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THE PROMISE OF OTEC AND ITS BY-PRODUCTS

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ABSTRACT: Ocean Thermal Energy Conversion (OTEC) is unique among alternate energy options in that there are a large number of valuable potential by-products from the energy generation process. The large volumes of cold deep seawater required for OTEC energy production make possible many unique applications, especially in the tropical areas where the OTEC process works. Air conditioning, fresh water production, industrial cooling, cold temperature tropical agriculture and a variety of aquaculture/mariculture products are examples currently being investigated.

1. INTRODUCTION

Ocean thermal energy conversion (OTEC) requires large volumes of seawater for production of useful energy from the temperature difference between surface and deep tropical seawater. It is unique among renewable energy resources in that it has the potential to supply all of man's current energy needs.[1] It is also unique in the wide range of by-products available from utilization of the cold deep seawater which the process requires.[2,3]

Typical OTEC plants will pump on the order of 70 m^3/s of seawater for each 10 MW of electricity produced.[4] Approximately 30% of this will be water from near 1000 m depth. This deep cold water will warm up while passing through the energy generation system from its initial temperature of 4°C to a discharge temperature of about 8°C. In addition to its coldness, this water also contains high levels of the inorganic nutrients essential to plant growth and it is extremely pure, with very low levels of pathogens.

This paper highlights present thoughts and research on some of the potential by-products obtainable from this deep water.

2. AIR CONDITIONING

The direct use of the cold seawater to cool buildings is the most economically attractive of all the by-product options presently being investigated. The electricity saved by using the cold water directly for cooling is an order of magnitude larger than the amount of electricity which can be obtained from the OTEC plant which pumps the water. Demonstration systems installed at the Natural Energy Laboratory of Hawaii (NELH) since 1986 have clearly shown the immense cost savings attainable even in small applications. Though this cooling capability is presently only available relatively near the shoreline (before the water warms up), wider distribution might be possible using insulated delivery pipelines.

Recent studies [5] have concluded that it is economically feasible to install deep seawater pipelines solely for air conditioning. Cost estimates indicate that the savings will quickly amortize the costs of pipeline installation using existing designs. Much greater savings may be possible with future reductions in pipeline construction costs.

3. FRESH WATER PRODUCTION

It has long been recognized that open-cycle OTEC systems can produce fresh water along with electrical energy.[7] There is however a concomitant loss in energy conversion efficiency using the required surface condenser in place of a more efficient direct contact condenser. Recent hybrid designs propose a separate "flash" cycle for potable water production, separate from the energy production system. A much simpler concept now being tested at NELH will allow large scale potable water production from either closed- or open-cycle OTEC systems by using the cold discharge water to condense fresh water from the humid atmosphere. Rough estimates by ALCAN/GEC [8] indicate that, under typical tropical humidity of over 80% and assuming realistic heat transfer from the cold water, up to 5l of fresh water could be produced for every 1000l of cold seawater pumped. Experimentation sponsored at NELH by Common Heritage Corporation has demonstrated production of approximately 1l/hr of fresh water by flowing a few liters/min of 6°C seawater through an off-the-shelf plastic heat exchanger with about 2.2 m^2 surface area. Production is slightly less at night, averaging about 0.7l/hr. A more rigorous experiment is now being designed to investigate optimum orientation relative to wind and sun. Many schemes have been proposed for increasing fresh water production from such an atmospheric condensing system by, for example, pre-heating and saturating the air flowing over the heat exchanger, but the simplicity of the basic concept and the large available volume of cold seawater may eventually decide in favor of a simple system similar to that now being tested.

4. INDUSTRIAL COOLING

There are many applications in which industry requires a source of cold, and deep seawater has the potential to meet many of those needs. For example, several companies have proposed refrigeration projects which would use NELH's deep seawater to improve the efficiency of traditional refrigeration systems. Another example is provided by Cyanotech, a company which produces Spirulina microalgae for health food on land leased from NELH. They dry the algae in a propane-fired drier, and they have discovered and patented a process using the cold seawater to extract CO_2 from the exhaust gas. This CO_2 then replaces that consumed by algal photosynthesis, saving the company more than $10,000/month. It is apparent that industrial uses of this inexpensive source of cold are limited only by the imagination.

5. OTEC AGRICULTURE

Common Heritage Corporation, started by Dr. John Craven, founder of NELH, has developed a cooperative garden at the laboratory in which more than 80 species of edible vegetables are being grown using the deep seawater to keep the roots cold. This work follows earlier NELH experiments sponsored by the University of Hawaii Sea Grant Program which demonstrated that temperate plants such as strawberries and several varieties of lettuce and alstroemeria flowers grow well in Hawaii's tropical climate when their roots are cooled. Dr. Craven has found that cooling the roots enhances the sugar content of several of the plants he is growing. There appears to be tremendous potential for producing profitable temperate crops in a tropical climate by using the deep seawater for cooling the roots.

6. AQUACULTURE

Properties and Advantages

As noted in several places (e.g., [2],[9]), there are three characteristics of the deep ocean water which make it valuable for aquaculture:

• Cold - The consistent low temperature of the deep water not only allows the culture of valuable cold water organisms in the tropics, it also provides (when mixed with the surface water or allowed to warm in the tropical sun) a means of precise, reliable and cost effective temperature control over the full temperature range from 6ºC to 24.5ºC.

• Nutrient-rich - The deep water is significantly enriched in the dissolved inorganic nitrates, phosphates and silicates which are essential and are the limiting factors to plant growth in the ocean.

• Pure - Since there is very little life at the depths from which it is pumped, the deep water has very few pathogens or viable plant cells. This permits the disease-free culture of sensitive organisms and the production of pure plant cultures without interference from competing species.

Plants

Both microalgae and macroalgae can be grown in appropriate mixtures of the deep cold seawater and warm surface seawater. All plants have a tremendous advantage over animals for commercial aquaculture, since their growout times tend to be on the order of days or weeks instead of the years typically required for growing animals. This makes recovery from potential catastrophic failures much more feasible. An algae producer can be back in full production within a month or so following a total loss of stock, while a fish or invertebrate grower will typically require several years to recover.

Microalgae. Cyanotech Corporation is successfully growing *Spirulina spp.*, which they sell as a health food supplement. Current production averages more than 10 tons/mo and they have just expanded production by 30%. They use the nutrients and trace minerals from the deep seawater to help maintain the balance in their culture media, which have been continuously recycled for more than five years. The company has also developed techniques for growing *Dunaliella spp.* microalgae and for extracting its cells containing 5% - 10% beta carotene. This represents the most concentrated known source of natural beta carotene and is seen as a potentially very lucrative product.

Macroalgae. Royal Hawaiian Sea Farms has been developing culture technology for a variety of macroalgae at NELH for several years. Following initial work with *nori* (*Porphyra spp*), they have recently developed a large production and marketing capability for several varieties of *ogo* (*Gracillaria spp*). They also produce and market some other "edible sea vegetables" (NOT "seaweeds") which are popular in the Hawaiian diet.

Animals

Though the longer growth spans dictate that animal culture involves more risks than that of plants, it has a strong attraction because of the very high value of the products.

Shellfish. Both oysters and abalone have been successfully grown in the cold seawater at NELH. Though the large operation of Ocean Farms of Hawaii has terminated, their technology for growing abalone appears sound and their culture of oysters is being carried on by others. Aquaculture Technology Incorporated is growing both oysters and shrimp in a polyculture system, and they have just received permits for marketing their oysters for human consumption. Culture Technologies, Inc. has done research on pearl oysters at NELH for several years and has recently received approval for expansion into the former Ocean Farms of Hawaii facilities.

Crustaceans. The former "Aquaculture Enterprises" has renamed itself "Kona Cold Lobster" and is actively pursuing both the culture of Atlantic lobsters (*Homarus spp*) from egg to market and the pounding of Maine lobster (*Homarus americanus*) for market on Hawaii Island. They plan a major expansion which will include an 8 hectare lobster farm, a 1-Mw OTEC plant to pump the water and an Ocean Science Center which will utilize the warm and cold water to create displays showing all of the habitats throughout the Pacific Basin.

Fish. Previous projects have grown salmon and mahimahi in mixtures of the surface and deep water at NELH.

Uwajima Fisheries (dba Yonezawa Suisan) has now expanded their production of *Hirame* so that they now fill a major portion of the Hawaii market for these delectable flounder.

7. PROBLEMS

Though OTEC has tremendous promise, both for alternate energy production and for the by-products described above, there are some problems which must be addressed before its potential can be realized.

Cycle Selection

The immaturity of OTEC technology is clearly indicated by the present lack of consensus on the appropriate cycle for various applications. The U.S. Department of Energy determined in 1980 that closed-cycle OTEC was a fully developed technology ready for commercial development as soon as market conditions warranted. This led to concentration on "advanced" open-cycle technology since it was seen as still appropriate for further government investment and also because of the obvious value of its potential fresh water by-product. DOE investigation of open-cycle OTEC has culminated in the present operation of a 210 Kw_e (gross), 50 Kw_e (net), open-cycle test facility at NELH's Keahole Point facility.[10] Though this is the largest OTEC facility ever built, it has not demonstrated the commercial viability of open-cycle systems which are plagued by the difficulty of scaling up low pressure turbines to commercial size.

The demonstration by ALCAN/GEC Marconi that roll-bonded aluminum heat exchangers can dramatically reduce the costs of closed-cycle plant construction [11] has significantly changed the trade-off between open- and closed-cycle OTEC. That, coupled with the recognition that large volumes of fresh water can also be produced in conjunction with closed-cycle systems, has led to the current acknowledgment that closed-cycle OTEC is the best choice for commercialization. Open-cycle may be viable for small island markets and would become much more competitive if realizable designs for larger turbines could be developed.

Cold Water Pipe

A 100 Mw OTEC plant will require a 10-m diameter cold water pipeline extending to 1000 m depth, or the equivalent in less efficient smaller pipes.[12] Present technology dictates that such pipes be made from either concrete or fiberglass-reinforced-plastic (FRP)[13]. Fabrication and, especially, deployment of these massive pipelines will be extremely expensive, amounting to 60%-70% of the total cost of OTEC plant construction.[4] It is difficult to conceive of significant potential cost reduction for the installation of such pipelines, so the pipeline remains a major stumbling block to the commercialization of OTEC systems.

Several investigators have suggested the possibility of developing "soft" or "inflatable" cold water pipes which might significantly reduce the fabrication and installation costs. These would probably place the pumps at the bottom end of the pipeline, which would relieve the requirements for rigid pipe walls. Engineers have concluded that such a plan would significantly reduce costs if a system for pump maintenance could be devised. Though a significant engineering development will be required, few question that this can be achieved. GEC-Marconi did some initial development work on this idea in the late 1980's, but there appears to be no effort directed toward this important task at the present time.

Economic Integration

As has been noted above, many potential by-products of the OTEC process have tremendous economic value. However, economic models have not yet been developed which integrate these by-products to demonstrate improved economic viability for OTEC. One problem arises from the significant difference between the very large seawater volume requirements for OTEC and the more modest requirements for by-products such as aquaculture and air conditioning. It is difficult to conceive of aquaculture projects which could use tens of cubic meters per second of seawater! There are major differences in deployment costs for pipelines sized appropriately for the different uses. Also, the data on the economics of potential by-products come mostly from NELH, where a major component of project expenses is often the cost of pumping the seawater (which users must pay, though NELH does not amortize the initial costs of the pipelines). In an integrated system, such charges would be absorbed in the energy production system. These factors make it difficult to model the interactions within an integrated system adequately.

8. CONCLUSIONS

There are many potential by-products from OTEC. Commercial-scale investigation of several alternatives is underway at the NELH Keahole Point facilities in Hawaii.

Most of these by-products (with the possible exception of cold water air conditioning) will require the development of commercially viable OTEC. If OTEC is to become economically viable so that all of its by-product potential can be realized, at least three steps are required:

1) A commitment must be made and funded to develop the economically more attractive closed-cycle OTEC;

2) Development work must be done on alternative coldwater pipe designs; and

3) Sophisticated economic models of integrated OTEC/by-product

systems must be developed to demonstrate the true potential of the synergistic use of the cold deep seawater resource.

REFERENCES

[1]Penney, T. R. and T. H. Daniel. 1988. Energy from the Ocean: A Resource for the Future. in Science and the Future: 1989 Yearbook. Chicago: Encyclopaedia Britannica. (98-111).

[2]Daniel, T.H. 1985. Aquaculture Using Cold OTEC Water. Oceans '85 Conference Record p.1284-89.

[3]Daniel, T.H., "An Overview of Ocean Thermal Energy Conversion and its Potential By-products", in Recent Advances in Marine Science and Technology, '92, PACON International, 1993, p. 263-272.

[4]Vega, L. A., 1992. "Chapter 7: Economics of Ocean Thermal Energy Conversion (OTEC)," in Ocean Energy Recovery: The State-of-the-Art, ed. by R. J. Seymour, Am.Soc.Civil Engrs., New York, p.152-181.

[5]van Ryzin, J. and Tore Leraand, 1992. "Air Conditioning with Deep Seawater: A Cost-Effective Alternative," Sea Technology, 33(8), September, p. 37-40.

[7]Claude, G., 1930. "Power from the Tropical Seas," Mechanical Engineering, 52(12), p. 1039-1044.

also:Othmer, D. F. and O. A. Roels, 1973. "Power, Fresh Water, and Food from Cold, Deep Sea Water", Science, 182(4108), p.121-125.

[8]Prakash, A., J. Craven, N. Fitzpatrick and E. Hay, "Recent Advances in Ocean Thermal Energy Conversion (OTEC) Technology and OTEC-Based Aquaculture," Presented at Caribbean Conference, August, 1989, 5p.

[9]Fast, Arlo W. and Karen Y. Tanoue, eds., OTEC Aquaculture in Hawaii, UH Seagrant College Program, Honolulu, 1988, 178p.

[10]Vega, L.A. and D.E. Evans, 1994. "Operation of a Small Open-Cycle OTEC Experimental Facility," Proceedings: Oceanology International, 1994, Brighton, U.K.

[11]Fitzpatrick, N.P., V. Hron, E. Hay and F.A. Johnson, 1989. "Alcan's Ocean Thermal Energy Conversion Program," presented at: 9th Miami International Conference on Energy and the Environment, 1989, 11p.

[12]Huang, N., G. Nihous, S. Oney, A. Syed and L. Vega, 1991. "Assessment of the Technical and Economic Potential for Hydrogen Production with OTEC Electricity and Desalinated Water," PICHTR Report to State of Hawaii Department of Business, Economic Development and Tourism, 89p.

[13]Vega, L.A., G.C. Nihous, L. Lewis, A. Resnick and J. van Ryzin, 1989. "OTEC Seawater Systems Technology Status," Proceedings, International Conference on Ocean Energy Recovery, Honolulu, Hawaii, Pub. by Am. Soc. of Civil Engrs., p.288-296.