ECONOMICS OF NATURAL TEMPERATURE DIFFERENCES UTILIZATION

Don E. Lennard
Ocean Thermal Energy Conversion Systems Limited, UK

Keywords: OTEC, DOWA, AWTEC, Economics, Cost-benefit, Efficiency, By-products.

Contents

Summary

The technology of utilizing natural temperature differences indicates processes that can have major attractions from an environmental point of view when compared with some established power generating processes. This Article describes the economic position of OTEC and OTEC/DOWA, and to a lesser extent AWTEC. In fact, AWTEC is assessed as being "a step too far" when compared with OTEC and OTEC/DOWA, with a very limited market, and much less attractive economics.

In contrast, this Article shows that OTEC and OTEC/DOWA are now approaching economic competitiveness with established fossil fuel power systems, and that with valuable by-products (for DOWA) and environmental cost-benefits there is a strong financial case for building a demonstration plant to validate financial calculations. Initial markets will be for island locations, where fuel oil is substantially more expensive than in major continental areas. It is noted that predictions expect the greatest increase in energy consumption to be in developing countries, which encompass most of the island locations, as well as larger land areas.

A case study indicates generating costs for a basic OTEC plant as 18 cents kWh^{-1} in 1998 prices, falling to 11 cents kWh^{-1} when a potable water by-product is incorporated. With the normal learning curve for engineering processes, it can be expected that generating costs will fall, and a 30 % cost reduction is estimated for an eighth production plant, compared with the proposed demonstrator, bringing the plant's generating cost down to 7.7 cents kWh^{-1}.

Additional, less tangible benefits, such as nutrition and sanitation, are also noted as by-products, but no economic benefits to the generating costs are claimed for these by-products at this stage.

The prospects for this environmentally benign process appear very encouraging during the first twenty five years of the 21th century, with economics becoming directly competitive with established processes, particularly when the by-products of DOWA, and environmental cost-benefits, are included.

1. Basis of Assessment

In conventional terms, the economics of energy use, when that energy is derived from temperature differences, is poor. This is because the efficiency of a thermal process is first and foremost dependent on the temperature difference in that process. Natural temperature differences – polar air over rivers (AWTEC), or surface ocean water compared with polar ocean water at a depth of about 1000 m (OTEC) – are of the order of 20^{o}C for the latter and up to 40^{o}C for the former. By comparison the efficiency of the internal combustion engine is very high, with a typical temperature difference one or two orders of magnitude greater.

However, these conventional assessments of efficiency take no note of the energy that may previously have been expended; for example, work done in producing the fuel for an internal combustion engine. Nor the energy that may be used after the power has been generated; for example, that which may be used in making safe the combustion products.

Also, in the case of OTEC there are potential by-products such as refrigeration processes and/or aquaculture products, some of which should also be allowed for as additions in the calculation of overall efficiency. These by-products are covered by the general term Deep Ocean Water Applications (DOWA).

Further, it should be noted that these systems that rely on natural temperature differences are also relatively environmentally benign, and this results in a further cost-benefit.

But as noted above, because the actual temperature differences between sea/river and air at high latitudes, and in the ocean between the surface and deep waters at low latitudes are small, the scale of equipment to generate power is large. It is therefore expensive when compared with, say, a gas turbine.

Further, the fact that the sea/river and air systems (AWTEC) make use of a gaseous fluid for the low temperature input aggravates the scale problem. The heat content of a gaseous fluid, when compared with a liquid fluid, is substantially dependent on relative densities. Consequently, the quantity of air to be passed through the AWTEC equipment is approximately three orders of magnitude greater than the quantity of water which would be needed to achieve the same heat transfer effect in an OTEC system – with a correspondingly larger piece of equipment to contain the air. The costs of AWTEC equipment will therefore be even more expensive when compared with traditional power sources, and with a lower cost-benefit ratio.

These factors illustrate that the assessment of systems using natural temperature differences are so different in scale, and in content, from conventional systems that it is necessary to stand back and view them impartially, without preconceived ideas of what is acceptable and what is not. The simple requirement in assessing efficiency when utilizing various power sources is to take into account all the relevant factors. Once this is done the calculations for finances and costs follow standard practice; and the economics of OTEC and OTEC/DOWA natural temperature difference systems then begins to look attractive.

2. Market

As it is well known, the world demand for energy is anticipated to continue to increase considerably, and the greater part of that increase is expected in developing countries. At the same time, it is anticipated that the percentage of "new" energies will also grow – from a near-zero figure at the end of the third quarter of the 20th century to 6 % by the year 2020. This translates into "new" energies of some 12 000 MW a year averaged over the period from 2000 to 2020. Capital costs for natural temperature difference equipment, because of the low efficiency, is of the order of \$5000 to \$10 000 kW^{-1}, up to ten times the capital cost for conventional power systems/engines. The funding of "new" energies therefore equates to a total each year of \$60-120 billion: by any standards of activity – civil or military – this is very substantial business. An important point to note therefore is that this is, for the construction, operational and financing sectors an activity of very considerable interest. But this business will only develop if it is economically attractive to the utilities that will invest in and operate. That situation is now rapidly approaching.

3. Opportunity

As already indicated, for natural temperature difference systems, particularly those based on OTEC, there is a range of products (DOWA) in addition to electrical power which must be considered in assessing the economic characteristics.

In order to incorporate these in an economic model it is necessary to assess:

- The objectives of each application;
- The state of the art;
- Other fields of application for the technology;
- Opportunities for further development.

In the early 1990s the European Commission assembled a group experienced in OTEC and DOWA research, and their conclusions for a number of these products may be summarized as follows:

1. Aquaculture/fish farming:

- Advantage must be taken of the very specific properties of DOW - its coldness, its high content of nutrients and its relative cleanliness (i.e. low content of chemical pollutants and pathogenic organisms);
- A number of applications of DOW already exist - to the extent that conventional power sources are used to pump up the DOW. A current example is the corporation in Hawaii which is manufacturing vitamins extracted from micro-algae;
- Further evolution of aquaculture technology is required to increase the chance of success for the adaptation and diversification of this activity;
- Whilst luxury seafood has been an important type of product up to the present, there are opportunities for fine chemicals produced by marine organisms, because of their very high market value. Those chemicals can include pigments, polyunsaturated fatty acids, polysaccharides, enzymes and other bioactive substances. They supply food, pharmacy and cosmetic industries, which are among the most reliable and durable human activities.

2. Fresh water production:

- The installed desalination capacity, worldwide, increased by about 20 % annually in the 1965-75 decade. Subsequently, this has dropped to about 10 % annually on average, but the expanding market seems likely to continue;
- Where an aquaculture plant is combined with an OTEC plant the most attractive desalination process is low temperature distillation, also called waste heat desalination. In the absence of an aquaculture plant, reverse osmosis is a more likely fresh water production process;
- Other situations with similar temperature differences to OTEC/DOWA installations are possible, but difficult to quantify at present;
- Before detailed research programs can be established an overall technical and economical study, including assessment of competing techniques, will have to be undertaken.

3. Use of cold water to increase efficiency of standard power plants and refrigeration units:

- Considerable data collection is necessary before the economics can be established. However, the OTEC cold water pipe can deliver water to improve the energy conversion efficiencies in conventional existing power plants (and sea water desalination units), whilst the utilization of the cold sea water may also be considered for the purpose of refrigeration - both directly, or for improving the efficiency of existing large refrigeration units e.g. for air conditioning of hotels and the like. It appears highly likely that a demonstration project would be necessary to endorse or amend the anticipated benefits;
- First assessments of this have shown that a reasonable degree of economy can be obtained, particularly if well known technologies for constructing a cold water pipe are used (where the diameter does not exceed 1.6 m for example). A pipeline of length 1400 m might yield a seawater flow of 7,000 $m^3 h^{-1}$ and could result in, at best, 2 % additional power output and 20 % increase in distillate

production, with a payback period of around one year for the additional investment, which therefore appears attractive;

- The subject is complicated to evaluate, as there is an extensive variety of chilling and refrigerating equipment and there are many different ways of benefiting from the supply of cold cooling water. However, calculations have resulted in the establishment of very substantial potential for energy savings in cooling facilities. For example, it was found that in a normal air conditioning system the savings can be 33 % if the cold sea water (at 7^{o}C) is used for chilled water precooling, 55 % if used for condenser cooling, and up to even 70 % when both options are combined;
- As noted, realistic data must be derived from existing installations, in order that the base position for benefits can be established. Development work is needed to establish the influence of increased seawater temperatures on the performance of such existing plants.

4. Environmental Effects (Upwelling):

- Opportunities exist to derive substantial biological/chemical/physical benefits from the deep water;
- The upwelled water is drawn from depths greater than the recycling depth.

Consequently nutrient brought to the euphotic zone is likely to be recycled many times before it ultimately returns to the deep sea. The exact nature of nutrient recycling remains to be determined in the DOW region. Chemical conditioning of upwelled water is required before it can support rapid photosynthesis, and the process is not yet understood completely. Chemical control of species abundance also requires investigation;

- The biochemical process industry generally is in a state of rapid development from infancy. This is true for land-based activities, and even more for marine systems. It is therefore particularly difficult to quantify the opportunity for technology transfer. However, transfer from land-based systems to DOW systems seems likely to be very cost effective;
- Opportunities include identification of the natural chelators that control trace metal speciation in oceanic waters; examination of the role of photochemical processes in recently upwelled water; and determination of the chemical controls of biological species dominant in newly upwelled water. Development of a predictive chemical model to relate basic knowledge of chemical processes in marine ecosystems to the enhancement of primary production is required.

Although these products offer significant potential improvements to the economy of the OTEC variant of natural temperature difference systems, a major reason for the lack of commercialization of OTEC/DOWA to date is that the economic benefits of these products have generally not been integrated into the scenarios of development. It is clear that, at present, it is very difficult to quantify these benefits, so in what follows these and other factors are cautiously assessed in terms of economic benefit, and only the potable water production benefit is quantified and included.

-
-
-

Bibliography

Creber D.K. and Johnson, F.A. (1994), Design Considerations For a Closed cycle OTEC plant for Keahole Point, Hawaii, IOA Conference, Brighton, UK, 1994. [This describes a 100 kW (nominal) system using aluminum plate heat exchangers, including economics.]

Cavrot D.E.G. (1992) Ocean Thermal Energy Conversion and Deep Ocean Water Applications: Scientific, Environmental, Technological and Economic Status. MSc thesis, University of Plymouth, UK, 1992. [A comprehensive review of OTEC technology, economics and environmental impact.]

Lennard D.E. (1994) Overview of OTEC/DOWA Activities in Europe, IOA Conference, Brighton, UK, 1994. [A country-by-country review of projects, including the various by-products.]

Lennard D.E. (1994) Viability and Best Locations of Ocean Thermal Energy Conversion Systems Around the World, World Renewable Energy Congress III, Reading, UK, 1994. [This considers the various factors – temperature difference, distance from shore, prevailing weather conditions, current energy sources, etc. that will determine the optimum locations for early OTEC/DOWA plants.]

Ministry of Economic Affairs, Republic of China (1994), Master OTEC Plan for the ROC, Energy Commission ROC, Taipei, Taiwan, China, 1994. [20-year plan reviewing the requirements of ROC for energy, the OTEC resource available, and the necessary steps to achieve construction, installation and operation.]

Vadus J.R (1997) A Strategy for OTEC Commercialisation, IOA Conference, Singapore, 1997. [Reviews the technical, environmental, economic and political factors which will influence the full commercial development of OTEC/DOWA.]

Vega L.A. (1994), Economics of Ocean Thermal Energy Conversion, IOA Conference, Brighton, UK, 1994. [Compares the cost of producing electricity from OTEC plants and from fossil-fuel plants, including OTEC by-products such as potable water.]

World Energy Conference, Survey of Energy Resources (2001), A World Energy Council publication, 2001. [Triennial review of all energy resources worldwide, including a Chapter on OTEC/DOWA.]

Biographical Sketch

Don E. Lennard

Originally qualified as an aircraft engineer - including a six years apprenticeship with Handley Page. Ten years were then spent with the Royal Navy and the Admiralty, on both operational and lecturing duties. The period included (1961) a one year Postgraduate course at the University of Cambridge.

The last thirty five years have been concerned with civil oceanic activities: including (1974) being Managing Director of a small offshore oil company based in the City of London, then (since 1979) running his own ocean engineering consultancy specialising in newer aspects of marine technology. In 1981, with two colleagues, he also established Ocean Thermal Energy Conversion Systems (OTECS) Ltd.

In 1988 he was contracted to run the UK Marine Technology Directorate Ltd. He served on the Council of the Natural Environment Research Council, and Chaired it's Marine Science Committee for 3 years. He was also a member of the UK Government's Co-ordinating Committee on Marine Science & Technology, and presently is one of two independent members of it's Foresight Marine Panel.

He has worked in many parts of the world and for two years from 1979 was Technical Director of the Monaco based international R&D organisation, Eurocean, where his interest in marine renewable energies developed. In 1994 he moved to Tasmania as Executive Director of the Australian Maritime Engineering CRC, under a 3-year contract, with its four cores in Perth, Launceston, Sydney and Melbourne, returning to the UK in 1998.

He is a Chartered Engineer and a Fellow of: The Royal Aeronautical Society, The Royal Institution of Naval Architects, The Society for Underwater Technology, and The Institution of Engineers Australia. He has played an active role in the International OTEC/DOWA Association (IOA) since it’s creation in 1990.