CHAPTER 4

ENERGY FROM THE OCEAN

Stephen Cameron

With the San Francisco Bay Area located on the coast, it is only natural that we look to the ocean for a supplementary energy source. The oceans provide a variety of potentially significant sources of energy, all of which are renewable, and, none of which produce excess heat or waste as do most conventional power generating methods. There are basically five sources that will be considered here: tides, thermal gradient, salinity gradient, ocean currents, and waves. Wind is also considered a form of ocean energy, however, it has been discussed in the previous section. While some of these methods have yet to be tested, others are presently being used as a viable power source. Some forms are feasible for Bay Area use, some are not. But in an effort to create a greater awareness, they will all be discussed here. Each will be reviewed for its potential as an energy resource, and for its feasibility in the Bay Area. Figure 1 indicates the resource potential of these energy forms.

Tidal Power

Several variations for harnessing tidal power exist. Basically, power is generated by a set of turbines placed where the ebb and flood of the tides are forced to pass through them. The requirements for a feasible system are a natural or artificial body of water with relatively large storage capacity and a tidal range of at least 15 ft. This exludes the San Francisco Bay as the tidal range is significantly less, usually about 5 ft.[13]

Two tidal power plants are in operation today. One is on the mouth of the Rance River in France which produces about 5 GWh of energy per year. It operates with a total of 24 generators, each of 10 MW. The other power plant is in the USSR with an output of about 400 kw.[15] Considering costs of construction and today's prices of conventional fuel, tidal power is presently not economically feasible. But, after much investigation, a tidal power plant has been proposed for the Passamaquoddy Bay on the border between Maine and Canada. Given likely increases in fuel prices, it will probably become reality.

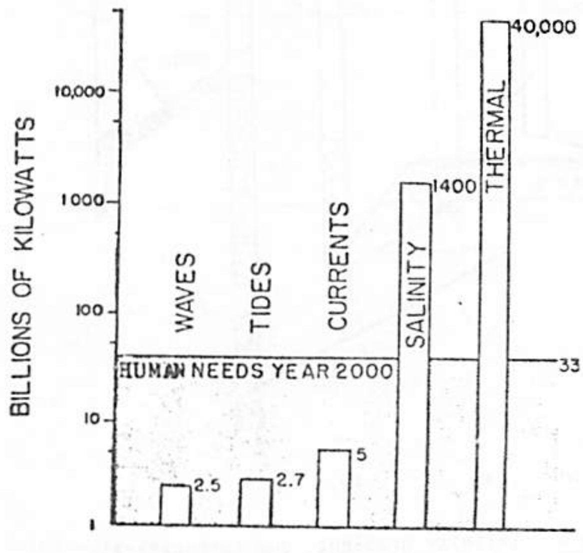

Figure 1. Estimates of the power dissipation rates in the oceans (Isaacs and Seymour, 1973).

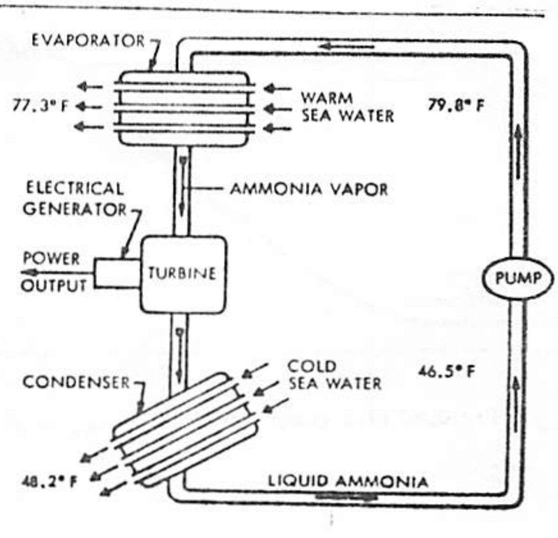

Figure 2. Simple heat engine(Trimble, et al.,1975)

Thermal Gradient Power

This, one of the more promising ocean energy sources, is also known as Ocean Thermal Energy Conversion (OTEC). It makes use of the fact that ocean surface temperatures are higher than those at lower depths. Work can be extracted by a simple heat engine powered by these temperature differences. An evaporator fueled by warm seawater converts the working fluid (ammonia or propane) into a high pressure gas which drives a turbine to produce electricity. A condensor fed by cold water then converts the lower pressure gas back into liquid (Fig. 2).

A commercial plant has yet to be built and successfully operated. In 1930, a small 22kw plant set up by Georges Claude in Cuba, functioned for two years though it was an economic failure.[1] Today, several groups, including Lockheed, are working on the OTEC system. Lockheed has designed a 240 MW plant with an estimated investment cost of $2,600/kW and a power cost of 36 mills/kWh. The plant would be anchored at sea with electricity transmitted via underwater transmission lines (Fig. 3). Some technological difficulties have delayed completion date to 1986.[12]

Unfortunately OTEC cannot be considered as a possible Bay Area energy source. The temperature difference required is at least 15°C between the surface and 700-1000 feet deep. Off the coast of San Francisco the monthly average is only about 9°C between the surface and 1000 feet.[6] OTEC is generally considered only for tropical regions where surface temperatures are high.

Salinity Gradient Power

This power source has somewhat less potential than thermal gradient power (Fig. 1) and is far less developed technologically. Its operation is based on the fact that when a semipermeable membrane is placed between waters of different salinities a pressure gradient occurs which causes water to pass from the reservoir of lower salt concentration to that of higher salt concentration. This pressure gradient, or osmotic pressure, which is also a function of temperature, will create a difference of water height between the two reservoirs.

Several methods have been proposed for conversion of salinity gradient energy into power. One is to sink a long vertical tube capped on one end with a semipermeable membrane into salt water. The tube will remain

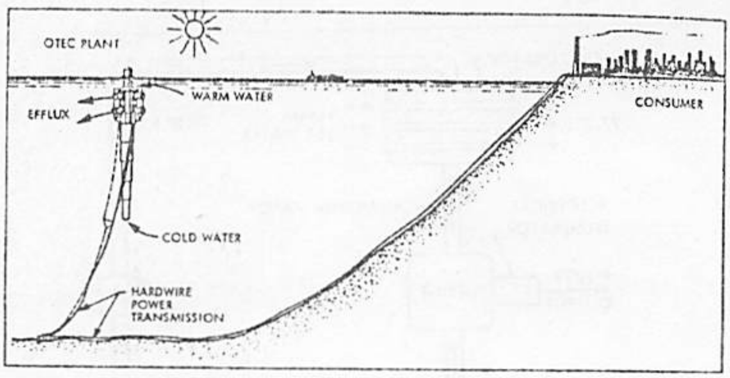

Figure 3. Deployed OTEC power plant (Trimble, et al.,1975).

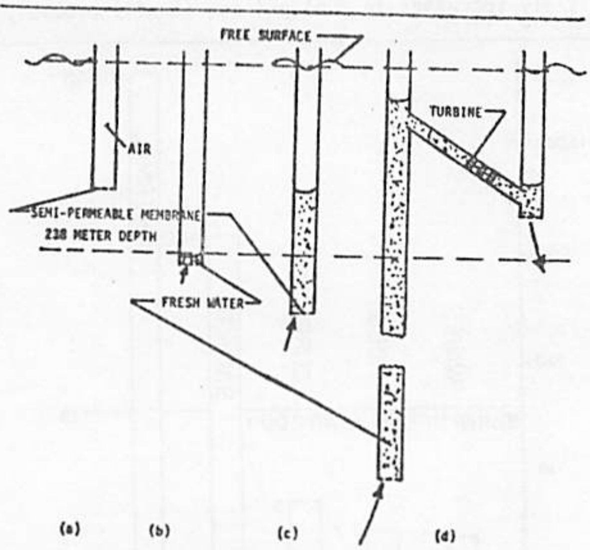

Figure 4. Salinity gradient, and turbogenerator (d) (McCormick, 1976).

empty until osmotic pressure is reached. If the salinity of the water is 35‰ (parts per thousand) then this pressure will be reached at a depth of 238 m (Fig. 4). Beyond this depth fresh water will pass into the tube leaving salts behind. If the fresh water is then allowed to pass through a turbogenerator and empty into a tube which draws less than 238 m then the fresh water will generate electricity and pass out through the semi-permeable membrane of the shallow tube (Fig. 4d). The fresh water will rise above the free-surface of the salt water given a long enough tube. For example, if the original tube goes to a depth of 10,000 m in 35‰ salt water, the fresh water will rise to 33 m.[4]

A second technique would involve the damming of the mouth of a river, where salinity gradients would be greatest. The fresh water would be allowed to pass through a turbogenerator and into a buffer lake, the free-surface of which is less than 238 m below both the river and ocean (Fig.5). Due to osmotic pressure the fresh water would then pass through a series of tubes capped with semipermeable membranes.[14]

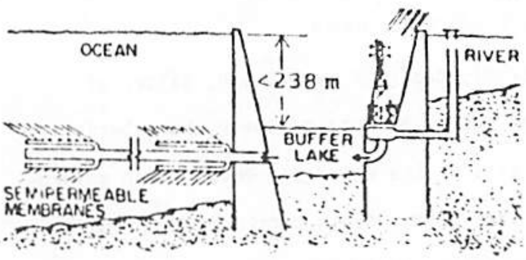

Figure 5. Salinity gradient power plant (Wick and Isaacs, 1975).

This latter system would not be environmentally acceptable. The salinity at the mouth of the estuary would be drastically altered and also possibly the temperature gradient. This, plus the impact of the twin dams would preclude construction of such a structure in a delicate estuarian environment.

The first system would have no environmental consequences of any significance since it would be placed in deep ocean where diffusion of fresh water would be local. However, membrane technology has not advanced to the point where large self-cleaning membranes can be manufactured. Until then, salinity gradients will not provide a viable energy source.

Ocean Current Power

This method has some potential, but is basically untested. Several types of underwater turbines capable of utilizing low velocity currents have been developed. One is a six-bladed "underwater windmill" rated at 20 MW in a 2.2 m/sec current.[2] A vertical axis turbine has been suggested for areas where the flow direction is variable and energy gradient is large.[11] Most proposals refer to such anomalies as the Florida Current where surface currents sometimes reach 2.5 m/sec. The California Current, off San Francisco, appears to be only about .5 m/sec.[6] However, it seems possible that the vertical axis turbine could harness the ebb and flood of the tides as they flow around islands and through straits in the San Francisco Bay where strong currents tend to build up. At this time, it is not clear how a generating plant would be set up, as the necessary technology has not been developed. An encouraging aspect of ocean current power is that the environmental impacts would be small, if any.

Wave Power

Waves are the most visible energy form of the oceans. An average of 38 GW of energy are dissipated along one mile of California coast each month.[5] Methods for harnessing wave energy have been devised since the turn of the century and hundreds of U.S. patents have been issued. But it seems that most, if not all, the inventions proved to generate insignificant amounts of energy. Many are still untested.

Often sea buoys that need power for a flashing light or whistle will use a wave generator. The first wave-activated whistle buoy was used in 1898.[10] The Japanese Maritime Safety Agency has been using more modern pneumatic wave-activated generators since 1965.[7] The buoys designed by Y. Masuda, contain an inner chamber directly in contact with the sea surface and as the buoy undulates, the air within it is compressed to drive an air turbogenerator (Fig. 6). Both the 70 and 120 W generators are standardized. Masuda has proposed a larger scale generator based on the same principles. The octohedral shaped ring-buoy would have an exterior diameter of 120 m, draw four feet, and weigh a maximum of 3000 metric tons. It would be designed to harness waves having lengths of 120 m. Masuda estimates that it would generate 3 to 6 MW of electricity in high seas. Electricity produced by this unit is calculated to cost 20 mills/kWh based on an electric output of 15 million kWh per year for 15 years. If electricity supplied 94 billion kWh, or about 7.7% of the Bay Area's energy needs per year in 1975, then this generator could provide .015% of this need.

A device which makes use of the transverse wave movement was recently designed by Dr. S.H. Salter of Edinburgh University.[8] These devices are often refered to as "nodding ducks" because of their characteristic shape and movement. They are a specially shaped vane (Fig. 7) which sits in the water and moves, when absorbing power from a wave, in such a way that the water displaced by the vane at any depth corresponds to the natural amplitude of the wave motion at that depth. The vane rotates about its center (O), and absorbs the wave coming from the right. The front curve is designed to match the displacement of the water in approaching waves so that the fluid motion of the oncoming wave is not perturbed or reflected in any way. The natural nodding period of the ducks is intended to coincide with the wave period. They have demonstrated remarkable efficiency for utilizing both monochromatic and mixed spectrum waves. The random rotations activate pumps in which high pressure oil is used to drive motors coupled to electrical generators. Each structure is proposed to be about 1 km long with 20 to 40 vanes rotating about a common axis (Fig. 8). One string of generators is estimated to produce 50 MW, and a group of ten may cost $480 million. It was suggested by Salter that a few hundred kilometers of generators could meet the total electrical energy needs of the United Kingdom in 1974.[8]

However, the nodding ducks could create two undesirable impacts. First, they will be a navigational hazard. Some accidents are foreseen, but these will be minimized with the proper navigational warnings. Second, the devices have a tendency to slightly reduce the waves to leeward. A series of generators of the magnitude that Salter suggests could alter the littoral ecosystems of the shore. But if they are over about

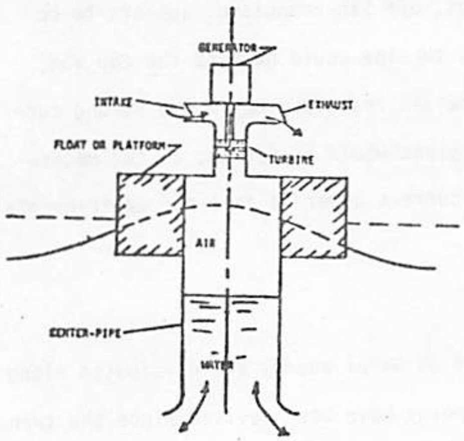

Figure 6. Pneumatic wave-activated generator (McCormick, 1976).

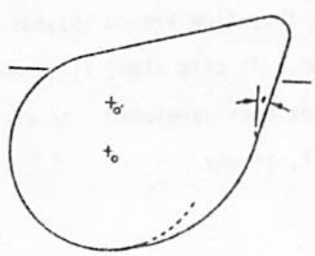

Figure 7. The Salter vane (Salter, 1974).

20 miles from the coast, waves will have sufficient time to rebuild themselves, lessening any possible adverse effects.

Of all the generators being studied today this appears to have the greatest potential. However, a few technological problems need solving. The device has not been tested at sea under severe conditions, and there is some uncertainty as to the amounts of stress it could withstand. It is purported that the difficulties will be solved and the device will be made available for commercial use in the very near future. This seems to have the greatest potential and feasibility as a Bay Area energy source derived from the ocean.

Conclusion

It is obvious that the oceans will not be supplying any major portion of the Bay Area energy at present. Tidal and OTEC generation systems are out of the question due to their feasibility requirements. Salinity gradients, excluding the damming of rivers, seem to have some potential but probably not inside of 20 or 30 years. Likewise for ocean currents, adequate technology is just not well enough developed. The nodding ducks are probably closest to providing any viable source of energy from the ocean for the Bay Area. A number of scientists and engineers find it to be a most remarkable invention having great potential for the future generation of power (Wiegel, 1977, oral communication).

It is probably true that ocean energy sources have not received the research and development attention they should have. But when the costs of conventional fuels rise sufficiently, perhaps this will change. Merely the fact that these sources are non-polluting and eternally renewable suggests that they should be taken advantage of. Though they will probably not supply the total energy needs of the Bay Region in the future, they can at least augment other energy sources.

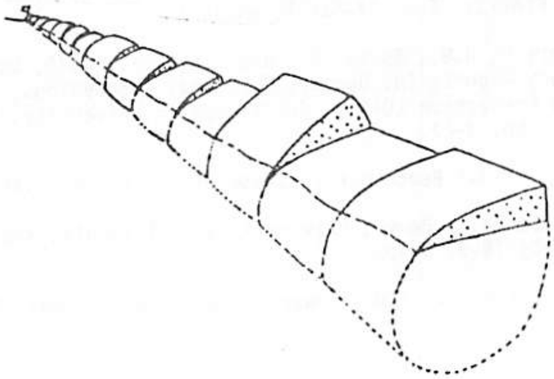

Figure 8. Series of vanes, or nodding ducks, absorbing power from waves comin from the right (Salter, 1976).

References Cited

1. Hagen, A.W., 1975, Thermal Energy from the Sea, New Jersey, Noyes Data Corporation, 150pp.

2. Heronemus, W.E., Mangarella, P.A., McPherson, R.A., and Ewing, D.L., 1974, On the Extraction of Kinetic Energy from Oceanic and Tidal Currents, In, Stewart, H.B., editor, Proceedings of the McArthur Workshop on the Feasibility of Extracing Useable Energy from the Florida Current. NOAA Atlantic Oceanographic and Meterological Laboratories, Miami, pp. 138-201.

3. Isaacs, J.D., and Seymour, R.J., 1973, "The Ocean as a Power Source", International Journal of Environmental Studies, Vol. 4, pp. 201-205.

4. Levenspiel, O. and deNevers, N., 1/18/74, "The Osmotic Pump", Science, Vol. 183, no. 4121, pp. 157-160.

5. McCormick, M.E., 1976, Salinity Gradients, Tides and Waves as Energy Sources, In, Kohl, Jerome, ed. Conference Proceedings--Energy from the Oceans Fact or Fantasy?, Center for Marine and Coastal Studies, North Carolina State University, Report N. 76-1 UNC-SG-76-04, pp. 33-41.

6. Rakestraw, N.W. and all, eds. 1960, Oceanic Observations of the Pacific--1955--The Norpac Atlas, Japanese Hydrographic Office, Univ. of Tokyo and Univ. of Calif. Press, 123 pp.

7. Richards, A.F., Feb.-Mar. 1976, Extracting Energy from the Oceans: A Review, Marine Technology Society Journal, Vol 10, no. 2, pp. 5-24.

8. Salter, S.H., 6/21/74, "Wave Power", Nature, Vol. 249, no. 5459, pp. 173-198.

9. __________, Jeffery, D.C., and Taylor, J.R.M., 1976, Wave Power--Nodding Duck Wave Energy Extractions, In, Kohl, Jerome, ed. Conference Proceedings--Energy from the Oceans, Fact or Fantasy?, Center for Marine and Coastal Studies, North Carolina State University, Report No. UNC-SG-76-04, pp. 5-8.

10. Schuessler, Raymond, Sept. 1975, "Wave Energy", Oceans, Vol. 8, no. 5, pp. 34-37.

11. Sheets, S.H., 1974, Energy Recovery from Fluid Motion, In, Stewart, H.B., ed. Proceedings of the McArthur Workshop on the Feasibility of Extracting Useable Energy from the Florida Current, Palm Beach Shores, Florida, Feb. 27-Mar.1, pp114-123.

12. Trimble, L.C., Messinger, B.L., Ulbrich, H.G., Smith, G., and Lin, T.Y., 1975, Ocean Thermal Energy Conversion System Study Report, In, Dugger, G.L., ed. Proceedings, Third Workshop on Ocean Thermal Energy Conversion (OTEC), Johns Hopkins University, Applied Physics Laboratory, APL/JHU 75-2, pp. 3-21.

13. U.S. Coast and Geodetic Survey, 1935, Tidal Bench Marks, State of California, 149 pp.

14. Wick, G.L., and Isaacs, J.D., 1975, Salinity Power, University of California, Institute of Marine Resources, IMR Reference No. 75-9, 33 pp.

15. Wilson, E.M., Aug. 1973, "Energy from the Sea--Tidal Power", Underwater Journal, Vol. 5, no. 4, pp. 175-186.