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SEA SOLAR POWER AND THE CHEMICAL INDUSTRY

It is only within the last three years that the world has suddenly awakened to the fact that our oil and gas resources are indeed exhaustible. We have also at long last realized that our whole civilization and economic well being depends on energy. We can thank the oil rich countries of the Middle East for forcibly calling this to our attention. By raising the price of oil a little more nearly to its real worth they have done the whole world a service.

We now recognize that all of the goods that we use and all of the economic blessings that we have enjoyed depend directly on cheap energy to convert the raw materials of the earth into useful goods. Prophets of doom now say that our diminishing energy resources will lead not only to a lower standard of living, but to an extreme shortage of all kinds of materials basic to our civilization. Does this really have to happen?

Let us stop and consider the availability of natural resources. We are fond of saying that we are running out of copper, iron, aluminum, etc.. Are we really running out of these materials? If we are, where did they go? Aside from an American flag left on the moon and a few rockets shot into outer space I believe that the earth has lost essentially none of its resources. They are all still here for our use and enjoyment. You all know that today's chemical industry can sort out any material that we want from the mixture that we find on this earth. Basically, all that it requires to do this is the know-how and energy in one form or another. Therefore, the real key to having a continued supply of usable materials is simply cheap energy.

Since we must admit that the oil that has been stored for us over millions of years by nature will soon be gone, then we must look at other possible sources of energy that are inexhaustible. What are these possible natural sources? First, there is geothermal energy or energy from heat within the earth itself. Suppose that we developed power from geothermal sources at the present world's rate of electrical power usage. I have calculated that at a reasonable expected efficiency, the earth's temperature would be reduced only one degree F in 41 million years. Not all of this geothermal power is available at low cost, however, and one of the often overlooked problems in developing geothermal power is the cost of cooling. This presents a real challenge and I do not expect that we will develop geothermal power to an extent that it will be able to supply the world's total energy requirements. This does not mean that it cannot make a very appreciable contribution.

By far the largest available natural source of power is solar energy. This can be divided into three general forms that are directly usable. First, there is the wind. The winds generated by solar energy selectively heating various areas of the earth have a huge power potential. Unfortunately, winds are not available and steady in many places, and cost studies have indicated that wind power plants will not be nearly as low in cost as presently available fossil fuel fired plants. The next source of solar energy is direct sunlight shining on the land, which can in actuality be converted into usable power. The problem here is that no really economic method for converting solar energy into useful power has yet been developed, nor is it very likely to be. There are two simple reasons for this. One, you must collect the energy over a large area, and the collectors themselves cost a lot of money. Two, the sun shines only about 8 useful hours out of each 24. This means that energy storage must be used, and this is extremely costly.

The next possible source is solar energy entering the oceans, which cover 70% of the earth's surface. If we can convert the energy of the sun stored in the upper warm layers of the tropic oceans into useful power, then it can easily be shown that we can have a continuous supply of power roughly equal to three hundred times the present world's usage. This has the huge advantage that it is available over large areas on the earth and it is available 24 hours a day and 365 days in the year. Therefore, no storage problem is involved and the collector is free. Sea Solar Power then merely refers to utilizing the warm sun-heated surface waters of the ocean in a heat engine to convert this energy into useful power. Any heat engine works on the principle of heat flow from a higher temperature body to a lower temperature body. In the tropic ocean we have a warm surface layer directly above very cold waters a few thousand feet beneath the surface. If we can connect the warm surface water to the cold water underneath with a suitable heat engine, then we can develop vast amounts of power from this source of energy. We became convinced that this could be done on a practical, economic basis 12 years ago, and are now more convinced than ever. Numerous other investigators are also beginning to agree with us.

IN 1963

How does Sea Solar Power work? Fig. 1 shows a skeleton model of a Sea Solar Power Plant. You have a floating vessel supporting a power plant consisting of a turbine generator set, a boiler, a condenser and suitable pumps.

The $82^{\circ}F$ water is taken in at the surface of the ocean and pumped thru the boiler where it gives up some of its heat to reduce the temperature to, let's say $79^{\circ}F$ in the boiler. This heat is used to boil a high pressure fluid such as propane, ammonia or a halocarbon. The vapor boiled off from the fluid enters the turbine and expands thru the turbine to give up power to drive a generator. The exhaust vapor from the turbine at low pressure must be condensed on a cold surface. The cold condensing surface is cooled by cold water at $42^{\circ}F$ pumped up from deep in the ocean thru the condenser, where it absorbs the heat of condensation from the vapor. The condensed liquid is then pumped back thru the boiler to complete the circuit. Such a power plant is extremely simple, works essentially like any steam power plant, but operates with temperature differences of approximately 40 degrees whereas an ordinary steam plant operates with temperature differences of several thousand degrees F between the heat source and the heat sink. Because the sea thermal plant must operate at such low temperature differences, the thermal efficiency is extremely low, approximately 3%. However, since the fuel cost is zero then efficiency has no significance as far as fuel cost is concerned. However, efficiency is important in the sense that the higher the efficiency the less water you have to pump into the plant, and the lower the cost of the equipment to pump the water into the plant. To put it another way, higher efficiency should produce more saleable output per unit of capital investment. Since the fuel cost is zero we can consider this to be a capital intensive source of energy, and the economics depend primarily on whether you can make it operate successfully and what is the capital cost of the plant.

Fig. 2 shows a model of what a floating plant might look like in a 100 megawatt size. This model was built in 1965, Ref. 1. We have no reason to change the general configuration very much today. Essentially this is a ship's hull with a warm water intake right at the surface of the ocean designed to take advantage of maximum water temperatures right at the sunlit surface. The physical size of the inlet is pretty well determined by the amount of water $566\ m^3/s$ required to generate 100 megawatts of power. It requires approximately 20, 000 cubic feet per second of warm water to be pumped thru the boilers. This water must be brought in at a very low velocity to avoid plugging inlet screens with fish. It is also important to use the warmest possible water, very near the ocean surface. For example, one degree Fahrenheit drop in warm water temperature will reduce net plant output by approximately 7%. This is why the length of the vessel should be approximately 360 ft., or the size of a moderate sized ship. The warm water is pumped down thru the four pipes shown to the boilers which are suspended from the vessel at a depth of several hundred feet in the ocean. The reason for submerging the boiler to such a depth is to take advantage of water pressure being equal to working pressure inside the boiler. By doing this the pressure difference between the working fluid' and the water outside is very low, Let us now look at some other possibilities for Sea Solar Power. As stated before if you have available energy then you can (as you in the chemical industry know this better than anyone else) use this energy to convert a mixture of all kinds of chemicals into separated and useful forms. Since the ocean is in fact a vast cesspool containing a mixture of a large percentage of the various elements available on the earth, then it can be a natural source for many of these materials. Once we have the energy available from a Sea Solar Power Plant it doesn't require too much imagination to think that we can convert the waters in the ocean into many useful materials.

The first and obvious material that we can get from the ocean is fresh water. Fig. **4** shows a skeleton model of the principle that can be used to obtain fresh water from a Sea Solar Power Plant. After removing the air from the sea water it can be boiled at low pressure in a vacuum. Therefore after the water has been utilized to produce power it can be passed thru a vacuum evaporator and part of the water is flashed as shown in the flash chambers. We can pass the cold sea water leaving the condensers of the power plant thru a fresh water condenser, and the evaporated steam will condense directly into pure water on the cold surfaces. This then provides a very simple source of fresh water. It also provides the cheapest known source of fresh water from sea water that has so far been conceived. Our early estimates made in 1967 indicate that fresh water production costs should be as low as 4¢ per thousand gallons (Ref. **4).** This is cheap enough to permit such water to be used for irrigation. Desalted water usually sells for more than $1. 00 per thousand gallons. One 100 megawatt plant could make up to 150 million gallons of fresh water per day without using any water other than that which passes thru the plant. By increasing the supply of warm water and cold water above the needs for the power plant itself it is possible to produce up to 800 million gallons per day of fresh water from such a plant.

The next obvious product from a combined Sea Solar Power Plant and water plant is oxygen. Since you must remove the oxygen from the water in order to produce the fresh water, it is logical then to convert and separate this oxygen from the other gases and thereby have a low cost source of oxygen. The reason for this being a low cost source of oxygen is that the amount of oxygen in sea water at the surface is roughly 34% of the dissolved gases, whereas air has only 23% oxygen. Therefore, with a higher concentration of oxygen in the gases the process of separation can be considerably lower in cost than would be the case in separating oxygen from air. The Sea Solar Power Plant has [illegible]

The next gas available from sea water in abundant supply is carbon dioxide. Since carbon dioxide is concentrated in much higher percentages than it is in air, during the oxygen separation process you also automatically obtain carbon dioxide. Carbon dioxide is a saleable and useful product.

The next obviously obtainable product from water is hydrogen. With electric power and pure water available from a Sea Solar Power Plant, then electrolysis can be used to separate the water into hydrogen and oxygen. Since hydrogen is a basic building block for all kinds of useful chemicals, as well as being a most useful fuel, it is immediately obvious that sea solar power provides a very convenient source of hydrogen.

Having oxygen, carbon dioxide and hydrogen in huge quantities from a Sea Solar Power Plant, let us next look at some other possibilities: Fig. 5 shows a skeleton flow diagram for some of them. Starting at the left we have warm water and cold water coming together to produce power. This is the key to all of the other products. The warm water is deaerated, and liberates oxygen, carbon dioxide and nitrogen with desalted water producing fresh water, and the cold water returning to the sea. It is well known that cold water from deep in the ocean contains much more nutrients than the water at the surface. If you bring this cold water up as is done naturally by the Humboldt current off the coast of Peru, then you supply vast amounts of food for the marine life chain. Since the cold water that has been brought up is warmed during the process of producing power and fresh water, then its density has been reduced enough so that it will stay near the surface where the sun can provide photo-synthesis to convert these nutrients into food for plankton and the whole life chain of marine organisms, with usable fish food at the end of the chain.

As noted, we can produce hydrogen and oxygen from the fresh water by electrolysis. Direct combination of nitrogen and hydrogen produces ammonia. Direct combination of hydrogen and carbon dioxide produces methanol. We now have in one location a chemical factory that produces some of the most basic and needed chemicals known to man.

Hydrogen can be mixed directly with natural gas to extend our precious gas fuel supply. It can be used to produce liquid fuel from coal. Ammonia is presently made from hydrogen obtained from methane. Production of ammonia from nitrogen and hydrogen directly not only simplifies the process, but eliminates the usage of methane for this purpose. Ammonia is our most important and needed fertilizer for world food production.

It requires very little imagination to realize that the ocean water itself contains practically an infinite supply of many kinds of useful chemicals.

There are many plants already in use to separate some of these chemicals from the water, as I am sure most of you know. The science of separation of small quantities of chemical elements out of water has been improved greatly during the past few years, and I am sure that the availability of Sea Solar Power will accelerate this in the future. It is patently obvious that Sea Solar Power can indeed be the source of many of our needed chemicals in the future.

Let us now try to evaluate and quantify the production quantities of various products that could be obtained from a 100 megawatt Sea Solar Power Plant. Fig. 6 portrays the potential value of the various products in million dollars per year. The key product is power. Such a plant would produce annually approximately $17 million worth of power priced at 25 mills per kilowatt hour.

It is advisable to deaerate the warm water in order to prevent corrosion and fouling of the heat transfer surfaces. The main gases removed are carbon dioxide, oxygen, and nitrogen. All are directly separable from the gases taken out of the water by a refrigeration process. From the warm water used in the plant there is approximately $32 million worth of carbon dioxide, $5. 5 million worth of oxygen, and $6. 5 million worth of nitrogen available. Prices used are shown at the bottom of the chart, in dollars per ton.

Assuming that we have degasified the water, then it is an easy step to produce fresh water in the amount of 1% to 2% of the total warm water handled in passing thru the plant to develop the power. The value of the fresh water produced is approximately $11 million at 20¢ per thousand gallons. Water is easily transportable by barges to numerous shore points.

In the production of fresh water, we also add additional heat to the cold water coming from the power plant condensers. If this heat is added, then the density of the cold water is reduced sufficiently so that it will stay in the upper layers of the ocean, where photosynthesis can take place. This nutrient-rich water can then supply food for an enormous population of marine organisms and fish. Various estimates of how much fish could be produced have been made. Dr. Roels has demonstrated that one kilogram of edible fish can be produced from 300 metric tons of nutrient-laden cold water brought up from the depths (Ref. 5, 6). If we assume this ratio of fish to water, then we could produce $80 million worth of fish annually at a price of $1. 00 per pound. On the other hand if we assume a much more conservative estimate of 3700 tons of water per kilogram of fish then we would produce only $7 million worth of edible fish. The actual value is probably somewhere between these two extremes.

If we use the power to produce hydrogen, the value of the hydrogen producible at $1900 per ton is $33 million per year. In addition the oxygen produced from separation of the water increases the total amount of oxygen produced to $12 million per year.

If we elect to combine the hydrogen with carbon dioxide to produce methanol at 40¢ per gallon the output of the plant would be worth slightly more than $11 million per year. If we used the hydrogen to combine with nitrogen and produce ammonia, then the output at $170 per ton would be $17 million per year.

The shaded bars on the chart show products obtainable directly from the plant while still selling most of the power. Production of water, carbon dioxide, oxygen and nitrogen would use up a relatively small percentage of the power produced. On the other hand production of hydrogen, methanol or ammonia require direct usage of the power by electrolysis.

Not all of the products are additive in value since the last three items require direct usage of the power output for their production. However, the production of fresh water, carbon dioxide, oxygen, nitrogen and fish are almost directly additive to the output of power from the plant. From these figures it is easy to see that Sea Solar Power would be a bargain at almost any price.

How much will Sea Solar Power cost, compared to other sources of power? Since it has now been studied by a number of independent groups, we have at least a fair idea of what such plants should cost. Fig. 7 shows a comparison of oil fired, nuclear, and Sea Solar Power costs.

FIG. 7 - POWER COSTS

Type of Plant	Oil	Nuclear	SSP	SSP
Source of Costs	P. E.	P. E.	TRW	SSP
MW Capacity	2320	2320	100	100
Cost - Million Dollars	1308	2436	133	50
Cost - $/Kw	564	1050	1333	498
Fixed Costs $/Kw Yr.	85.30	164.87	294,70	115.00

O&M here is 2.38 of Capital

FIG. 7 - POWER COSTS (cont'd.)

Type of Plant	Oil	Nuclear	SSP	SSP
Load Factor	.80	.80	.90	.90
Fuel Cost $/MM BTU	3.54	.385	0	0
Power Cost Mills/Kwh	44.5	27.3	37.5	14.7

The costs for oil fired plants and nuclear plants were taken directly from an official estimate furnished by the Philadelphia Electric Co. to the Public Utilities Commission of Pennsylvania. This eatimate was dated. January 7, 1975.

The first column for Sea Solar Power was taken from an estimate by TRW in a comprehensive study for the National Science Foundation (Ref. 6). This estimate represents an initial estimate of costs of a plant based on presently available technology, without any extensive building and operating experience, and without expected development and improvements.

The second column for Sea Solar Power was taken from our own estimate of 1965 multiplied by three to allow for inflation. Most estimates from various studies fall between the two sets of figures shown.

Note that the cost estimates for Sea Solar plants are made for 100 Mw plants, whereas the others are made for 2360 Mw plants. It is probable that a most effective size for Sea Solar plants will be in the 200 Mw to 600 Mw range, and they should be less costly per Kw than the 100 Mw size. Note also that nuclear power costs are based on 80% load factor, yet nuclear plants today average less than 60% load factor, after 18 years experience! If you correct nuclear power costs on the basis of 60% load factor, then the costs would go up to 35.15 mills per KwH.

It is clear that Sea Solar Power can be competitive with other forms of power, even in its early stages of development. When you add on its production of fresh water, food and chemicals, it becomes a real bargain.

The AEC presently projects the development cost of the first breeder reactor to be $10 billion. Environmentally safe Sea Solar Power can be developed for a tiny fraction of that amount. When you consider the great need and the many obvious benefits, it becomes clear that this is both the best bargain and the most important technical project facing us in this country.

The chemical industry, if it will, can be the real force to bring this development to fulfillment.

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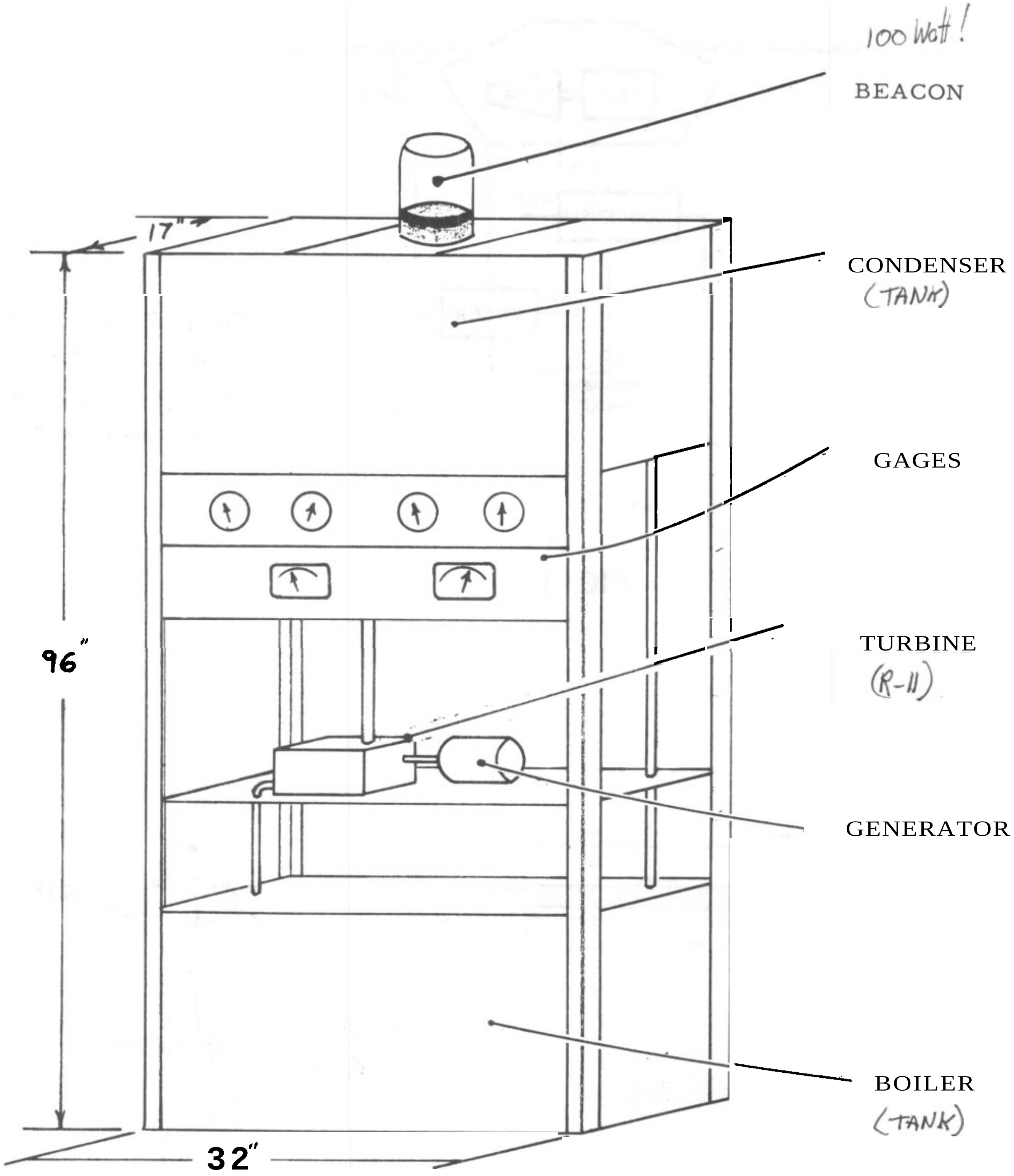
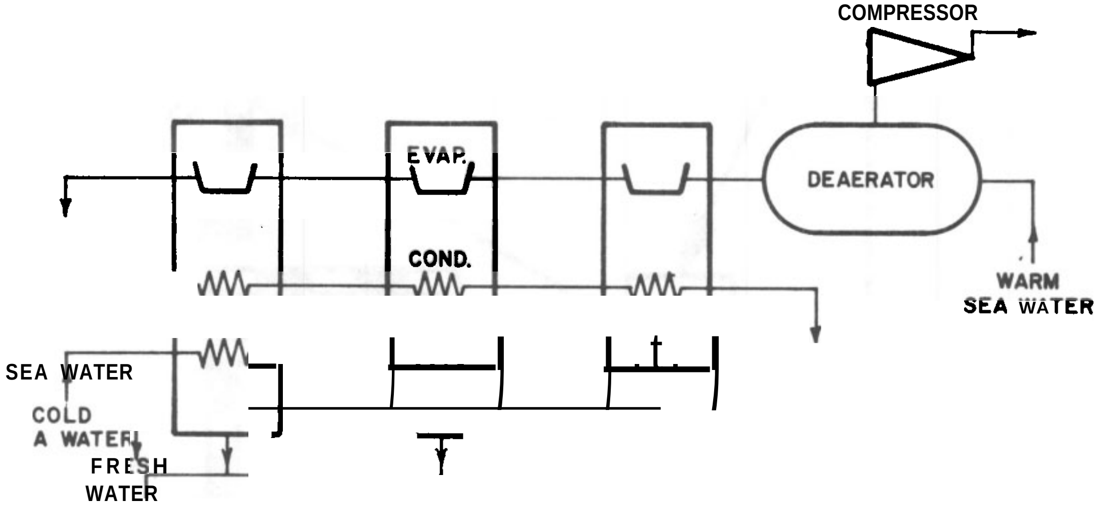

100 Watt!
BEACON
CONDENSER
(TANK)
GAGES
TURBINE
(R-11)
GENERATOR
BOILER
(TANK)
17"
96"
32"

FIG. 3



WATER DESALTING PLANT

FIG. 4

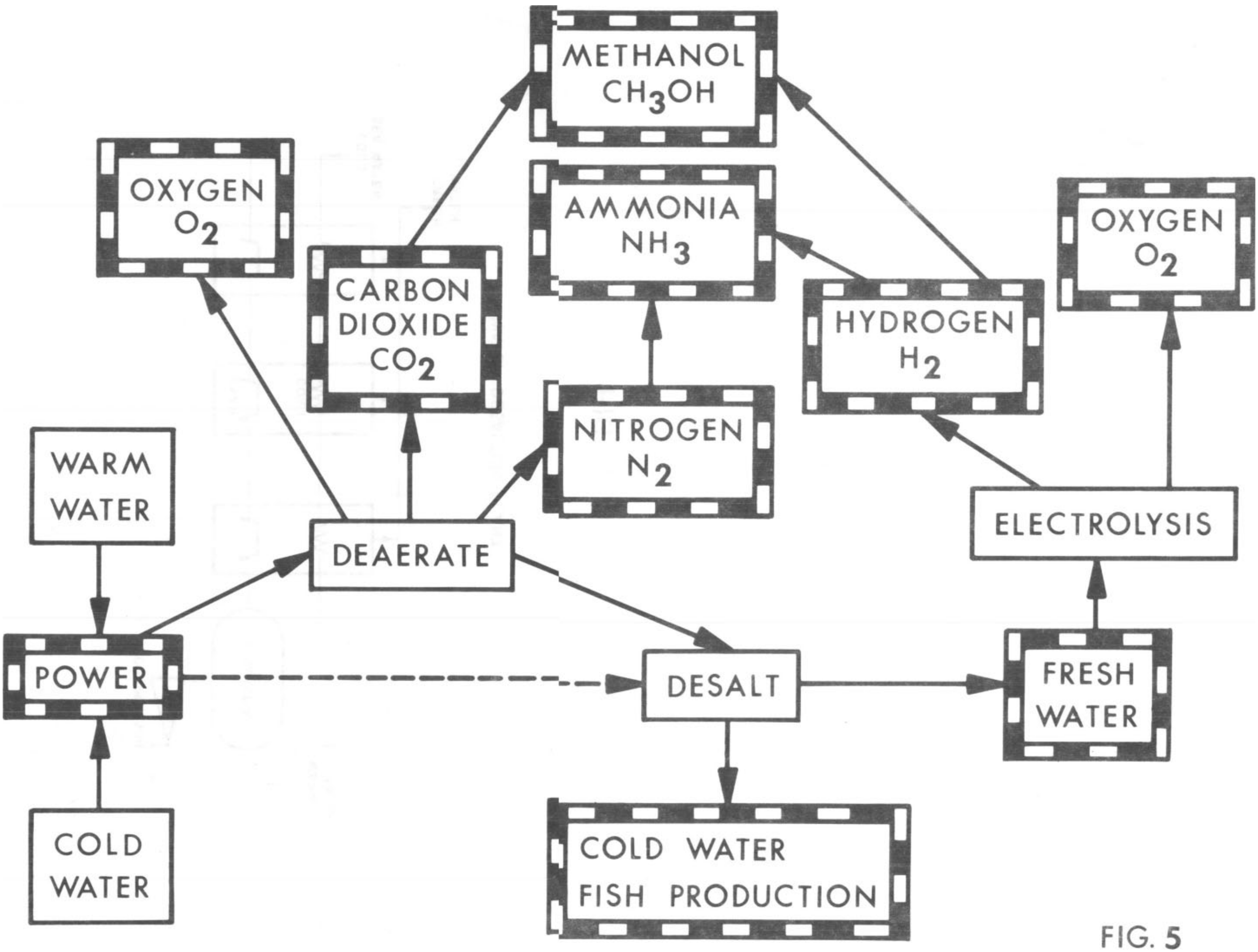
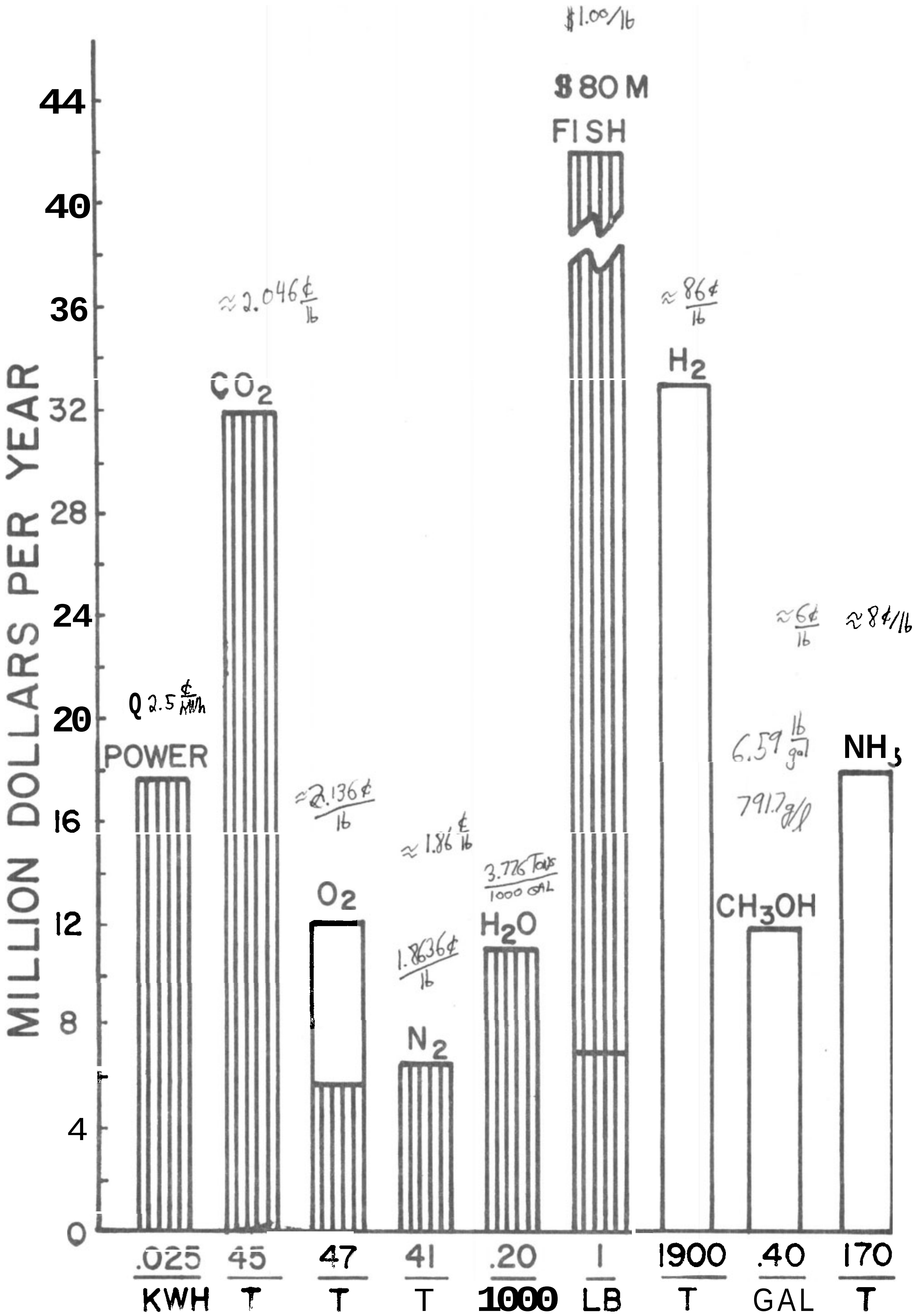

METHANOL
CH3OH
OXYGEN
O2
AMMONIA
NH3
OXYGEN
O2
CARBON
DIOXIDE
CO2
HYDROGEN
H2
NITROGEN
N2
WARM
WATER
ELECTROLYSIS
DEAERATE
POWER
DESALT
FRESH
WATER
COLD
WATER
COLD WATER
FISH PRODUCTION

FIG. 5



MILLION DOLLARS PER YEAR
0
4
8
12
16
20
24
28
32
36
40
44
POWER
CO2
O2
N2
H2O
FISH
$80M
$1.00/lb
H2
CH3OH
NH3
.025 KWH
45 T
47 T
41 T
.20 1000
1 LB
1900 T
.40 GAL
170 T
Q 2.5 ¢/kWh
≈2.046¢/lb
≈2.136¢/lb
≈1.86¢/lb
1.8636¢/lb
3.776 Tons/1000 GAL
≈86¢/lb
≈6¢/lb
≈8¢/lb
6.59 lb/gal
791.7g/l

FIG. 6