Commercial Implementation Of Ocean Thermal Energy Conversion

Using the Ocean for Commercial Generation Of Baseload Renewable Energy and Potable Water

By José A. Martí

Manuel A.J. Laboy
Vice President and Director
Offshore Infrastructure Associates
San Juan, Puerto Rico
and
Dr. Orlando E. Ruiz
Assistant Professor
Department
of Mechanical Engineering
University of Puerto Rico, Mayaguez
Mayaguez, Puerto Rico

Ocean thermal energy conversion (OTEC) is a renewable energy technology applicable to tropical and subtropical areas that works by recovering solar energy absorbed by the ocean. As opposed to other renewable technologies, such as solar and wind, OTEC generates power on a continuous (baseload) basis. In addition, if desired, OTEC can coproduce potable water through desalination—up to two million liters per day can be produced for each megawatt of electricity generated.

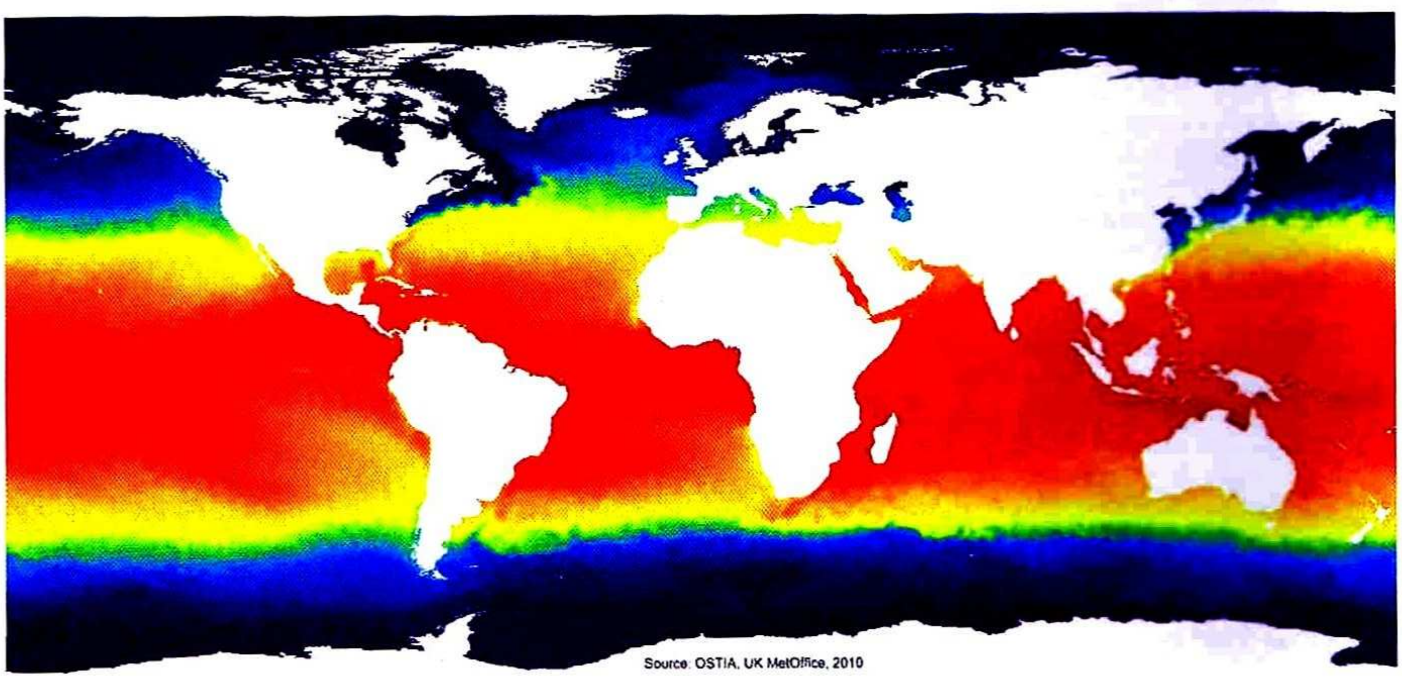
OTEC requires no fuel; thus, the cost of producing electricity and water is not susceptible to the volatility that affects other energy sources like petroleum, coal and natural gas. It generates energy from purely local sources at a cost that is essentially fixed and predictable. Furthermore, since no fuels or radioactive materials are used, the environmental impacts (including greenhouse gas generation) are much less than those of conventional methods of power generation.

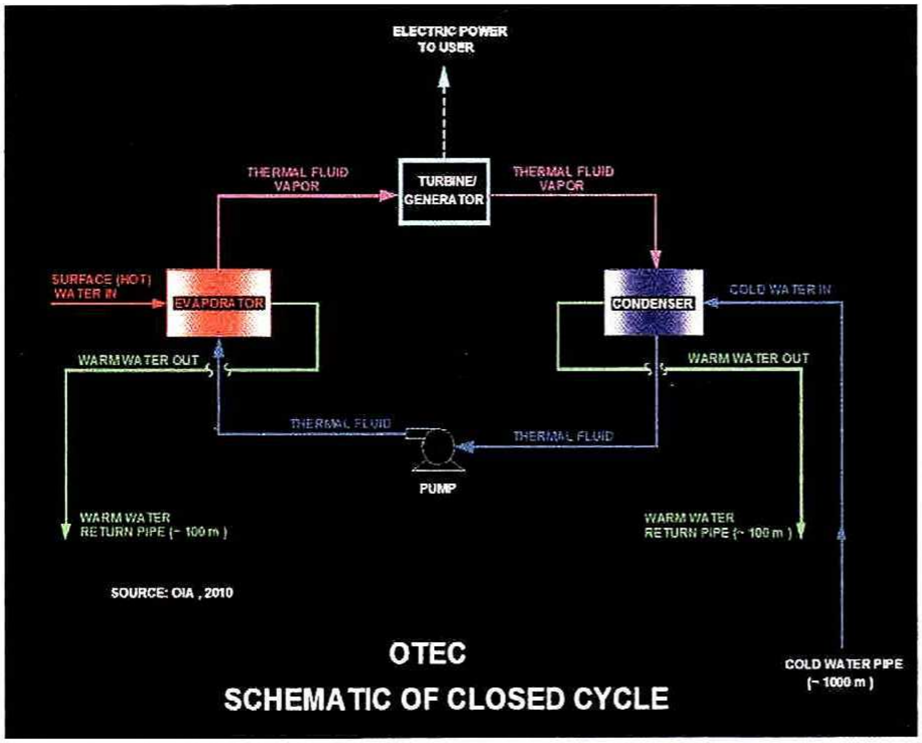
Basic Principles

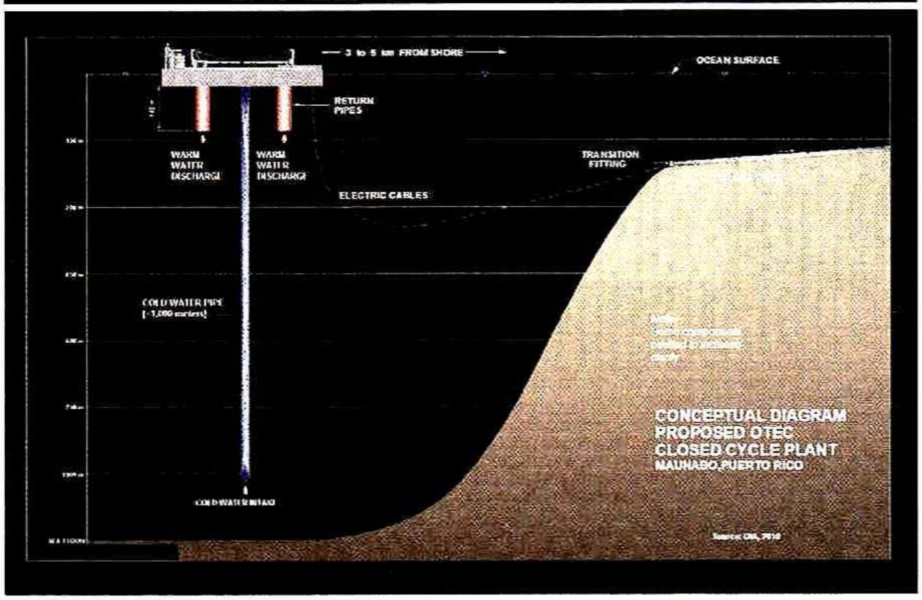
OTEC plants are heat engines that convert heat into work by exploiting the energy gradient between a "source" and a "sink." This is similar to a steam engine, although in the case of OTEC, the temperature gradient is much smaller. This makes OTEC plants larger than steam plants of comparable capacities.

OTEC has three basic modalities: closed, open and hybrid cycles. In the closed cycle, the temperature difference is used to vaporize (and condense) a working fluid (e.g., ammonia) to drive a turbine generator to produce electricity. In the open cycle, warm surface water is introduced into a vacuum chamber where it is flash-vaporized.

Ocean surface temperatures in February of this year. OTEC is feasible in deep waters in the regions marked in yellow and red. (Courtesy of the Operational Sea Surface Temperature and Sea Ice Analysis program, U.K. Meteorological Office)

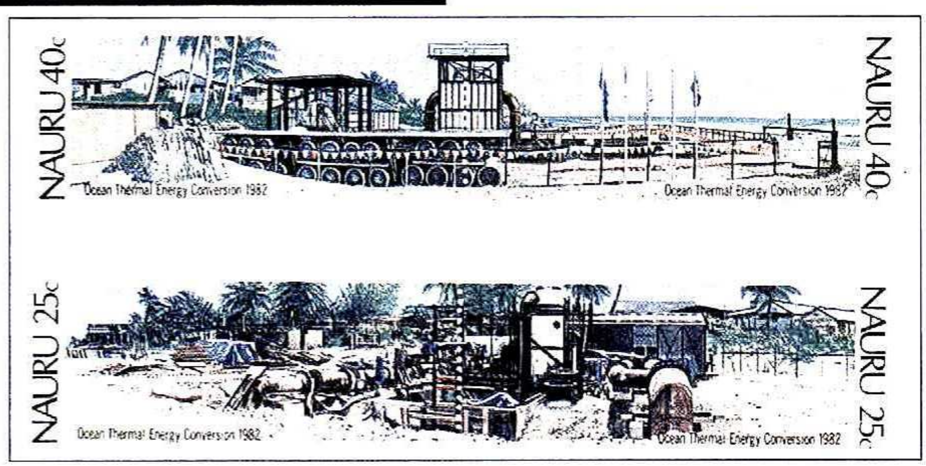






(Above, top) Schematic of OTEC closed cycle.

(Above, bottom) Platform-mounted commercial OTEC plant proposed by OIA for Puerto Rico. Some components have been omitted for clarity.



(Right) Postal stamps commemorating the OTEC plant built for the Republic of Nauru.

This water vapor drives a turbine generator to produce electricity. The remaining water vapor (essentially distilled water) is condensed using cold sea water, and this condensed water can either return to the ocean or be collected as potable water. The hybrid cycle combines characteristics of the closed and open cycles and has great potential for applications requiring higher efficiencies for the coproduction of energy and potable water. In all three cycles, cold ocean water, normally available at depths of 1,000 meters, where the water temperature remains constant at around 4° C, is required to condense the working fluid.

History of OTEC

OTEC was formally proposed in 1881 by French physicist Jacques Arsène d'Arsonval, based on an idea presented by Jules Verne in the novel *20,000 Leagues under the Sea*, published in France in 1869. One of d'Arsonval's students was Dr. Georges Claude, a French engineer and businessman, often called "France's Edison." Claude began work on OTEC during the 1920s, initially conducting experiments in Belgium. In 1930, he built an OTEC open-cycle plant at Matanzas Bay in Cuba, but it only operated for a few days before being destroyed by a major storm. He made a second attempt in 1935, which consisted of a ship-mounted plant off the coast of Brazil, but this also failed due to poor weather.

During the 1950s and 1960s, a number of research and development (R&D) projects were conducted, including design proposals by the French company Energie des Mers, meaning "energy from the seas," and the Sea Water Conversion Laboratory at the University of California, Berkeley.

During the energy crisis of the mid-1970s, interest in OTEC increased in the United States and elsewhere. The U.S. government launched various R&D programs that included performance tests, preliminary designs and demonstration plants. Major efforts included preliminary designs for OTEC production plants by the Applied Physics Laboratory (APL) of Johns Hopkins University, General Electric (GE) Co. (Fairfield, Connecticut), and TRW Corp. (Lyndhurst, Ohio); heat exchanger performance tests by

Argonne National Laboratory; and demonstration plants in Hawaii (Mini-OTEC and OTEC-1).

Other major R&D efforts during this period include the Toshiba (Tokyo, Japan)/Tokyo Electric Power Services Co. (Tokyo) 100-kilowatt closed-cycle land-based plant in the Republic of Nauru and the studies completed at the Natural Energy Laboratory of Hawaii, which led to the construction and operation of a 210-kilowatt open-cycle pilot plant for the coproduction of electric power and potable water.

The more than 20 years of R&D and design efforts addressed all major issues involved in constructing and operating a commercial-scale OTEC plant. Some of the preliminary designs prepared during this period are sufficiently extensive to allow a real project to proceed to the detailed design and/or design-build stages.

What Happened?

At one point, the U.S. federal government contemplated building several 40-megawatt-electrical OTEC plants as commercial demonstration units. Proposals were submitted, but, despite this extensive work, OTEC was not implemented. A major reason was that government funding for the larger plants never materialized. During the 1980s, federal energy funding tended to favor nuclear energy and shifted away from renewable energy. However, there was a general loss of interest in OTEC in other countries as well, largely due to the fact that after the energy crisis of the 1970s, oil supplies stabilized. Eventually a production glut caused prices to drop to unprecedented lows, with the average cost per barrel of imported oil reaching $11.18 in 1998.

In addition, during this period there was a general lack of awareness about the potential effects of fossil fuel combustion on climate at a global level. These events conspired to make renewable energy in general, and OTEC in particular, become less attractive.

Why Now?

Recent world events have created a new interest in OTEC. First of all, the price of oil has increased vertiginously, reaching as high as $148 per barrel in 2008. There are also serious concerns about the stability of oil production in conflictive areas such as the Middle East and the possibility of world oil production peaking, which some commentators believe began in the period between 2000 and 2010. History shows that increases in the cost of oil invariably result in increases in demand for and cost of other fuels such as coal and natural gas.

More importantly, there is now a general awareness about the potential contribution to global warming caused by greenhouse gas emissions from combustion of fuels (from renewable or nonrenewable sources). Both the United States and the European Union have seriously discussed the imposition of taxes on greenhouse gas emissions.

Another significant issue is the "energy-water nexus" created by conventional power facilities like coal and nuclear: To produce energy, large quantities of water are required, and to produce and distribute water, large quantities of energy are required. OTEC is the only technology for baseload power generation that not only does not consume water, but can also be used to produce potable water.

All of these factors have revived interest in OTEC. For the first time, the high cost of oil and its volatility and fluctuations in the world market, together with concern about the environmental effects of fossil fuels, have created conditions that can make OTEC plants commercially viable without the need for government subsidies.

Technical Feasibility

The nearly 80 years of studies and designs since Claude's first attempt to demonstrate OTEC technology in Cuba in 1930 and the investment of more than $500 million in R&D and engineering during the mid-1970s to the early 1990s—in the United States alone—have provided sufficient data to build commercial-scale OTEC plants at the present time, given the proper economic conditions and the right markets.

In 1980, a report prepared by the RAND Corp. (Santa Monica, California) for the U.S. Department of Energy found that power systems and platforms required for OTEC plants were within the state of the art. Subsequent work, such as designs developed by APL in 1980 and GE in 1983, addressed other issues like the cold-water pipe and the cable used to transport electricity to shore.

Commercial viability depends on a number of conditions. First, technologies capable of producing baseline power at a lower cost than OTEC must not be available in the proposed location. In addition, the thermal resource must be present on a continuous basis (i.e., the temperature gradient must be equal to or greater than 20° C throughout the year) and located relatively close to shore. Finally, there must be a market for the output of the plant.

These conditions occur in developed locations that presently consume large amounts of power from fossil fuels, such as Puerto Rico and Hawaii, and also in other locations, such as smaller Caribbean and Pacific islands.

OIA estimates that power from an OTEC plant can be sold to consumers at $0.18 per kilowatt-hour or less. More importantly, the price will be stable.

For comparison purposes, the average price of electricity in Hawaii in October 2009 was $0.2357 per kilowatt-hour, and it had reached levels as high as $0.3228 per kilowatt-hour the previous October due to record high oil prices in the preceding months.

In locations such as smaller Caribbean or Pacific islands that presently use small diesel plants for power—and that rely on desalination for potable water production—the economics of OTEC are even more attractive.

If renewable energy credits or other incentives are available, the economics of OTEC could be even more favorable in these areas and perhaps beyond. In addition, there would be significant benefits to the environment, since the air pollutants and greenhouse gases resulting from fuel combustion would not occur.

Acknowledgments

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References

For a full list of references, please contact José Martí at general@offinf.com. ■

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