turbine/generator removed.

ADVANTAGES OF OTEC

OTEC uses clean, abundant, renewable and natural resources to produce electricity. Research indicates that there are little or no adverse environmental effects from discharging the used OTEC water back to the ocean at prescribed depths. As well as producing electricity, OTEC systems can produce fresh water and cold water for agricultural and cooling purposes. The use of OTEC also assists in reducing the dependence on fossil fuels to produce electricity.

DISADVANTAGES OF OTEC

One of the disadvantages of land-based OTEC plants is the need for a 3 km long cold water pipe to transport the large volumes of deep seawater required from a depth of about 1000 m. The cost associated with the cold water pipe represents 75% of the costs of current plant designs. Studies show that OTEC plants smaller than 50 MW cannot compete economically with other present energy alternatives. A 50 MW plant will require 150 m^3/s of cold water thus, the 3 km long cold water pipeline has to be at least 8 m in diameter.

Another disadvantage of a land-based plant would be the discharging of the cold and warm seawater. This may need to be carried out several hundred metres offshore so as to reach an appropriate depth before discharging the water to avoid any up dwelling impact on coastal fringes (i.e., fish, reef, etc). The arrangement also requires additional expense in the construction and maintenance.

To minimise construction costs of the cold water and discharge pipes, a floating OTEC plant could be an option. However, the costs associated with the maintenance and mooring facility of such a structure is of significance.

Further to the structural needs of the OTEC plant there is also energy required for pumping the sea water from depths of about 1000 m. Meeting the energy requirements for the OTEC plant’s operation is a factor to be noted as the need to install diesel generators may arise.

OTEC ECONOMICS

OTEC power will be cost effective if the unit cost of power is comparable with other power plants such as wave, hydro and diesel. However, it is important that all capital costs and ongoing maintenance/service costs are included so that the individual technologies are compared on a level playing field. Work carried out by Dr Luis Vega and his team in Hawaii has shown that for plants of the 1 MW range, the unit cost is considered comparable, see table below.

Comparison of Unit Cost of OTEC with Conventional Energy Sources in the Pacific Region (1990).

	Plant Capacity (MW)	(Plant Life (Years)	Capacity Factor (%)	Annual Output (GWh)	Cost of Energy (US$/kWh)
Wave	1.5	40	68	9	0.062-0.072
Hydro	1.2	40	48	5	0.113
Diesel	0.9	20	64	5	0.126
OTEC	1.256	30	80	8.8	0.149
		source:	*IOA Newsletter*	*Vol. 11 No. 2/Summer 2000*	

Adopting Dr Vega's calculation procedure to OTEC plants in India, the following shows the unit cost of electricity for the range of 1 MW to 100 MW.

Estimation of Unit Cost of Electricity from OTEC Power in India (1999)

Power Output (MW)	Power Output Net (MW)	Heat Exchanger Cost (US$m)	cost of cold water pipe US$m	cost of barge US$m	Mooring cost US$m	Turbine plus inst cost (US$m)	Total Cost US$m	cost of electricity US$/kWh
1	0.617	1.7	0.69	0.69	2.09	1.16	6.42	0.189
25	16.39	44.4	1.74	2.33	3.49	17.44	69.42	0.082
50	30.88	878	2.67	4.65	4.65	34.48	134.67	0.079
100	64.23	1526	4.65	9.3	5.81	69.76	242.1	0.068
		source:	*IOA Newsletter*	*Vol. 11 No. 2/Summer 2000*				

ACHIEVEMENTS, THE NEED FOR FURTHER DEVELOPMENT AND THE CURRENT STATUS THE OTEC TECHNOLOGY

Since Jacques D'Arsonval's idea of tapping the thermal energy of the ocean in 1881, OTEC system development ranges from a 22 kW, gross power, plant in 1930 to a record 255 kW, gross power (103 kW, net power) plant which also produces 23 litres (6 gallons) of desalinated water per minute.

Some of the areas currently being considered in the research and development of OTEC are:

- The improvement of the heat transfer coefficient for heat exchanges over a period of time; and
- The development of new materials for the cold water pipe. Apart from being able to withstand the marine conditions, the materials should provide for easy fabrication and deployment.

The State of Madras, India is preparing to build and test a 1 MW floating plant offshore. The Sea Solar Power Inc. of USA proposed some 100 MW floating plants around the world including a 10 MW pilot plant in Guam. Currently the bid for funding these proposals has been unsuccessful. Research in OTEC is still being pursued by the Japanese who funded a major symposium on OTEC and Deep Ocean Water Applications (DOWA). The Taiwanese government has a long interest in OTEC with Taipei being the home to the international OTEC/DOWA (IOA)[5].

On 20 April 2001, Saga University of Japan and Palau signed an agreement to promote research and technological exchange for power generation by OTEC. The university plans to build an OTEC plant in Palau in the near future.

PROSPECTS AND CONCERNS/APPROPRIATENESS OF THE OCEAN THERMAL ENERGY CONVERSION TECHNOLOGY

Prospects

A number of proposals to develop OTEC/DOWA in many Pacific island countries have been written and submitted to potential donors/investors for their consideration. The OTEC technology is perhaps the solution to meeting some of the region's increasing energy requirements thus, reducing the need to import petroleum products.

The OTEC technology seems to have worked well at research and development projects however, the involvement of the private sector developers are quite reserved, as there is an enormous initial investment required. This has been a major obstacle for the development of commercially-based plants.

Concerns/Appropriateness

Ocean thermal energy conversion may seem promising and ideal for some Pacific island countries however, the region has to take precautions. The question(s) the region should now consider are:

- Is it time to adopt the technology as an integral part of electricity generation?
- Given the vulnerability of our small island states, what are the environmental impacts of having an OTEC plant in the region?
- The establishment and running of an OTEC plant requires an enormous amount of power and water. Where will the power come from? Do we have to install more diesel generators to supply power for the plant?

[5] International OTEC/DOWA Association

- Can the region maintain and service such an installation?

And the list goes on.

RECOMMENDATION

Like the introduction of any other new energy technology, the question of suitability, appropriateness and sustainability arises. “OTEC for the Pacific” is what many people will perhaps agreed to, given its benefits of not only producing electricity but also desalinated water, nutrient-rich water for agriculture and cold water for cooling purposes but the benefits have to be weighed against the potential hazards to the marine environment which many Pacific islanders rely upon as a source of food, income and recreation.

With a few countries in the Pacific region (Annex 1) identified as having the potential for OTEC plants, perhaps researchers should consider carefully the recommendations provided from feasibility studies that look at options to build a pilot/demonstration plant at these sites. However, the issues raised above relating to the concerns and appropriateness should also be fully answered. Lessons learnt from the Nauru plant (which operated for 10 months from October 1981) and current research results provide a basis on which to form a consensus on whether to build another plant in the region or not.

The consideration to adopt OTEC into the Pacific region may be premature as the technology has not yet been commercially proven, however, given the right development parameters and a feasibility study including environmental impact assessment that are consistent and acceptable will ensure the development of a sustainable project in the not-too-distant future. Another consideration would be whether OTEC works out cheaper than the currently available renewable energy technologies such as solar photovoltaics, hydro, biomass and wind.

The Pacific region can always sit back and wait for the right opportunity. However, while doing so, the region should be aware of the developments in the technology. The region should also consider improving its institutional structures for managing renewable energy technologies as the deciding factor in their introduction is usually whether the technology is economically viable, environmentally sound and sustainable in the region.

The Pacific small island states on their own will definitely not be able to adopt and sustain the new technologies. The region needs assistance and guidance from its neighbouring developed nations.

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Annex 1 Less-Developed Countries in the Indian and Pacific Oceans with Adequate Ocean-Thermal Resources – 25 kilometres or less from Shore

Country / Area	Temperature Difference (^{0}C) of Water between 0 and 1000 m	Distance from resource to Shore (km)
Comoros	20-25	1-10
Cook Islands	21-22	1-10
Fiji	22-23	1-10
Guam	24	1
Kiribati	23-24	1-10
Maldives	22	1-10
Mauritius	20-21	1-10
New Caledonia	20-21	1-10
Pacific Islands Trust Territory	22-24	1
Philippines	22-24	1
Samoa	22-23	1-10
Seychelles	21-22	1
Solomon Islands	23-24	1-10
Vanuatu	22-23	1-10