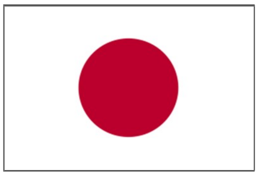
Ocean Thermal Energy Conversion
for the
Bahamas



SIDSDOCK
SMALL ISLAND DEVELOPING STATES
ISLAND ENERGY FOR ISLAND LIFE

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Abstract:

Ocean Thermal Energy Conversion (OTEC) is a system for converting thermal energy into electricity by utilizing the temperature difference between the surface and deep ocean water. The water temperature at a depth of 1,000m is approximately 4°C to 6°C. Surface water temperature depends on the amount of solar energy and countries near the equator can have temperatures as high as 29°C. OTEC utilizes this temperature difference only to generate electricity. With the enormous heat capacity of the ocean, the surface temperature does not vary between day and night making OTEC a base load power generating system capable of operating 24 hours a day, all year long. This report also illustrates an electricity generation cost of US$ 0.13/kWh and a water system at US$ 0.14/m^3 for a 100MW class system.

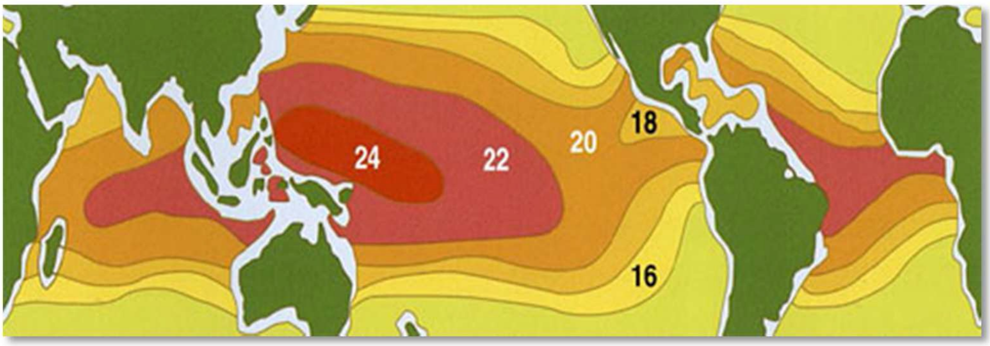


Figure 1: Ocean temperature difference (°C) between the surface and 1,000m depth.

Deep waters surround the Bahamas and therefore have relatively easy access to 1,000 meter deep water which is necessary for the OTEC process. Having latitudes between 21° N and 26° N, ensures warm seawater and in fact the Caribbean region has long been recognized as an excellent thermal energy source, see figure 1. With the source for the warm and cold seawaters established this report suggests the best locations given the current information and promotes an offshore type OTEC system.

Other systems which can be incorporated to the OTEC plant are; desalination of seawater for various usages (potable to industrial); hydrogen and oxygen gas production, and lithium recovery from seawater. After the OTEC process, the deep seawater retains all its natural nutrients and therefore encourages natural fisheries development. Therefore the advantage of OTEC is not only cheaper electricity but a gigantic leap towards a self-sustainable economy.

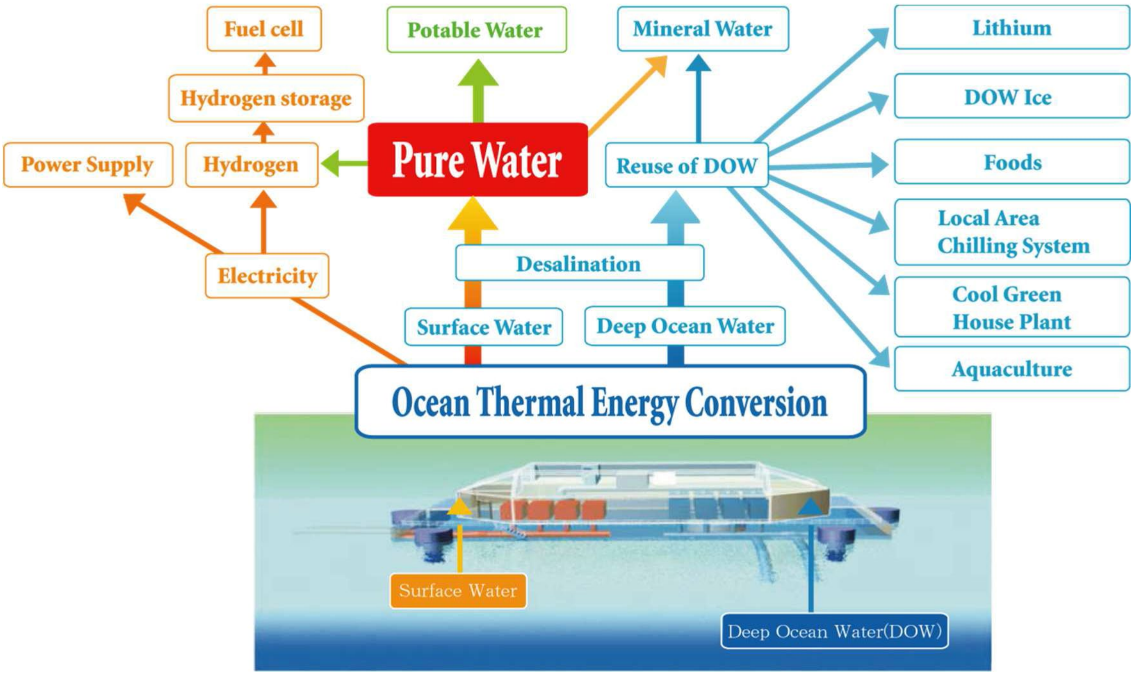


Figure 2: The OTEC Primary and Secondary product map

Contents:

Overview:

Bahamas

Capital: Nassau

Population: 347,176 (2011 Estimate) [1]

Language: English

The Bahamas is a country consisting of more than 3,000 islands, cays and islets located in the Atlantic Ocean. The main populous centers are the islands of New Providence and Grand Bahama representing approximately 71% and 15% of the total population respectively. The total land area is 13,878 km^2 with many uninhabited islands, cays and islets. New Providence alone would rank in the top ten most populated countries in the world.

Figure 3: Caribbean & the Bahamas Map

With less than one percent of arable land for farming and a limited food-processing sector, the Bahamas imports the majority of its food needs. In addition, over 1.6 million stopover tourists visit the Bahamas each year further increasing the volume of food imports, electricity & water. As one of the most prosperous countries in the Caribbean region, the Bahamas tourisms not only accounts for over 60 percent of the Bahamian GDP, but provides employment for more than half the country's workforce. After tourism, the next most important economic sector is financial services, accounting for some 15 percent of GDP.

Electricity & Water

All electricity is generated by fossil fuels. Two electricity companies supply electricity for the entire country, the Bahamas Electricity Corporation (BEC) and the Grand Bahama Power Company (GBPC). The BEC has a total installed capacity of 438MW, with the majority of generation in New Providence and the remainder in the Family Islands. The GBPC has a total installed capacity of 137MW and is the sole provider in the Grand Bahama Island. Combined, the average generation in 2011 was 2,042,000MWh [2].

The BEC’s lower residential electricity rate is currently 10.95¢/kWh. In addition to this a fuel charge is passed onto the customers. In the recent years, this charge rose by 1.9% on a monthly basis, and by 18.9% year-on-year, to a current charge of 26.50¢/kWh [3] giving a total tariff of 37.45¢/kWh. The GBPC’s lower residential electricity rate is currently 18.39¢/kWh with a fuel charge of 22.72¢/kWh [4] giving a total of 41.11¢/kWh.

The ground water resources of The Bahamas are both finite and the vulnerable. The current estimate of available water per head of population will decrease with time as the increased demands from tourism, industry, agriculture, and population growth continues. The water sector in the Bahamas is controlled by several government and Quasi-governmental organizations. The Water and Sewerage Corporation (WSC) is charged with the responsibility of providing potable water to communities throughout the Bahamas and ensuring the quality of all suppliers. The largest water supply franchise forms an integral part of the Grand Bahama Port Authority, which developed and is the municipal authority for Grand Bahama. Water is costly on both islands and rates start at an average of 3.5\$/m^3 (for a residential usage rate of 8m^3/month).

Temperature and Depth Information:

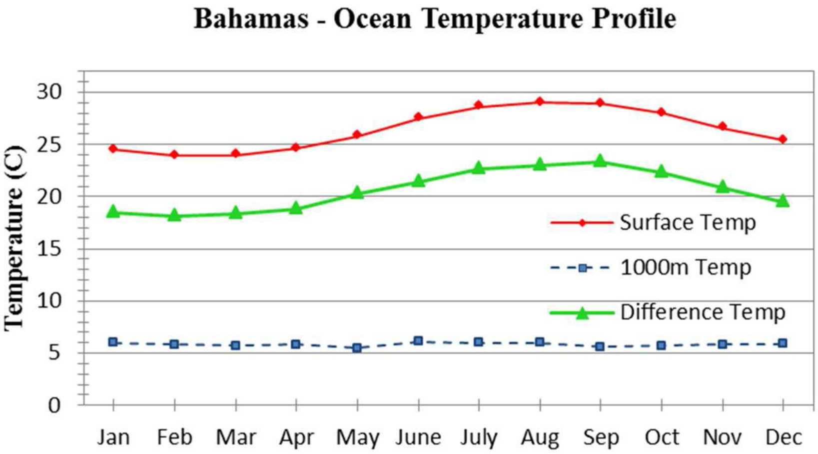


Figure 5: Monthly Mean Temperature Difference [5]

Previously, figure 1 illustrated the annual average annual temperature differences between the ocean surface and 1,000 meter depth for the world. With the use of ocean temperature databases, figure 5 illustrates the monthly ocean temperatures. The surface temperature varies from 24°C to 29°C and the 1,000 meter deep water is approximately 6°C confirming an average temperature difference of approximately 20°C.

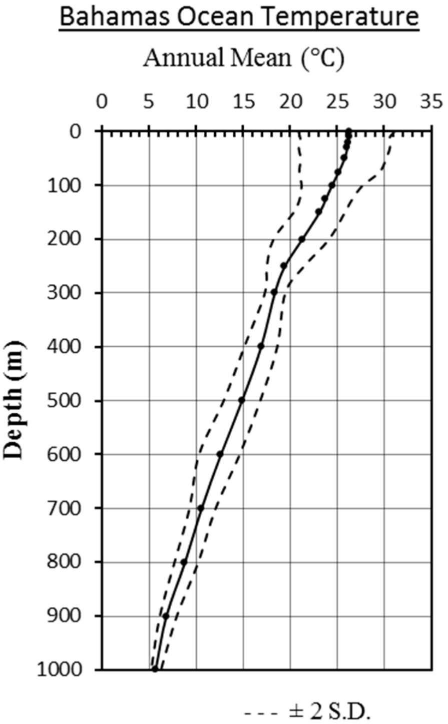


Figure 6: Temperature V's Depth [6]

Figure 6 illustrates the changes in the ocean temperature with respect to depth. Also the minimum and maximum recorded temperature data at each depth is indicated by dotted lines. Within the upper 100 meters, the variation in temperature is approximately 10°C, proportional to seasonal variations. The minimum temperature recorded at 50 meters is 21.1 °C and with a 1,000 meter temperature of 6°C, a minimum temperature difference of 15.1°C is available. With this large annual fluctuation, the monthly demands are utilized in an off-design calculation matrix. This OTEC design approach was first developed by Dr Uehara in 1992 and prioritizes two factors; the annual peak demand period and year round operation.

Figure 7 below illustrates the 1,000 meter depth line surrounding the two main islands. New Providence is closer to deep water access at approximately 6 km offshore, while Grand Bahama is approximately 10 km from deep water. For a land based OTEC plant, it is necessary to access deep water within 2 km to avoid large pumping losses of deep ocean water and therefore only offshore OTEC will be considered at this time. Various locations around the coastline are relatively close to the deep water giving various viable options.

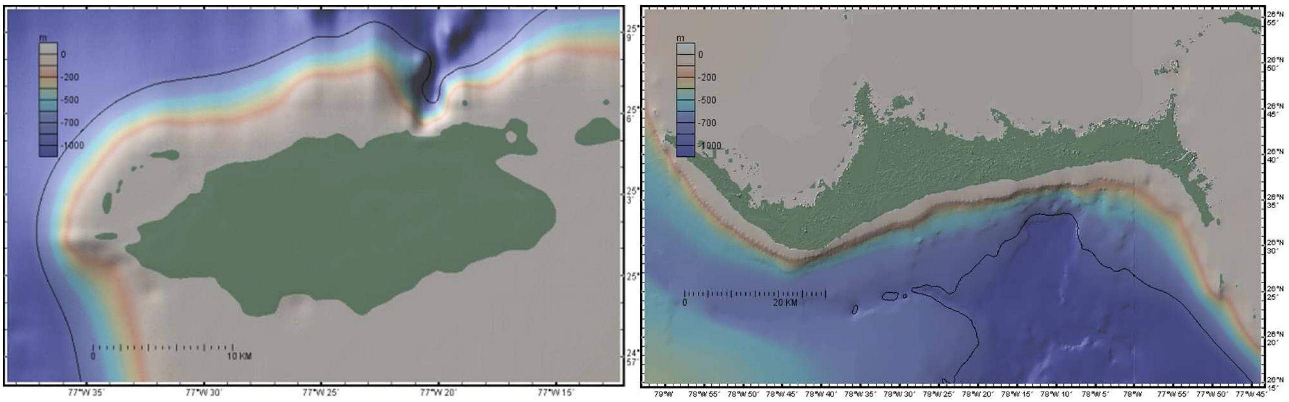


Figure 7: 1,000 meter Depth Line at New Providence & Grand Bahama [7]

Bathymetry, ocean temperatures, annual fluctuations and seawater analysis will be confirmed by site measurements during a feasibility study. This data is together with consumption requirements are utilized in the system design and component size optimization to meet the annual consumption and operate throughout the year.

Potential OTEC Plant Locations:

With the many factors discussed in the previous pages, many initial possibilities are available. To reduce the transmission cost and associated losses, it is practical to locate the OTEC plants near the main consumption points and for this purpose, the population density is utilized. Initial potential locations are illustrated in figure 9 below. In addition to electricity, the large amounts of desalinated water would argument the existing water supply system. The majority of the Bahamas Islands have easy access to deep warm water however with the small populations, only New Providence and Grand Bahama are considered at this time. Other similar locations with high consumption rates can be included in a feasibility report.

Figure 9: OTEC Potential Locations on Grand Bahama & New Providence [8]

With the largest consumption, New Providence is initially considered. The Clifton Pier power station is located on the most westerly point of the island and as the largest power plant in the country has direct access to the main 132kV electric grid. The distance from shore to the offshore structure is approximately 6 km. Secondly, the Paradise Island Hotel complex is a high load point but has access to 1,000 meter water at approximately 6 km offshore. Therefore an OTEC plant at this location would connect to the main substation on Paradise Island, supply the hotel complex and utilize the existing grid to argument the main Island.

The second highest consumption is Grande Bahama and due to the deep water located exclusively on the south of the island is the proposed site at this time. The distances from shore to OTEC plant is approximately 15km and this is well inside the subsea cable and piping ranges. The majority of the population is located on the west side of the Island and the subsea cable would be connected here.

As the above potential locations were derived from various databases, a feasibility study will confirm the exact bathymetry conditions as well as the ocean currents, temperatures and water nutrient content. Also the final consumption point for the OTEC products will be analysed. This information will pinpoint the available locations for the OTEC system. The current consumption rates are also critical in determining the correct volume and transmission methods of the different products. Also other alternatives to the overall layout will be investigated as they become apparent.

A large requirement of the tourism industry is potable water and the OTEC systems would pump water directly to the public water authority and possibly act as a pick up point for the cruise ships. The ship would pull alongside and “pick up” a large water bag. This cruise ship would continue to port with the bag floating behind continuously pumping its contents aboard. This method would reduce the stress on the port infrastructure and reduce the time required on port.

Besides water, another export potential is lithium recovered from the deep seawater. The largest worldwide resource of lithium resides in the oceans. A total of 230 billion tons of lithium in seawater is an immense source, though the lithium concentration in seawater is quite low (ca. 0.2 ppm). Current seawater recovery technology allows for approximately 35% of the lithium to be recovered per pass by the absorption media. As large amounts of seawater pass through the OTEC plant, the volume of lithium is significant. The absorption media is granular in form and is similar to a large filter which can be located anywhere in the piping system. This filter is replaced as necessary and can be sold internationally for further refinement processes. Japan is the largest importer of lithium in the world, importing 2,170 tons in 2009. A single 100MW OTEC plant can recover approximately 1,050 tons of lithium annually.

Illustration of an OTEC Plant:

The barge style OTEC plant is illustrated below. The majority of the plant is underwater with only a small portion visible over the water line. This design ensures a stable platform even during extreme storms and eliminates wave stress on the Deep Ocean Water (DOW) intake pipe and electricity supply cable.

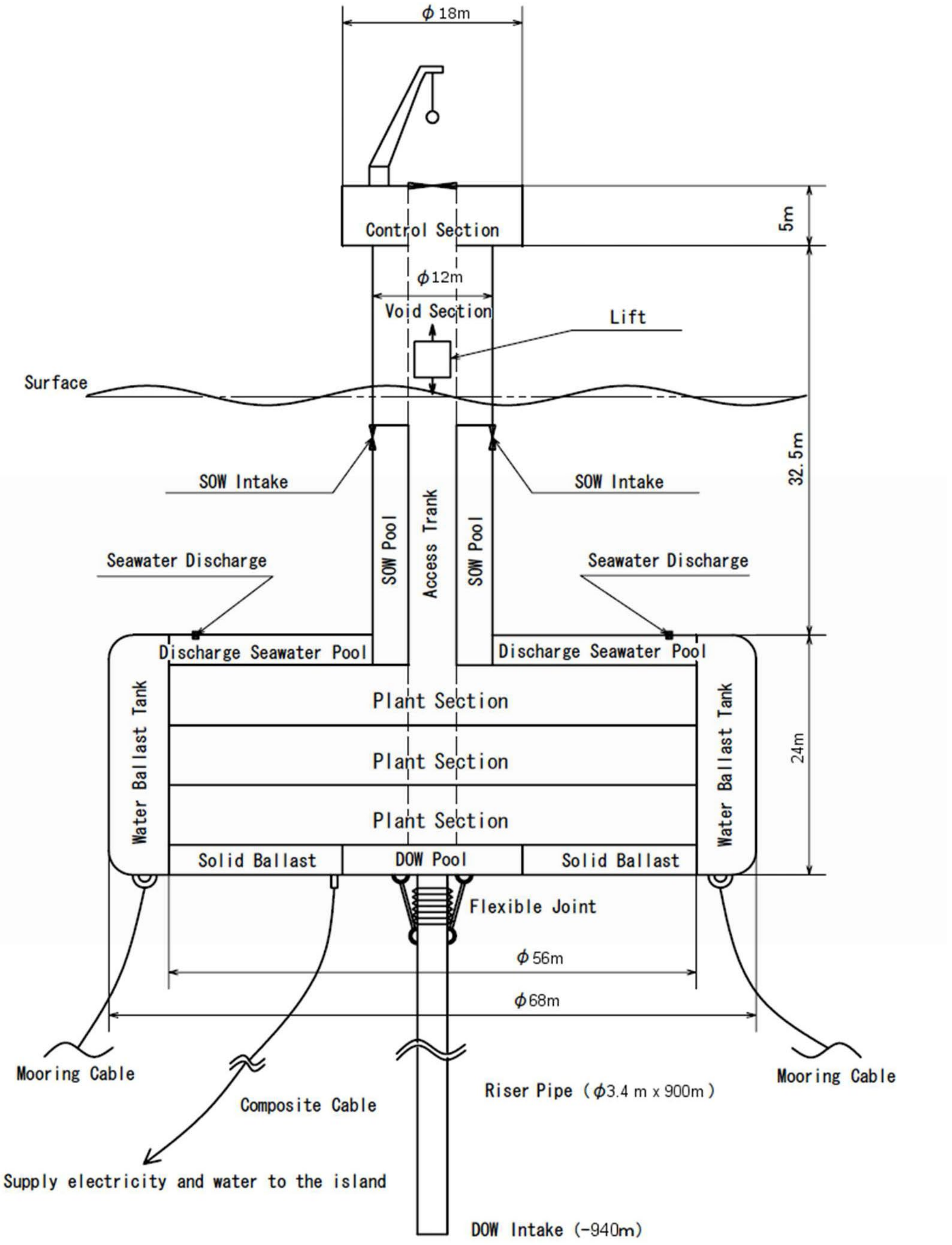


Figure 10: General Arrangement of 10MW- Class [9]

Many developments in offshore structures and mooring systems have occurred over the last twenty years with mooring depths of over 1,000 meters attainable since 1996. Currently mooring depths of up to 3,000 meters have been achieved. The above structure is classed as a very stable design as the deep draft minimizes the effects from wind, wave and currents. All structure and OTEC plant operations are carried out from the Control Section with access to the Plant Section for inspection and maintenance only. The structure is accessed by a helideck and a mooring deck.

OTEC Cycle – The Uehara Cycle:

Dr. Uehara began research into OTEC in 1973 and developed his own cycle in 1994. The Uehara cycle offers the highest efficiency currently available and is proven by the extensive testing carried out in the pilot plant. Titanium, with its high anti-corrosion properties and excellent heat transfer efficiencies is the material of choice for all heat exchangers, evaporators and condensers. Computer simulation and various testing ensure component suitability and optimization of the operating conditions are achieved prior to testing. The first pilot plant was commissioned in 1995 and is used by the Saga University OTEC research center.

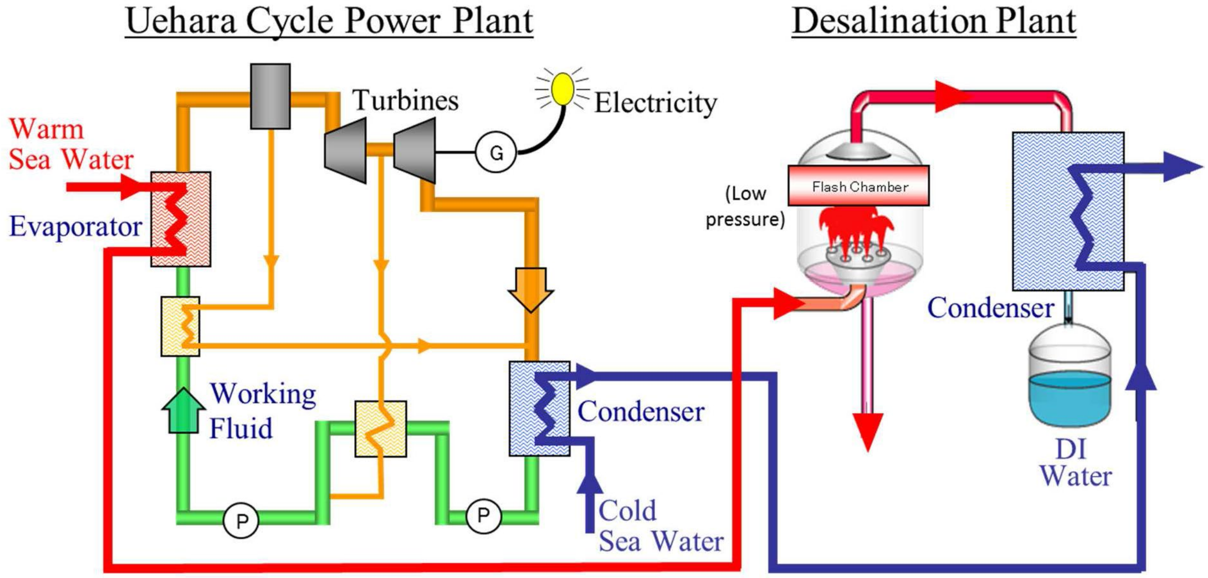


Figure 11: The Uehara Cycle with Desalination

Figure 12: The Uehara Cycle pilot plant, Saga University

Costing and Economics:

The estimation of sales, costs and profit for manufacturing, setting-up, operation and running is carried out for the cases of 10 MW, 30 MW and 100 MW classes. In addition to electricity and water, the growth of fisheries by utilizing the ocean's natural nutrients is substantial.

OTEC Products Sales & Costs

(Electricity, Water & Fisheries)

Item			**Units**	**10 MW**	**30 MW**	**100MW**
Sales	**Electricity**	Gross Turbine Output Power	MW	10.83	29.28	108.33
		Pump Power (Parasite power)	MW	3.25	8.78	32.50
		OTEC Net Output Power	MW	7.58	20.49	75.83
		Income from Electricity Sales*	m US $/y	17.4	47.1	174.2
	Water	Upwelling Capacity	m^3/hr	83,333	225,224	833,330
		Fresh Water (0.5% of DOW)	ton/y	3,467,486	9,371,584	34,674,861
		Energy Consumption for Desalin.	kWh/y	17,337.4	468,579.2	173,374.3
		Income from Water Sales	m US $/y	5.2	14.1	52.0
	Fisheries	Increase Primary Production	tonC/y	23,280	62,919	23,279
		Increase Fish (Wet Weight)**	ton/y	5,450	14,092	38,168
		Income from Fish Sales***	m US $/y	5.5	14.1	38.2
	Total Sales		**m US $/y**	**28.1**	**75.2**	**264.4**
Costs	**Operation**	Personnel Cost	m US $/y	2.0	2.5	7.5
		Maintenance Cost, etc.	m US $/y	2.3	4.7	12.3
		Amortization 25yr & 2% Interest	m US $/y	11.5	23.5	62.1
	Construction	Total Initial Construction Cost	m US $	230.6	468.5	1,235.8
		Barge Structure	m US $	116.0	228.5	538.6
		OTEC Cycle	m US $	94.6	202.5	597.2
		Desalination Plant	m US $	20.0	37.5	100.0
	Total Costs		**m US $/y**	**15.81**	**30.69**	**81.90**
Results	**Profit (Sales - Costs)**		**m US $/y**	**12.3**	**44.5**	**182.5**
	Generation Cost of Electricity only		US $/kWh	**0.26**	**0.18**	**0.13**
	Generation Cost of Desalination		US $/ton	**0.29**	**0.20**	**0.14**

notes: * Calculation: 0.30US$/kWh (8% Grid Loss, 95% Rate of Operation)

** In terms of Anchovy (Iseki 2000) *** 50% catch @2.0 US$/Kg

Figure 13: Sales and Cost Estimations for OTEC Products

With an electricity tariff of 0.30 US$/kWh, water rate of 1.5US$ per cubic meter (5.7US$/kgal) and fishery rate of 2.0US$/kg, yearly profits of 12.3mUS$, 44.5mUS$ and 182.5mUS$ are calculated in the above table. These profits are gained as the actual generation costs of electricity and water are much lower and the fisheries is an additional by-product with very little additional costs. Also as the scale increases, the construction and operation cost per unit output decreases dramatically.

The above three outputs were calculated to display the economic viability of relatively low and high power outputs. In addition, it should be noted that OTEC is more competitive when all secondary products are utilized and we also promote the addition of hydrogen and lithium production units to this system. The viability and economic benefit of these products are outside the scope of this report but will be included in a feasibility study.

The major economic benefit of OTEC is that this base load electricity generation system is not dependent on fossil fuel price fluctuations or other international influences, thereby allowing full control on the pricing and volumes to be decided domestically.

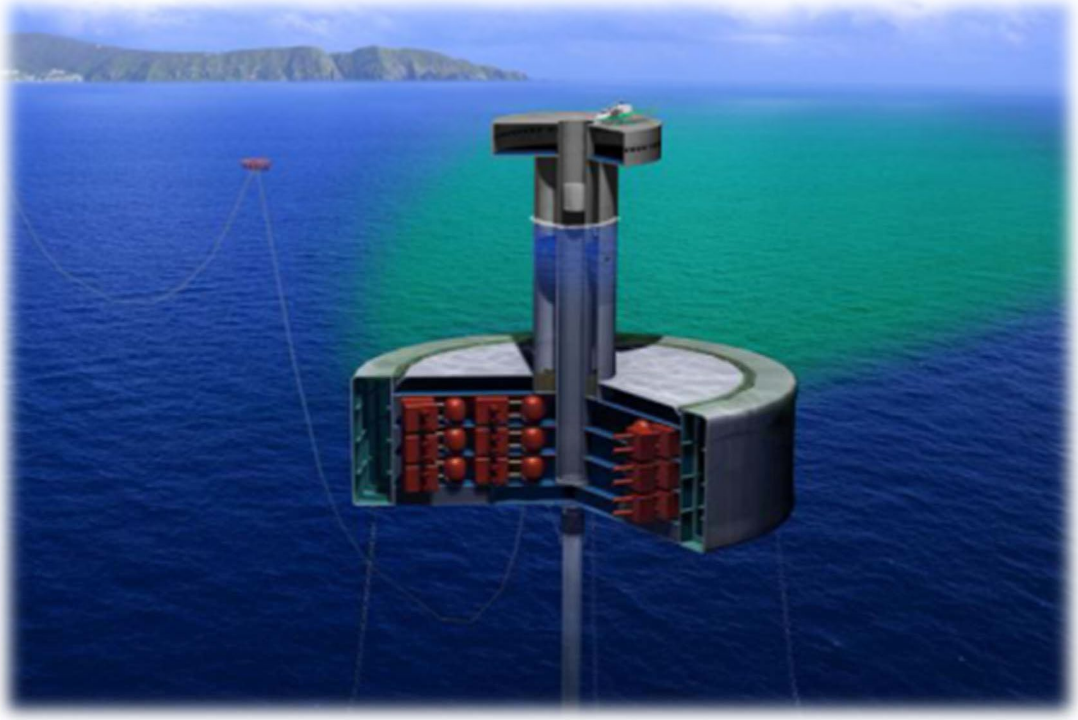
Included in the Barge Structure cost is the mooring system, transportation to site, power cable, and assembly of the deep water pipe, power cable and water pipe connection to the mainland, testing and start-up. Additionally, all operating parameters and sensory information of the OTEC power plant is relayed to a support office.

Conclusion:

Potential OTEC locations on the coasts of Bahamas are proposed in this paper. An electricity generation cost of 0.12US$/kWh and water generation cost of 0.14US$/ton has been described for a 100MW class system. With a cheaper and stable power source available, a new energy era for the country is possible. A natural fishery is developed by the deep water nutrients and therefore the OTEC barge becomes a central point by providing energy, water & food. In addition, lithium recovery and hydrogen production are possible as export products increasing the overall potential.

The low cost electricity can free resources to focus on other infrastructure developments and lead to an increase in tourism and marine related industries. Strong infrastructure allows small businesses to flourish as well as attracting overseas businesses. OTEC is the cleanest energy resource available to the Bahamas bringing stable power day & night, every day of the year.

The next technical step is to perform a feasibility study which will confirm the ocean data, optimal site location, electrical grid connection point, costing and consumption data. These details will then be used in the detailed design process of the OTEC plant.



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