WREC conference, Aberdeen 2005

Ocean Thermal Energy Conversion and the Next Generation Fisheries

by

Lars G. Golmen[1], Stephen M. Masutani[2] and Kazuyuki Ouchi[3]

1: NIVA, Norwegian Institute for Water research, Regional office West, Nordnesboder #5, 5006 Bergen, Norway. e-mail: lars.golmen@niva.no.
2: Hawaii Natural Energy Institute, University of Hawaii, Honolulu,USA.
3: Ouchi Ocean Consultant, Shiozawako-Nomura C-11, Karuizawa, Japan.

ABSTRACT
The world's fisheries are in decline and so are also the reservoirs of fossil fuels. OTEC (Ocean Thermal Energy Conversion) is a process that can harness vast amounts of renewable thermal energy from the ocean and convert it to electricity. OTEC prototypes of the order of 1 MW have been tested, and GW-size floating plants have been designed. The cost per kWh is marginally higher than for fossils fuel power systems, but is projected to become more competitive in the future. Work is now in progress in the USA, Japan and Norway to design OTEC plants that are combined with large-scale fish farming. Nutrient-rich deep ocean water used by the OTEC process would be applied to produce phytoplankton which, in turn, would be consumed by zooplankton and thus provide feed for fish. Present offshore fish farming is based on up scaling traditional fish farms, and their placement off the coasts, e.g., in the USA, have raised environmental concerns. The Next Generation Fisheries (NGF) design as presented here is different, and will have minimal or no negative environmental impact. Additionally, excess renewable energy that is produced that can be converted into useful products, or exported to the onshore power grid. This presentation provides an overview of the concept and possible design, and discusses scaling and some calculations of fish vs. electricity production.

INTRODUCTION

Most conventional fuel stocks are in decline, with the reserves of oil and natural gas expected to last for only another 50-100 years. Meanwhile, the world continues to become ever more dependent on fossil fuels both for stationary energy production and for transportation, with consumption rates of oil and gas now soaring to 3.5 Gtoe/yr. For coal, the picture is similar, but with stocks expected to last for another few hundred years.

On a related front, world population, currently at about 6.5 billion, continues to grow. Although the rate of increase is lower than what was projected a couple of decades ago, a 40% rise to 9 billion by 2050 is anticipated. This will result in rising demand for food and energy. On top of this, we are faced with the challenge of trying to control greenhouse gas emissions arising from the burning of fossil fuels; the expansion of human population, living standards and habitats with more agriculture; deforestation; and decline in the ecosystem's ability to absorb CO_2. These factors have already resulted in atmospheric CO_2 concentration reaching 370 ppm, up from the pre-industrial level of approximately 250 ppm, and a further 100 ppm rise is expected within the next ca 50 years. Even the conservative climate change scenarios arising from this increase in atmospheric CO_2 inventory are quite discomforting.

This presentation describes a concept that would help address the aforementioned three major global challenges: food supply, energy supply and greenhouse gas emissions. The concept is based on integrating Ocean Thermal Energy Conversion (OTEC) and mariculture to yield renewable energy with minimal associated GHG emissions and enhanced fish stocks.

OTEC

OTEC produces electricity from a heat engine driven by the temperature difference between warm surface ocean water and cold deep ocean water (Avery and Wu, 1994). The most favourable conditions are found in the tropical and sub-tropical regions, and usually the concept is envisioned as a floating plant in deep water, but it can also be installed on land, near-shore. Unlike other renewable energy systems utilizing non-steady sources like wind, solar PV, ocean waves and tides, OTEC is a base load renewable, available 24 hours a day due to the large heat resource available in the ocean. The history of OTEC goes back more than 100 years. The 1973 'oil shock' fostered intense interest in renewables as an alternative to fossil fuels. As a result, significant R&D funding for OTEC became available and new designs were developed and test plants were installed in Hawaii, Japan, and Nauru. After the subsequent collapse of oil prices, interest in OTEC and other renewables waned and development slowed. The 210 kW (gross) open-cycle OTEC demo plant at the Natural Energy Laboratory of Hawaii Authority in Hawaii was closed down around 2000. Still, some OTEC research is continuing, especially in the USA, Japan and India. India recently has been working with organizations in Japan to install a 1 MW OTEC unit offshore SE India.

Most OTEC plants are based on the Rankine cycle or its variants, i.e., they operate by heating and evaporating a working fluid in a boiler/evaporator, then expanding the vapour produced through a turbine before condensing the low-pressure vapour in a condenser. Heat is extracted from the warm surface water and rejected into cold sea water brought up from depths below the thermocline. A minimum temperature difference of about 20°C is needed in order to generate net power.

Closed cycle OTEC (CC-OTEC) utilizes pressurized working fluids with low boiling points such as ammonia, refrigerants, and some hydrocarbons. The small operating temperature range, which is established by the temperature difference between the surface and deep sea water, complicates heat transfer in the evaporator and condenser and generally requires large heat transfer surface areas. As a result, reducing the cost and improving the performance of heat exchangers remain the primary focus of CC-OTEC development. Still, industry claims that present available technology can be applied to the construction of modular Closed Cycle OTEC plants with generating capacity of hundreds of MW (Gautier *et al.,* 2001).

Open cycle OTEC (OC-OTEC) uses seawater as the working fluid. The system is operated under partial vacuum to allow flash evaporation of the warm sea water. While direct contact heat exchangers can be employed in the OC-OTEC process, which represent a major cost savings over CC-OTEC, this cycle has its distinct technical challenges such as maintaining vacuum and eliminating non-condensable gases that evolve from the sea water at low pressure. Furthermore, the low density steam requires very large turbines to produce any significant levels of power. One advantage of OC-OTEC that has been routinely touted is that it can be configured directly to produce potable water as a by-product. Design studies have indicated that modular OC-OTEC plants with capacities up to tens of MW can be constructed using currently available technologies.

The tropical ocean regions most suitable (with regard to available ΔT, proximity to shore, etc.) for OTEC power generation have an approximate area of 60 million km^2. It has been estimated that about 0.2 MW could be generated per km^2 of tropical ocean without incurring significant negative environmental impacts (which include thermal pollution from the mixed sea water discharge and a small amount of CO_2 outgassing from the depressurized deep water brought to the surface). On this basis, there is capacity for sustainable energy production of about 12 TW, which is about twice the current global demand for primary energy. In any practical scenario, however, only a fraction of this potential could be feasibly realized.

In the short-to-medium term, floating OTEC plants of a few hundreds of MW capacity could supply a significant amount of electricity in subtropical areas with direct access to the deep cold water resource. In colder regions where the natural ΔT between the surface and deep water pools is less than 20°C, land-based variations of the OTEC cycles have been explored in which warm waste water from commercial processes (such as the cooling water discharge from fossil fuel or nuclear power system condensers) takes the place of surface sea water. OTEC systems could also be configured to produce energy carriers, such as ammonia or hydrogen (Gauthier *et al*., 2001) or other marketable by-products such as potable water. Figure 1 shows a number of commodities that could be generated by a multi-product OTEC system.

SUSTAINABLE FISH FARMING

Recent studies by a number of organizations, including the Food and Agriculture Organization of the United Nations and the Pew Ocean Commission, have concluded that the world's commercial marine fisheries are currently fully exploited, overexploited, or depleted. As shown in the example given in Figure 2, capture fisheries production has declined in many regions. Global marine catches peaked at 80 million tonnes in the late 1980's. Per capita availability of fishery products has declined from 15 kg a year in the late 1980's to 12 kg presently (Clers and Nauen, 2002). While traditional fish farming can, up to a point, fulfill the demand, it relies heavily on feed made from fish and other marine species. This serves to contribute to the decimation of the natural marine protein pool. Moreover, fish farming also poses some serious environmental threats, e.g., escape of farmed species and spread of disease into the wild population, even if farms are moved to offshore (Dalton, 2004).

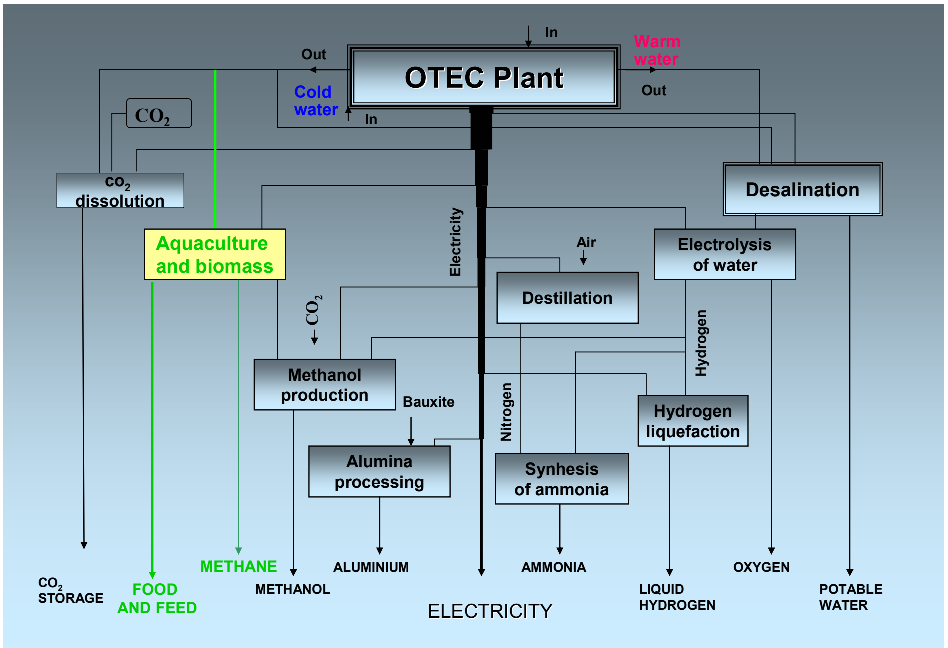

Figure 1. Schematic of an OTEC plant and the products, also including aquaculture and biomass (the NGF concept).

From a feeding perspective, fish farming can be very efficient. Salmon, which has the best feed conversion ratio, need 1.15 kg of feed (dry weight) to produce 1 kg of salmon. In comparison, poultry requires 1.94 kg feed and pigs need 3 kg feed to achieve equivalent growth. In spite of this relative efficiency, it is believed that marine feed stocks (krill, small herring, capelin, etc) are already overexploited so there is no potential for increased production following conventional approaches. To circumvent this barrier without applying additional pressure to increasingly vulnerable marine environment, an alternative approach has been proposed to enhance natural fish stocks locally. Organizations in Japan, the USA, and Norway have initiated efforts to advance this Next generation Fisheries (NGF) concept (Takahashi, 2004).

The key factor for feed production in NGF is the utilisation of nutrient rich Deep Ocean Water (DOW) that has been pumped to the surface for use as a thermal sink in OTEC. After passing through the OTEC system, the DOW will be warmed by 5-10°C. Typically, this still cold water is mixed with the effluent warm surface water before being discharged below the surface to minimize thermal pollution. Since the effluent DOW has high nutrient content (nitrates, phosphates and silicates) compared to surface waters, it has great potential for enhanced production of biomass by photosynthesis. DOW fertilization is the same mechanism that drives new production following natural, wind-driven ocean upwelling that occurs along the continental margins, which enhances primary production that sustains fisheries (e.g., offshore Chile). In fact, DOW from

OTEC is expected to have higher nutrient levels than the naturally upwelled water that originates from shallower depths corresponding to the thermocline.

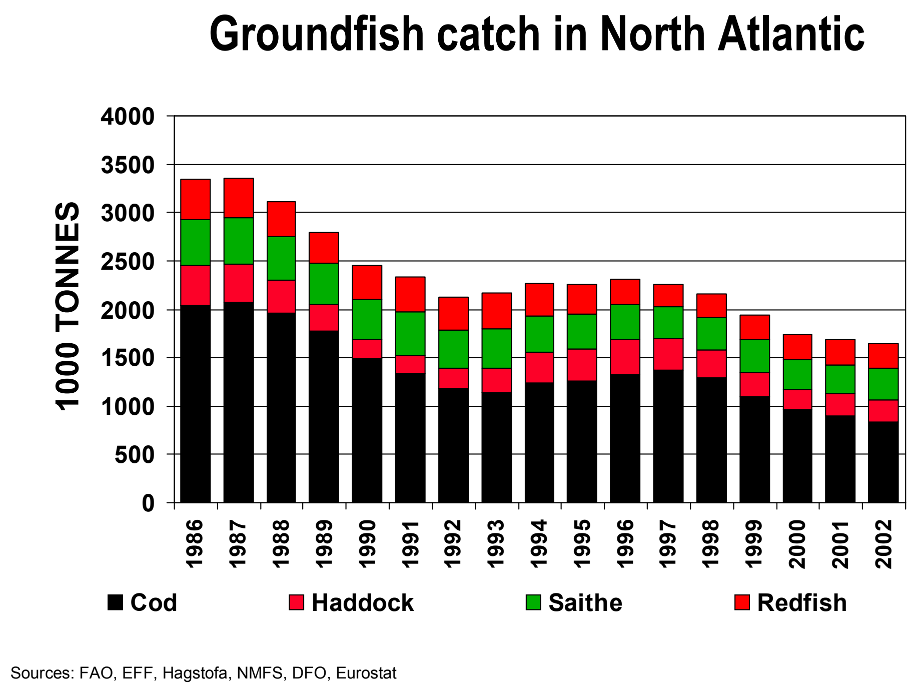

Figure 2. Catch of common fish stocks in the North Atlantic, 1986-2002.

The effectiveness of using DOW to enhance local fish stocks depends on the ability to retain the nutrients at appropriate concentrations in the euphotic zone for a long period of time relative to the photosynthetic timescales. Cold DOW is more dense than the ambient surface sea water and will descend unless it is heated or diluted sufficiently. Several strategies to implement artificial upwellings have been designed and some are currently being tested (Ouchi and Ohmura, 2004). The rationale of integrating OTEC and mariculture is that the OTEC cycle can provide the power required to bring up large volumes of DOW with a net surplus of electricity which can, in turn, be sold or used for other fisheries operations or to produce marketable by-products.

Zooplankton will feed on the algae, and in turn become feed for herbivorous fish downstream in the plant. Herbivorous fish (like tilapia) can feed directly on the algae. Alternatively, the agae biomass can be converted by biodegradation to useful products like metane. Figure 3 shows an outline of the OTEC/NGF principle.

The NGF concept has been studied for some time, and designs have been proposed (Takahashi 2004). In October, 2004, the Japanese Ministy of fisheries hosted a meeting on NGF between representatives from Japan, USA and Norway, with the aim to boost development of the NGF concept, preferrably in several countries. The meeting set up the priorities for further development, where the Pacific International Center for High Technology Research (PICHTR) in Hawaii may become the coordinator. Priority number one is to secure funding for a joint, multilateral project involving the present partership as well as newcomers, including maritime industry. Especially the offshore industry is now expected to possess skills and technologies that are suitable for building full-scale OTEC and NGF plants.

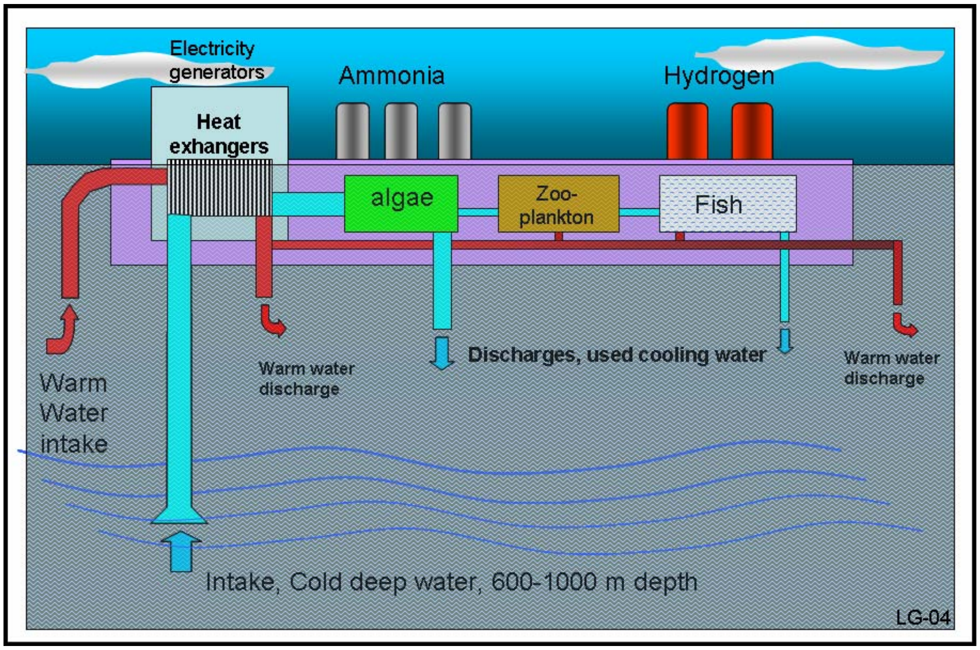

Figure 3. Schematic of the NGF concept based on a floating OTEC platform, with major material and product flows.

SUMMARY

The potential of OTEC in combination with the Next Generation Fisheries (NGF) concept has a great potential for providing large quantities of food and renewable energy in a sustainable manner. Both designs can work well on a stand-alone basis, but the combination as described in this overview should be seriously considered as it constitutes a win-win concept. There are challenges ahead both on the technical, biological and possibly on the environmental side, but recent assessments suggests these can be met. As prices for energy and food continue to rise, the OTEC/NGF concept will soon cross the break-even line to become a profitable industry. As the global surface ocean warms due to climate change, the vertical temperature gradient will increase and thus the area of interest to OTEC/NGF will expand. However, the candidate countries for the first installations will probably be located in the tropical or subtropical region, with the small island states in the Pacific Ocean and south Asia as particularly interesting. The recent initiative taken by Japan, USA and Norway to form a consortium for enhanced R&D on the NGF should be supported by the governments as well as by international organisations dealing with global sustainable development.

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