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REPORT OF THE REVIEW OF THE OCEAN THERMAL ENERGY CONVERSION PROJECT (OTEC)

BRIDGETOWN, BARBADOS
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(Prepared by the Scientific and Technical Advisory Panel)

Report of the Review of the Ocean Thermal Energy Conversion Project (OTEC)

Bridgetown, Barbados
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Prepared by
The Scientific and Technical Advisory Panel (STAP)
Of the Global Environment Facility (GEF)

STAP Secretariat
United Nations Environment Programme

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PREFACE

It is a pleasure to present the final report of the "STAP Review of the Ocean Thermal Energy Conversion Project" (OTEC). The review session took place on February 21, 2000 in Bridgetown, Barbados as an integral part of the Fifth Meeting of STAP II.

The review was undertaken at the request of the GEF Secretariat with the view of assessing the technology in the context of being a potential candidate for inclusion as one of the technologies to receive GEF support under Operational Programme 7 "Reducing the Long-term Costs of Low Greenhouse Gas-Emitting Energy Technologies"

This report was written by the STAP Working Group on Climate change and Energy, namely, Dr. Dennis Anderson, Dr. Michel Colombier, Dr. Zhou Dadi and Prof. Shuzo Nishioka with inputs from the STAP Secretariat.

Madhav Gadgil

STAP Chairman

EXECUTIVE SUMMARY

STAP's review of the Ocean Thermal Energy Conversion Technology (OTEC) was undertaken at the request of the GEF Secretariat. Since the technology is not presently covered by the current GEF Operational Programme, STAP's main task was therefore to review the technology in the context of it being a potential candidate for inclusion as one of the technologies to receive GEF support under the GEF Operational Programme 7 *"Reducing the Long-term Costs of Low Greenhouse Gas Emitting Energy Technologies"*.

The technology as put does not strictly meet the OP7 criterion of being *"proven or demonstrated on a commercial scale"* (OP7, paragraph 7.7), though it meets all other criteria. These are at (OP7, paragraph 7.3):

- *The proposal is country driven (very high score on this count);*
- *The technology can be made to be environmentally sound and sustainable (see recommendations);*
- *A wider application is feasible;*
- *Allowing for the benefits of the by-products, and the scope for innovation, it has the prospects of becoming one of several cost-effective, climate friendly' technologies;*
- *There is significant interest from co-funders, private and public.*

STAP is of the view that the potential of OTEC is too promising to be ignored, particularly for the small island states, and that the potential multi-purpose benefits of the technology deserve recognition. It is, in fact, a potentially cross-cutting project concept. The technological problems raised in this report are not fundamental, and could be tested and checked through a relatively modest targeted research and development effort.

STAP is therefore recommending that consideration be given by the GEF to finance OTEC, particularly in small island developing states but taking into consideration the recommendations made in 2.4 of this report.

1.0 INTRODUCTION

The GEF Secretariat has received a request from the Caribbean region to fund an OTEC project. Since this technology is not presently covered by the GEF operational program, STAP were requested review it and make recommendations to the GEF regarding: (a) the desirability and rationale for GEF funding under Operational Programme 7, and (b) a plan of action for taking the initiative forward if this is merited.

2.0 SUMMARY

OTEC is a promising, 'carbon free' technological *concept* for small island developing states in the tropics, and has good prospects for qualifying for support under OP7. However, the actual project put forward to STAP has a number of technical and environmental aspects discussed below that still need to be tested and researched, and the scale of the project goes beyond previous experience. For these reasons further developmental work is required to enable the technology to be placed in the OP7 category and for a full GEF project to proceed. We believe the GEF should support such work, on which recommendations are made below.

2.1 The Merits and Potential of OTEC Technologies

The merits are:

(a) The generation of electricity at costs that are not extra-ordinary given the current state of development of the technology. Based on the estimates given in the report, they are between 15 and 26 US cents/kWh for an 8-10 MW scheme, though there are significant risks of cost escalation. On the other hand:

(b) There is considerable scope for innovation to reduce costs. One example, identified by research institutes in the Caribbean: the possibility of a second generation of plant using solar ponds to raise inlet temperatures, which would more than triple the efficiency of the plant. Solar pond technologies, which also have a good potential, would also benefit by having access to a low temperature coolant. In other words, OTEC may hold considerable benefits for another promising renewable energy technology, and vice versa.

(c) A range of by-products is feasible, though most have still to be demonstrated. They include: (i) marine aqua-culture (mari-culture); (ii) horticulture, in which cold water supplies are used to cool soils through underground pipes to in greenhouses to reduce evapo-transpiration and increase the yield of high value crops; (iii) the production of desalinated water on an appreciable scale; (iv) the biological extraction of fertilizers from the nutrient rich cold waters from the ocean depths; (v) cold water for district cooling; and (vi), the possibility—this is a testable hypothesis—of using the cooled water from the outlet side of the heat exchangers to irrigate and restore coral reefs under threat from rising ocean temperatures in the region. Experience in Hawaii suggests that the economic benefits can be significant for (i) and (ii); all six need and merit further analysis.

(d) The scale of the ocean thermal resource is immense and a large number of possible sites have been identified in the region.

(e) There is interest in the concept from private industry, charitable foundations, and other donors. The prospects for co-financing seem to be good.

Thus the concept has considerable merit, and deserves some form of support for its development from the GEF. There is, however, a major qualification:

2.2 Technical and Environmental Uncertainties.

No plant—single- or multi-purpose—on a MW scale has been built. The biggest so far is about 100kW. Some components of the technology have still to be demonstrated and require a comparatively modest research effort. Others need further analysis, especially the by-products. The components requiring attention are:

(a) The working fluid for the 'steam' cycle. Propylene has been proposed in preference to the alternatives of water or ammonia, in the former case to raise efficiencies and reduce the size and costs of the turbines and heat exchangers, in the latter case to eliminate corrosion ;
(b) Uncertainties as to the engineering parameters of the heat exchangers and turbines, and thus:
(c) Uncertainties as to the system design and dimensions itself.
(d) The vacuum pumping and evaporation process in the boiler also needs further testing and analysis. This is also a theoretically attractive possibility, since it provides desalinated water as a by-product. Once again, however, the approach needs to be demonstrated.
(e) Certain novel technical features of the heat exchanger, which are thought desirable to improve efficiency.
(f) The environmental impact of the technology if deployed on a large scale, which include dealing with very large volumes of nutrient-rich cold water on the surrounding biota ;and the dangers of under-water erosion of local coastal resources.

With regard to (f), the volume of warm water pumped from and discharged back to the ocean for the proposed 8-10 MW project would be approximately 30 cubic metres per second, and of cold water approximately 15 cubic metres per second. These are large volumes, equivalent to those of minor rivers, or alternatively to the cooling water flows a coastal thermal power station without cooling towers (of which there are a number of examples) of about 300 MW.

2.3 OTEC and the Criteria of Operational Programme 7

As put forward in the proposal, the technology does not strictly meet the OP7 criterion of being "proven or demonstrated on a commercial scale" (OP7, paragraph 7.7), though it meets—or is capable of being designed to meet—all other criteria. These are that (OP7, paragraph 7.3):

- The proposal is country driven. (Very high score on this count.)
- The technology can be made to be environmentally sound and sustainable (see recommendations).
- A wider application is feasible.
- Allowing for the benefits of the by-products, and the scope for innovation, it has the prospects of becoming one of several cost-effective, 'climate friendly' technologies.
- There is significant interest from co-funders, private and public.

OP7 also recognizes two types of risk, one of undertaking investments and the project failing, the other of *doing nothing* and losing the potential benefits (paragraph 7.8, where it is noted that "surprises" are common).

In this vein, we believe that the potential of OTEC is too promising to be ignored, particularly for the small island states, and that the potential multi-purpose benefits of the technology deserve recognition. It is, in fact, a potentially *cross-cutting* project concept. The technological problems are not fundamental, and could be tested and checked through a relatively modest R&D effort, one that, in the first place, would not require the construction of expensive pipelines and pumps, which are proven technologies. This would minimize downside risks. The technology could be tested on existing facilities on Hawaii.

Also, while the proposal highlights the by-products, the required analysis of the system to identify the best combination of products has yet to be done. In some circumstances it may be best to concentrate on one product only (electricity), in others two, and in others several.

2.4 Recommendations

We have thus suggested a two track approach toward taking the technology forward, prior to a decision to support a full-scale investment. These are:

(1) For GEF to support the development of the technology through targeted research and/or a technical assistance or other grant, perhaps in collaboration with other institutions. (The Rockefeller Foundation and the Norwegian Government have been very supportive of the OTEC concept.) In parallel with this:

(2) For the GEF to support further project development work on:

(i) The design concept, in particular the balance between the products of the project: electricity, desalination, mari-culture, and the others noted above. It is suggested, in the first instance, that the by-products would best be tested on a small scale, sufficient to provide experience for larger scale operations in subsequent generations of the technology. The analysis would look at the technical and economic feasibility of the various product mixes and the environmental impact.

(ii) The analysis of possible sites for a project on a smaller scale than proposed. This would entail engineering site surveys and, for engineering and environmental reasons, an analysis of local current and tidal streams to throw light on the likely dispersal patterns of large volumes of warm and cold outlet waters from the plant.

(iii) The environmental impact of the project.

(iv) The environmental impact of the possible wider deployment of the technology in small-island states.

Work on (i) to (iii) cannot be done in the abstract, but needs to be related to the possibility of a specific project, whose merits can be appraised once the work is done. We have suggested that this would best be done in relation to an initial project in the 1-3 MW range, as proposed by Professor Rienhard Radermacher of the University of Maryland. An 8-10 MW project was proposed. This would be too big a leap from previous experience, and would introduce too many unknowns with respect to performance, environmental impact, and the construction of the cold water inlet pipe. (The cold water pipe would be approximately 4000 meters in length going to a depth of 1000 meters; it accounts for over 1/3rd of the total cost.)

If the investigations identified under (1) and (2) are successful, the technology could then be classified for support under OP7. At this stage, the GEF will also be in a position to decide on the weight that should be given to the multi-purpose, potentially *cross-cutting* benefits of the technology, for example in other operational areas such as fisheries, land and international waters.
Both (1) and (2) need to be proceed in parallel since there are both technical problems to be resolved requiring engineering research and testing, as well as questions of system design, choice of products and environmental impact.

Technical Notes

1. The Basic Water and Thermal Cycles

The technology was outlined by the project proponents. Figure 1 taken from the consultants 'report shows the basic cycle. Warm water is taken in from the ocean surface at about 80° F and used to evaporate a working fluid. In this case, the working fluid is proposed to be propylene. The evaporated fluid drives a turbine, in the process giving up heat and pressure, and is condensed back to a liquid using cold water at 40° F drawn from approximately 1000 meters depth via a long pipe line. (See the second figure.) As shown, the water at the outlet of the boiler is discharged at around 75° F, while the temperature of the cold water is raised to around 53° F.

On account of the low temperature differences in the cycle, the efficiency is low. The Carnot efficiency(the maximum efficiency that the cycle could achieve in theory), is only **7.4 %**, and in practice the actual efficiency would fall well short of this**.** Hence large volumes of water are required, with correspondingly large pumping requirements. On the other hand, the energy available is almost limitless. In the daytime, the peak insolation in the region is about 1000 MW per km^2, and the ocean absorbs almost all the incident energy.

2. **Variants on the Cycle and Desalination**.

Variants on this simple cycle, proposed by the Caribbean region are to include a vacuum pump on the warm water inlet side so as to evaporate the water. Aside from supplying a water vapor to heat the working fluid, this process also provides a supply of desalinated water as a by-product, with the advantage that the heat energy generated by the vacuum pump, which would otherwise go to waste, can also be recovered by using it to heat the propylene (or whatever fluid is used in the boiler-turbine cycle).

In addition, it was proposed to couple a solar pond with OTEC technologies. The rationale is as follows. Use of a solar pond of 10,000 m^2 (about 2 football pitches), would enable the temperature of the working fluid in the cycle to be raised to around 210° F. This would raise the Carnot efficiency more than threefold from **7.4%** to **25.5%** and provide a significant additional source of energy input. Further, it would, open up opportunities for further innovations in low temperature thermodynamic cycles, and possibly, widen the choice of working fluids and, because of the increase in inlet temperatures and the provision of two sources of heat rather than one, may lower the overall risks of investment.

A pure solar pond technology, on the other hand, working with upper and lower temperatures of 210 and 80° F, the latter being the cooling temperatures currently available in the region, would have a Carnot efficiency of **19.4%**. But with the cold water from the ocean depths as the cooling medium, the efficiency would be raised to **25.5%**. Thus both OTEC and solar ponds stand to benefit mutually from the coupling.

It is well known that no thermodynamic cycle can reach its Carnot efficiency. But the *ratio* of the increases just indicated provides a good indication of the *ratio* of the increases in efficiency that might be expected in practice, and serve to indicate the potential of the technology for further development. Aside from reducing the costs of power production, water pumping volumes from both the ocean surface and the ocean depths would be greatly reduced for any given amount of energy produced. This too would help to reduce costs per kWh. At the same time, all the by-products discussed above would still be available in principle. It was suggested that this option should be explored as a future possibility once the technological uncertainties noted have been resolved.

Further possibilities for cost reductions in future generations of projects would arise from scale economies in manufacture and in plant size, increases in the diameters of and materials used for the cold water pipes, developments in low-temperature turbine designs, and modularity of particular components of the technology. The technological uncertainties have already been noted.

3. By-Products in Addition to Desalination

The cold water from the outlet of the condenser could be used for several of the by-products noted in the summary—mari-culture, horticulture, fertilizer production and district cooling. Only one or two of these would be tested in the first place. However, one can see that there is much potential for development here.

Another possibility, which STAP believe is worth experimenting with on a small scale, and monitoring, is to use a portion of the slightly cooler water from the outlet of the boiler to irrigate a portion of a coral reef currently under stress from rising ocean temperatures.

4. Costs and Risks of Cost Escalation

Two estimates of costs are made in the proposal. In the lower estimate, the capital costs of an10 MW plant are $67.5 million, with an annual operating and maintenance cost of $2.63 million. Using a 10% discount rate and assuming 70% load factor gives a generation cost of 15.5 cents per kWh. In the higher estimate the capital costs are $75 million; but given the uncertainties, the meeting concluded that a 25% contingency allowance was merited; in addition, there would probably be significant insurance costs, especially on the cold water inlet pipe, of about $1 million per year. This would raise generation costs to 26 cents per kWh.

In a multipurpose project, the benefits of the by-products would be deducted from this figure.
The biggest cost item by far is the cold water pipeline, which is estimated to be $24 million. The second biggest cost is that of water pumping, which consumes around one third of the gross output of the plant. (The 8-10 MW figure is net output.) An experienced pipeline engineer, Dr. Van Ryzin advised the meeting that the pipeline costs would likely be closer to $30 million. While confirming that parallel systems of pipes for the required volumes were proven, he also drew attention to the risks and, among other things, the difficulties of installation and anchoring of the pipes. He also felt that the pumping volumes for the specifications in the proposal were "aggressive", roughly twice those usually achieved.

Reducing the scale of the project to 1-3 MW would greatly reduce risks in the first phase. This would raise costs per kWh for an initial project, but the basis would be laid for subsequent generations of larger projects with appreciably lower costs arising from scale economies and the innovations discussed above.

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