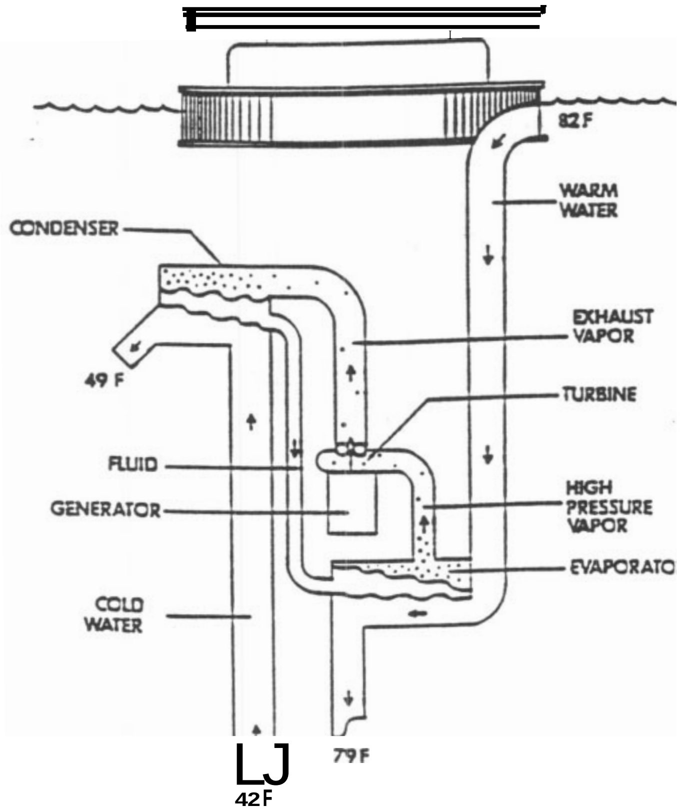
OCEAN THERMAL POWER EFFECT ON GREENHOUSE GASES

BY: J. HILBERT ANDERSON

In the ocean thermal power process electrical power is generated from the thermal energy available in the ocean. An ocean thermal power plant generates power by transferring heat from a warm body through a heat engine to a cold heat sink. In this case, the source of heat is the warm surface water in the tropical ocean, and the cold heat sink is the cold water deep in the ocean.

The cycle diagram on Figure 1 shows the power cycle (Ref. 4) developed by Sea Solar Power, Inc. for generating power from the temperature differences in the ocean. Warm water at the surface is pumped through a heat exchanger which transfers the heat from the warm water to boil a working fluid, in this case, the ordinary household refrigerant designated R-22. The fluid boils into a vapor at high pressure, and flows upward through a turbine driving a generator that generates electricity, which is transmitted from the floating plant to a shore based station.



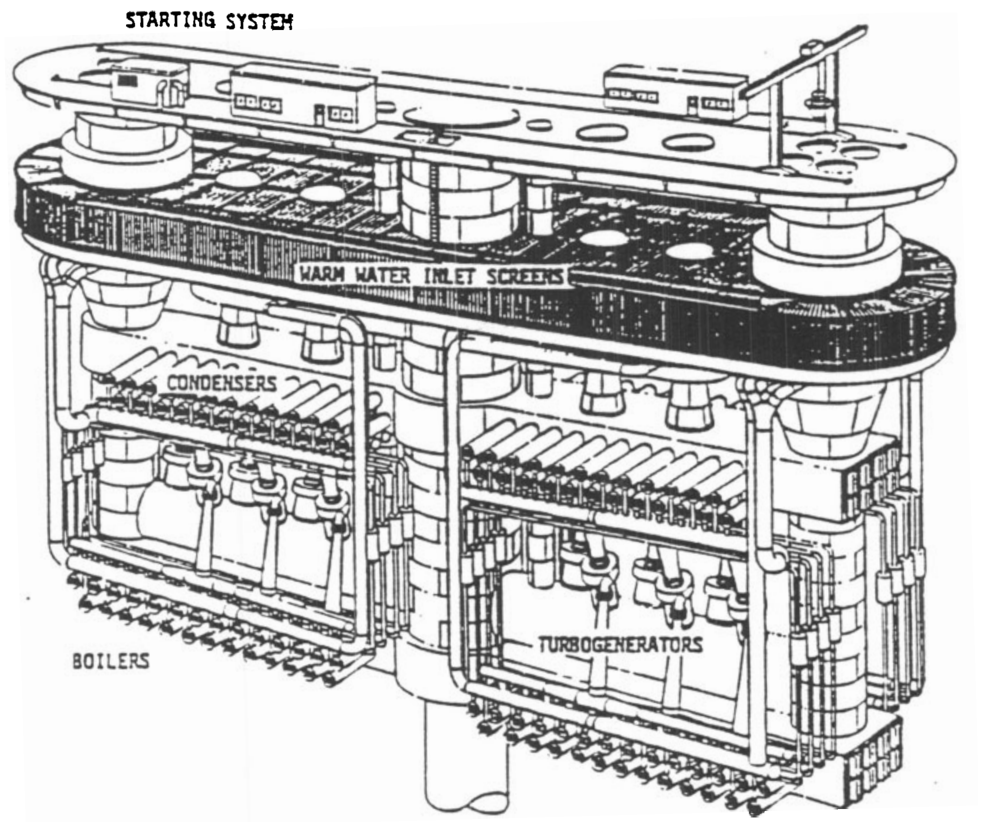
OCEAN THERMAL ENERGY CONVERSION
CLOSED POWER CYCLE

Figure 1

After passing through the turbine, the vapor pressure is reduced. The vapor then flows to condensers that are cooled by cold water pumped from the ocean depths. The heat of condensation from the vapor passes to the cold water, and the vapor is thereby condensed to a liquid in the same way that your breath condenses on a cold window pane. The liquid then flows by gravity down to the boiler to be boiled again. Thus a continuous cycle of power generation is sustained. In this cycle there are no discharges of working fluid to the atmosphere, since the R-22 merely circulates through the system much as it does through your kitchen refrigerator, except in reverse.

Figure 2 shows a conceptual sketch of a 100 megawatt Sea Solar Power plant (Ref. 4). This plant works in the same way as shown on the diagram. Warm water is drawn through a screen from the warm mixed layer at the surface of the ocean. This water is pumped down to the boilers at the bottom of the power plant, and from there discharged into the ocean.

Ocean thermal power - the coming energy revolution



100 MWe **OTEC** plant

Figure 2

The R-22 vapor rises from the boilers and passes through the turbogenerators where it generates electrical power. From the turbine, it exhausts upward to the condensers where it is condensed into a liquid, and flows by gravity down through the small pipes to the boilers at the bottom of the plant.

The cold water is pumped through a pipe approximately 8.5 meters in diameter and 900 meters long suspended from the ocean platform. The water is pumped through the condensers into the ocean at a level approximately 35 meters below the surface.

A typical 100 megawatt power plant weighs approximately 25,000 metric tons, including the cold water pipe and the working fluid. The plant is approximately 110 meters long and the bottom of the plant is approximately 60 meters below the surface.

Since there are no gases discharged from the plant itself, the only possible effect on the atmosphere is that of discharging dissolved gases from the water, or absorption of gases from the atmosphere.

It is difficultto estimate whether CO_2 will actually be discharged from the water coming out of a Sea Solar Power plant. The cold water is discharged at a level higher than the warm water, but both discharges are into the upper mixed layer in the ocean. Therefore, we can assume that the net effect is that of mixing warm and cold water. There are two possible effects.

The first effect is that which will occur if you assume that both the warm and cold water streams are saturated solutions of CO_2.

The second effect is that of photosynthesis. Since the cold water contains a large percentage of nutrients including both nitrogen and phosphorus compounds, then it has been well established, both in nature and by experiment (Ref. 5), that increased photosynthesis does occur, and marine life is greatly increased.

The solubility of CO_2 in sea water is much more sensitive to the pH value than to the temperature. If we use Takahaski's values (Ref. 3) for the CO_2 dissolved in cold water, and assume that the warm water is saturated, as per the data from the Office of Saline Water (Ref. 1), then by mixing the two streams in the upper mixed layer, we should theoretically discharge .00179 grams of carbon in CO_2 per kilogram of water passing through the plant. The total amount of water passing through the plant is 136 cubic meters per second of cold water, and 248 cubic meters per second of warm water. This total amounts to 12.4 billion metric tons per year. The theoretical amount of carbon released would then amount to 22,200 metric tons per year.

Next, let us estimate the amount of carbon that would be absorbed into marine life by photosynthesis.

Roels (Ref.3) estimates that one kilogram of fish would be produced for each 300 metric tons of cold water brought to the surface. On the basis of 4.4 billion metric tons of cold water per year pumped through the power plant, the weight of fish produced would be 14,700 metric tons per year. If we conservatively assume that an equal tonnage of plankton is produced to supply food for the fish, and assume that the plankton are 44% carbon, typical of cellulose, then photosynthesis would absorb 6500 metric tons per year.

Based on these conservative estimates the maximum net discharge of carbon into the atmosphere from a 100 megawatt power plant would be 22,200 minus 6500 equals 15,700 metric tons per year.

This would appear to be the maximum possible release of carbon to the atmosphere from a 100 megawatt power plant. The probability is that the discharge would be considerably less than this, both because the water is likely not to be fully saturated with CO_2, and because the plankton consumption by fish is likely to be much more than that estimated here. Therefore, CO_2 coming out of the solution should be less, and carbon absorbed by photosynthesis should be higher than 1 have estimated here.

George Woodwell (Ref. 2) reports that the net increase in carbon in the atmosphere is approximately 2.3 billion metric tons per year. If we calculate the amount of carbon released by coal fired power plants, then we can calculate how many coal fired power plants must be replaced by ocean thermal plants in order to eliminate this increase in atmospheric carbon.

Assuming 30% thermal efficiency, a 100 megawatt coal fired power plant will discharge approximately 250,000 metric tons of carbon per year into the atmosphere. If we assume that we will replace sufficient coal fired power plants to eliminate completely the net increase in carbon in the atmosphere, the number of 100 megawatt power plants that would need to be replaced by ocean thermal plants would be 2.3 billion divided by 250,000 equals 9,000 power plants. Nine thousand 100 megawatt power plants would generate 900,000 megawatts of electrical power. This is roughly equivalent to one and one half times the total electrical power generated in the United States. It is quite conceivable that this many power plants could be replaced by ocean thermal plants in a period of 25 years.

Another approach toward reducing carbon dioxide in the atmosphere is to substitute electric driven heat pumps for wood stoves used for heating homes, Ponte (Ref. 8) reports that 33,000,000 acres of forest land are being denuded each year. Most of these forests are being destroyed for use in heating rather than for use as lumber. Therefore, we can calculate how many ocean thermal power plants would be required to replace the wood burned from 33,000,000 acres or 13,300,000 hectares of forest land, which is now being destroyed.

Tropical forest land should absorb at least 5.6 metric tons of carbon per hectare per year (Ref.2) by photosynthesis. On this basis the total area of forests destroyed each year would correspond to 74.5 million metric tons per year of carbon that would otherwise be absorbed from the atmosphere. If we assume that electric heat pumps could heat a house with a coefficient of performance of 2.0, and also assume that wood is burned for house heating at 60% efficiency, then each kilowatt hour would replace 286 grams of carbon. A 100 megawatt plant would then eliminate 250,000 metric tons per year that would be discharged into the atmosphere from domestic heating. On this basis it would require 297 power plants to replace the heat produced by 13,300,000 hectares of forest lana burned for domestic heating. Note that these calculations are based on the assumption that burning the forests produces heat equivalent to 5.6 metric tons of carbon per hectare year. Actually, when a forest is destroyed by burning, much more than 5.6 tons of carbon per hectare is discharged to the atmosphere. Therefore, it would require many more than 297 ocean thermal power plants to cancel out the carbon discharged by burning 13,300,000 hectares per year.

If this land were allowed to continue to absorb carbon from the atmosphere, the total reduction in carbon from the atmosphere would be 149 million metric tons per year produced by the 297 ocean thermal power plants.

If we subtract 149 million tons from the 2.3 billion tons net increase in the atmosphere, then this would leave 2.15 billion tons yet to be accounted for.

The number of power plants to replace 2.15 billion metric tons produced by coal fired power plants would be 8540 plants. Adding 8540 plus 297 equals 8837 ocean thermal plants required if plants used for domestic heating equivalent to the forests being destroyed and the replaced coal fired power plants. This is somewhat less than the figure calculated above, based only on replacing coal fired power plants to eliminate the increase in carbon in the atmosphere.

Although replacement of coal fired power plants is by far the most important effect producible by ocean thermal plants toward reducing carbon in the atmosphere, the effect on food supply for the world should also be considered.

The following table shows the approximate world food production in million tons per year (Ref. 9). The table also shows food production in the United States (Ref. 6) in tons per hectare for various of the more important foods used for human consumption.

World Food Production

Item	World in Million Tons	US Tons per Hectare
Meat	144	
Eggs	30	
Fish	75	
Dairy Products	483	
Potatoes	260	31.20
Other Roots	300	
Other Vegetables	350	
Fruit	280	
Corn	450	6.69
Rice	410	7.89
Wheat	460	2.69
Other Cereals	340	
TOTAL	**3582**	

If we use the figure of one kilogram of fish per 300 metric tons of cold water required for ocean thermal power plants, then 8837 plants would produce 129,600,000 metric tons of fish per year. This is one and three quarters times the total present world production of fish. This would obviously have an enormous impact on the world's food supply, and would probably accentuate the present trend toward substituting fish for meat in our diet. If this results in a continued decrease in the production of meat from grazing animals, then this would also reduce the methane production by grazing animals (Ref. 7), which is not considered to be an important factor in increasing the methane content of the atmosphere.

In addition to generating a huge additional food supply, each 100 megawatt ocean thermal plant could produce approximately 18,000 cubic meters of fresh water per day. This occurs primarily because it is desirable to remove some of the oxygen from the water entering the heat exchangers so that barnacles will not grow and attach themselves to the interior passages in the plant.

At this rate of fresh water production, the total production from 8837 plants would be 60 billion cubic meters per year. This would irrigate 3.3 million hectares of land at the same rate of water usage as in the Imperial Valley in California (Ref. 10). This acreage is equivalent to approximately 17 times the cultivated area in the Imperial Valley. Since the Imperial Valley is one of the most productive food and grain areas in the United States, *it* is obvious that this could have an appreciable impact on the food supply.

If we assume that irrigated food producing land would absorb three metric tons of carbon per hectare per year, then the carbon absorbed by this irrigated land would amount to 9.8 million metric tons per year.

If this irrigated land were used for producing potatoes, the yearly tonnage would amount to 102 million tons per year or almost half the present world's production.

From the foregoing crude estimates, it becomes clear that ocean thermal power plants can provide by far the most important solution for reducing the increase in carbon dioxide in the atmosphere. It can provide many benefits in addition to this. There is no question that Ocean Thermal Power can and will become the most important factor in providing means for controlling our change in climate.

Ocean Thermal Power is no longer a scientist's dream. It will soon become a practical reality. We already have commitments for installing four 700 megawatt power plants in the tropics, and are negotiating for furnishing some 50 more power plants. We estimate that one shipyard alone could produce four of these power plants per week. Therefore, it is easy to see that we could indeed solve the problem of carbon increase in the atmosphere with a very reasonable time frame such as 20 or 25 years. The important point is that we need to start this program with all possible speed.

REFERENCES

1. Office of Saline Water, Saline Water Chart, p. 12,581.

2. George Woodwell, "The Carbon Dioxide Question", Scientific American, Jan. 1978.

3. Takahashi, Dept. of Energy report DOE/EA-0147.

4. J. H. Anderson, 'Ocean Thermal Power, the Coming Energy Revolution", Solar and Wind Technology, Jan. 1985, The Pergamon Press.

5. Othmer and Roels, 'Power, Fresh Water and Food from Cold, Deep Sea Water", Science 12 Oct. 1973.

6. Agricultural Statistics, U.S. Dept. of Agriculture, 1985.

7. Jerry Bishop, Methane as Culprit in Greenhouse Effect, Wall Street Journal, 24 Oct. 1988.

8. Lowell Ponte, 'What's Wrong with our Weather", Reader's Digest, Nov. 1988.

9. 'Farmed Animals", Torstar Books.

10. Private Correspondence from R.F. Carter, General Mgr., Imperial Irrigation District.