The Project for Ocean Thermal Energy Conversion (OTEC) and its Multi-purpose Utilization in the Republic of Palau

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1. Understanding of Pacific Islanders for the Crisis and Way out

The most profound global threat facing humanity today is the prospect that our economic activities result in global warming, with serious consequences for the earth's entire ecosystem and for the way of life in rich and poor societies alike.

The global warming and climate change triggered by the increase of CO_2 is not just a matter of critical, but survival in Palau. It is proved that Palau is one of the four countries which are facing the greatest risk in the world because the sea-level rise will lead to the loss of coastal zone of the country. The expected sea-level rise would inundate the lowland, damaging coastal croplands and displacing millions of people from small island communities. Water resources of small islands are at risk also. Seawater intrusion will degrade the quality of underground water and reduce the quantity of fresh water supplies. The recent El Nino has caused severe draught in the pacific region as well as in Palau.

On the contrary, the flood is causing a spill out of coastal soil to the sea, destroying the livelihood as well as the agricultural production of the islands, also giving a severe impact to the marine life, and may cause a decrease of fish resources. Palau is proud of its beautiful islands and ocean surrounded by coral reef, which makes the place one of the most beautiful scenery in the world. Tourism with its beautiful natural resources represents industry in Palau, however the sea-level rising would totally destroy the industries and economic activities of the country. Energy in Palau is totally depending on the imported oil, of which purchase cost is equivalent to 10% of Gross Domestic Products. Considering the above situations, people must change the energy system, which is based on fossil fuels.

In this context, Palau chaired the South Pacific Forum in 1999 and appealed to the world the characteristics of island country, which have limited energy resources, land and underground resources, unstable water resources, and tourism are the basis of islands economies, and therefore islands countries must preserve the ecosystem. At the representative conference, it was recognized and confirmed that energy system of island country must be self-sufficient, and stable water resource development is quite important. Thus, the country is actively appealing to the developed countries on the decrease of CO_2 amount, as well as the establishment of domestic policy on the shift of diesel-powered generation to that of utilizing renewable energy. Contrary to the limited

resources in the islands, the surrounding ocean is an immense source of energy and water.

2. Achievement of Palau for the Practical Use of Ocean Thermal Energy Conversion

In order to convert the energy sources to renewable energy, Palau kept her eyes on ocean energy, and especially on the Ocean Thermal Energy. Ocean Thermal Energy Conversion (OTEC) is a technique in converting the thermal energy to electricity from temperature difference between the warm surface and cold deep seawater. The ocean is occupying 2/3 of the whole earth surface area and always receiving solar radiation, thus the ocean thermal energy is huge and renewable resource. According to the data, temperature differences between surface and 1000m depth at the equatorial region of the Pacific Ocean, includes the Palauan sea, is the biggest and most favorable for OTEC.

There are other merits of OTEC, such as:

- No emissions of green house gas such as CO_2 gas.
- Stable power generation through the year, no matter what climate such as Solar PV or Wind.

Under the initiative of the former President Nakamura, the Government of Palau has started its study on the Ocean Thermal Energy Conversion since 1999 and has requested technical cooperation from Saga University of Japan. This policy is being carried over to the Administration of the new President Tommy E. Remengesau Jr., and in April 2001, the Government of Palau has signed an Agreement on the research and development with Saga University as well as Japanese private company Xenesys Inc.

By the series of researches and studies conducted under this Agreement, it has resulted that;

- There are many potential sites, which are close to the deep sea, suitable for the Ocean Thermal Energy Conversion along eastern coastal line of the Island, which is estimated to fulfill the power demand of the country;
- Permanent water resources can be expected by the spray-flash desalination plant which utilize temperature differences of the sea water after power generation; and
- Deep seawater can be utilized as natural resources such as for air conditioning, fish culture and production of mineral water.

3. The Grand Project of OTEC and Multi-purpose Utilization in Palau

Ministry of Resources and Energy carried out survey on several possible OTEC site and marine investigations with Saga University and Xenesys. Inc., which is a private engineering company of Japan, and the survey team reported the feasibility of comprehensive ocean energy utilization project in Palau. The outlines of the Grand Project are described as follows:

(1) Power Generation

The present public power supply in Palau is generated completely by diesel engine. The main power stations are located in Koror and southern Babeldeob Island, with total generating capacity of 24.8 MW, which can hardly meet the demand of the island.

When development of Babeldaob Island, such as metropolitan relocation to Melkeok and road network maintenance, was taken into consideration, the demand rate would increase and probably its increasing rate would be accelerated in the future. Therefore, an increase in 4% a year until 2010 expects 23 MW (1.5 times) of peak loads, thus 35 MW is required as the power generation capability. Department of Resource and Energy in Palau planned to provide 20 MW in the electricity demand in 2010 with OTEC. Shortage during peak hours and detached islands with small population was considered to compensate with diesel power generation. Then, the amount of gross power generation is set to 30 MW for 20 MW electric power supply.

In the east coast of Babeldaob Island, which is the largest island of Palau, the geographical feature, which the depth of water becomes deeper on the outside of the lagoon, is the most optimal to pump-up deep seawater, to utilize for the OTEC plant. The coast of Pelilue and Angaur Island are also suitable. Moreover, in order to lessen a power transmission loss, the locations should be distributed in 7 sites to cover the nation. It is proposed that around ten sets of 2 to 4 MW plant will be built in the future. The proposed site is shown in the table below and Figure 1 shown in next page.

Table.1 Location and Size of Potential OTEC Site in Palau

Potential OTEC Site	*Size of OTEC plant*
Melkeok	3MW x 2 + 4MW x 1 = 10MW
Airai	3MW x 2 + 4MW x 1 = 10MW
Ngarchelongs	2MW x 1 = 2MW
Ngaraard	2MW x 1 = 2MW
Ngiwal	2MW x 1 = 2MW
Peleliu	2MW x 1 = 2MW
Angaur	2MW x 1 = 2MW
Total	30MW

(2) Seawater Desalination for Permanent Water Resource

There are still about 15℃ temperature difference between cold water after OTEC power generation and surface water. This thermal energy can desalinate seawater 1,200 m^3 per day per 1MW OTEC plant. When a total of 30MW OTEC plants are installed, fresh water of approximately 30,000 m^3 per day will be available automatically. The amount of fresh water fully covers the water demand of Palauan domestic use, which is in total 9,500 m^3 per day (500 liters per person in 19,000 population), hotel consumption by the tourists, agricultural use and industrial use are included. It must be specially mentioned that this fresh water resource is permanent.

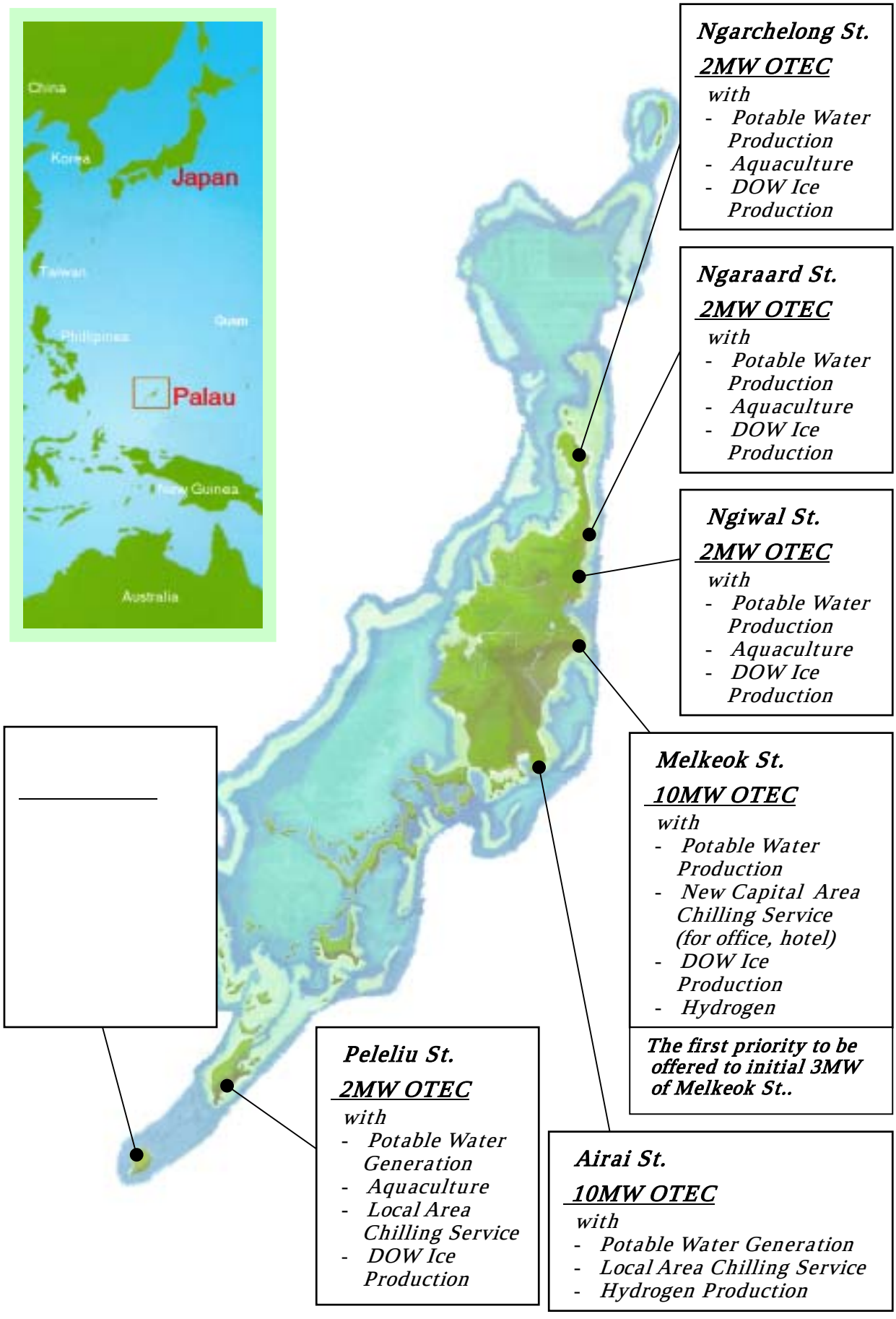

Figure. 1 Grand Master Plan of OTEC Power Station in Palau

(3) Aquaculture and other utilization of Deep Ocean Water

(A) Fishery Culture and Seawater Ice Production

Since sunlight does not reach the deep-sea water, which is deeper than about 200m under sea surface, photosynthesis of seaweed and plankton are not performed. Therefore, nutritive substances, such as Lynn, Kay Acid, and Nitrogen, are contained abundantly, and oxygen concentration is relatively high. Then, the deep seawater can be supplied to culture pond and plankton can be proliferated, and the best environment can be provided to fishery culture. Fishery nursery shall be built near this plant, and it will raise as a main export industry. In the upland, the pipeline from this plant will supply the deep seawater directly.

In order to store various marine products in its freshness, a lot of ice is necessary. Utilizing surplus deep-seawater and electric power after the generation, ice also can be manufactured, thus contributes to keep the marine products fresh, especially those for export.

(B) Deep Ocean Mineral Water Production

Abundant nutritive substances mentioned above are contained in the deep seawater. Moreover, in the deep-sea, disease, germs and microbes, such as bacteria, can hardly reproduce and the influence of air pollution can be ignored, so it is highly regarded its safety. That is the reason why the product development using deep-seawater is performed in various places in recent years.

Then, a part of deep-seawater pumped-up as the cooling water of OTEC will be moderately mixed at the plant with pure water manufactured in the desalination plant, and the mineral water will be merchandised. It will not only fill domestic demands, but also it would be valuable export merchandise.

(C) Air conditioning and Greenhouse by Cold Seawater

The temperature of cold seawater after power generation and desalination will be about 13℃, and very suitable for air conditioning use. Fresh water is first cooled at about 15 to 18 ℃ by cold seawater using the heat exchanger. The fresh water is circulated through the cooling coil laid in the ceilings, as a result, room temperature can be maintained by about 23 to 25 ℃.

The cold seawater is used also to control the temperature of the greenhouse, like the air conditioning system for the buildings. The cultivation of vegetables and fruits, which cannot be produced in the tropical region, will be grown easier in the air-conditioned environment. It can be considered to utilize the minerals obtained from the ocean depths or by-product for the hydroponics as nutrient.

(D) Hydrogen Manufacturing

Development competition of the fuel cell has already started by the manufacturers worldwide

now. If fuels for vehicles and boats in Palau are converted to hydrogen, people can keep minimum consumption of fossil fuels. It will also put up the value of tourism-based country. However, supply of the hydrogen is also one of the subjects. Then, the fresh water with very high purity refined by the OTEC plant is electrolyzed with self-generated electric power, which manufactures hydrogen, is planned. Since impurities are hardly contained in the purified water by the OTEC, efficiency of procedure is very high and maintenance/ management also becomes easy. Moreover, cheaper hydrogen can be manufactured using the surplus electric power at night.

(E) Lithium Recovery

In the seawater, minerals, such as lithium, are in abundant. First of all, the lithium ion contained in the deep seawater, which finished its use as cooling water, can stick to a manganese dioxide adsorbent column. Then, it is made to melt from the column with dilute-hydrochloric-acid water, and finally 99% or more of high purity chlorinating lithium can be taken out. Since impurities, such as organic matter and plankton, are hardly contained in deep seawater, it is mentioned that the absorption and melt are very efficient.

(F) Fertilization of Seawater by Density Current Diffusion Equipment

Nutrition ion, such as nitrogen and phosphorus, is contained abundantly in the seawater. If it is pumped up near the surface, where sunlight can reach, phytoplankton and algae will increase. Increased phytoplankton and algae mean increased number of fish. As a result, rich fishing ground like that of South America such as Peru will be formed. However, only by scattering on a surface as it is, cold deep-sea water sinks again and plankton is not reproduced. Then, mixing warm surface water to deep seawater in this plan and discharging after the density adjustment, the density current, which flows at a level into the layered seawater, would be generated artificially. As a result, nutrition ion is made to spread and pile up at a large area and the ocean would be fertilized. In the future, the development of the marine ranch is aimed at using this technology. If this is in practical use, the developing countries that are troubled not only with water shortage but also with food difficulty will be supportable.

4. The Pilot Project

(1) Aim of the Pilot Project

It is considered that the comprehensive utilization of ocean thermal energy is available for all Pacific Islands Nations, which are Federal States of Micronesia, Marshall Islands, Philippines, Kiribati, Nauru, Tuvalu, Samoa, Vanuatu, Solomon Islands, Cook Islands, Tonga, Fiji, New Caledonia, Papua New Guinea, etc.

Once the project proves its feasibility, there are great chances to obtain finance source for

the construction cost, from lending institution such as the World Bank, Asian Development Bank, and many private bank which provide soft loans.

In order to prove the practicality and economic feasibility of OTEC and multi-purpose utilization, The President of Palau, Tommy E Remengesau Jr. and the Government of Palau are proposing to the Pacific Nations to let Palau be the show case of natural energy and water supply system from the ocean for the pacific nations, by its first pilot OTEC power plant and spray-flash desalination plant, as multi-purpose facilities.

This pilot project provides chances to researchers and manufacturers for proof, improvement and integration of their technology for commercial scale OTEC Plant for 3 to 10MW. Moreover, the project aims to demonstrate OTEC system including desalination and application technology and enlighten the leaders and citizens in the world to promote natural energy and multi-purpose utilization of DOW, and also to train engineers to maintain and control OTEC and multi-purpose utilization plants.

(2) Outline of the Pilot Project

(A) Project Site

The pilot project site is planned to be located on Melekeok State of Babeldaob Island among the seven sites of the Grand Plan. The Government of Palau is promoting the development of this Babeldaob Island vigorously now, for example the metropolitan relocation to Melkeok and beltway (Compact Road) construction. In the new capital, the Diet Building, the Executive Office of the President, the Supreme Court, etc. are under construction, and will be completed in 2003 including the surrounding infrastructure.

Furthermore, the recent marine investigation executed by Saga Univ. shows that the coastline along the proposed new Capital is very suitable for the construction of the pilot plant. The proposed project site is shown on the map as Figure 2.

(B) Major Specifications of the Pilot Project

- OTEC power generation plant: 3MW by Uehara cycle method
- Desalination plant : 1000 m3/day by spray flash method
- Mineral water manufacturing plant: 20m3/day
- Hydrogen production : 1 Nm3/h
- Off-shore Laboratory : Researchers+Technician=Total 40
- Off-shore mounting barge : 1 barge for plant and 1 barge for lab
  Total : 2 Barges. Barges are fixed in the lagoon
- Seawater Intake and discharge system :
  For deep seawater : ϕ1,600mm x L 3,000m x 2 lines

		Inlet to be set at 800 m depth, out of coral reef
	For warm seawater :	ϕ1,600mm x 2 lines
		Inlet to be set in the coral reef
	For discharge water :	ϕ1,800mm x 2 lines
		Outlet to be set out of the coral reef
■	Heat exchange system for air-condition:	For new capitol area 300kW
■	Transform and power supply facility :	2,300kVA
■	Supply pipeline for deep seawater :	100m3/day
■	Supply pipeline for fresh water :	100m3/day
■	Connecting road between off-shore plant and lab :	W 8m x L 600m
■	Breakwater facilities:	
■	Supplementary facilities:	Greenhouse with cooling, workshop
■	Others :	Equipment for R & D and education

The image of the pilot plant is shown on Figure 3.

(C) Implementing Schedule of the Pilot Project

1st Year	Investigation, survey and basic design
2nd Year	Detail designing and manufacturing of equipment
3rd Year	Plant and seawater intake system construction
4th Year	Deployment, installation and operation

(D) Approximate Cost for the Pilot Project

It is estimated as US$ 125 million (or Yen 15.6 billion)

Figure 2. Proposed Project Site

Figure. 3 Imaginary of Pilot Project