SOLAR ENERGY CONVERSION *

By

DR. RUBEN A. GARCIA**

I. *GENERAL CONSIDERATIONS*

The inflow of solar radiation warms the earth's surface and atmosphere, drives the winds and ocean currents, and produces through photosynthesis all the food, fuel and free oxygen on which life depends.

In the past, solar radiation provided a major share of the total energy used in preindustrial and early industrial societies. As wind, it served to grind the grain, pump the water and propel the ships. Converted to firewood, it heated homes and other buildings, cooked foods and provided steam for industrial heat engines. As the forests disappeared, man turned to coal and other fossil fuels to meet the increasing demand for cheap energy. Coal and other fossil fuels may be considered indirect effects of solar energy. It took mother nature millions of years to produce what we now call as coal and oil reserves.

A return to some limited reliance on direct utilization of solar energy would mean a turn toward familiar technologies.

Figure 1 shows a flow diagram of our potential sources of solar energy: direct radiation, wind, ocean thermal gradient, and organic forms. Each has its own unique characteristics and its own potential time scale. None is likely to have any major impact in the next 10 years but increased efforts in R & D activity will insure that a number of pilot projects will be in operation within a decade.

II. *THE PHILIPPINE ENERGY SCENARIO*

It is estimated that in 1977, our total energy consumption was around 83 million barrels oil equivalent (M.bbls.OE). This does not include energy from burning firewood, etc. We imported fuel oil to the tune of $1 billion during that year. This represents 95% of

---

* Presented at the NEC-EDPITAF Seminar on Mechanical Engineering, August 1979 at the University of Negros Occidental Recoletos, Bacolod City.

** Professor and Chairman, M.E. Department, College of Engineering, University of the Philippines our total energy requirement. In 1973, our fuel oil bill was only #231.000. With the present trend, the Ministry of Energy estimates that our energy consumption will reach 127 M.bbls. (O.E.) in 1982 and 190 M.bbls. in 1987.

TABLE 1. *Total Energy Consumption and Sources Profile*

Total energy consumption consumption M.bbls. oil equiv.		*Sources %*					*Non- Con- ventional*
		Oil	*Hydro*	*Geo- thermal*	*Nuclear*	*Coal*	
1977	82.9	94.7	4.3	—	—	1.0	—
1982	127.1	84.3	5.2	4.4	—	4.1	2.0
1987	190.0	67.4	12.2	4.4	3.4	5.4	5.2

Table 1 shows the predicted total energy requirements up to 1987 and the expected contribution from the major sources as predicted by the Ministry of Energy. Although the percentage contribution of fuel oil decreases from 95% in 1977 to 67% in 1987, the absolute quantity of fuel oil needed increases from 79 M.bbls to 107 M.bbls in 1982 and 132 M.bbls in 1987. Energy from hydroelectric power is expected to increase by 1982 and increase again by 1987 increasing its overall share from the 4.3% to 12.2%. Similarly, nuclear energy will supply 3.4% by 1987. Coal will also be tapped and will supply about the same order of magnitude as that of hydro and geothermal sources by 1987.

There is a need to accelerate development of alternative energy sources and special efforts should be aimed at the development of non-depletable or renewable energy sources. One such source is the energy from the sun.

III. *SOLAR ENERGY AVAILABILITY*

Solar energy arrives at the outer limits of our atmosphere at a practically constant value of 429 btu/hr/ft^2. Even on clear days, this solar radiation is depleted as it passes through the atmosphere on its way to the earth's surface. It is a split into 3 parts: one part is (1) turned aside by air molecules, water vapor molecules, and dust particles and is scattered in all directions; (2) a second part is absorbed chiefly by water vapor and ozone; and (3) the remainder passes through the atmosphere unchanged and reaches the earth's surface as direct radiation. A portion of the scattered radiation reaches the earth's surface as diffuse radiation. Typically, the total solar radiation (direct and diffuse) that reaches the earth's surface is in the order of 300 Btu/hr/ft^2 at noon time on a clear day, 20 to 30 Btu/hr/ft^2 of which is diffuse radiation. Assuming that we receive solar radiation (insolation) at an average rate of around 1,800 Btu/ft^2/day on a clear day and assuming further a yearly average sunshine of 50%, then the net insulation received per year is 3.53 x 10^{12} Btu per sq. km. At 20% conversion efficiency, only about 2,300 sq. km. (less than 1% of our total land area) is needed to produce the energy equivalent to that of the 1.17 x 10^8 bbls of oil that we anticipate to import in 1987 or 3,400 sq.km. to produce all the energy requirements in 1987. These estimates show that if we can set aside just around 1% of our land area for solar energy collection, we would theoretically be self sufficient in energy supply by 1987.

It may, however, be unrealistic to expect solar energy as our sole source of energy in the near future unless we classify hydro and geothermal sources as energies that are essentially brought about by solar energy. Solar energy systems therefore offer the potential of an important contribution to self-sufficiency and eventually capable of supplying major portion of our energy requirements.

The sun is a continuing source of domestically available energy. There appear to be no insurmountable technical barriers to its implementation and several systems show early promise of achieving cost competitiveness with conventional systems. Sociological and environmental impacts resulting from the utilization of solar energy are expected to be relatively small. Because solar energy is available over the entire country, it is possible to provide either small individual or integrated solar energy systems at points of use or large central power stations with associated distribution networks. Disperse systems are less vulnerable to single point failures or damage compared to large central power systems.

However, solar energy as presented so far ignored the very real problems associated with its use or utilization. Because of its intermittent nature with variations caused by weather and with daily and seasonal changes, energy storage or back-up power is needed to provide adequate continuity or reliability at night or when the sun is obscured. A second major problem is the low density or its relatively dilute form requiring large collection areas and structures. Finally, solar energy systems have relatively low efficiencies. Thus, even though the "fuel" itself is free, the capital investment for collecting, storing, and transforming the energy is high.

In considering the cost competitiveness of solar energy systems, one needs to take into account life cycle costs, including fuel and environmental impact costs, in addition to initial capital expenditures. When this is done, solar energy systems are expected to be economically competitive with conventional systems sooner than if capital outlays and fuel costs alone are considered.

IV. *TECHNICAL FEASIBILITY AND ECONOMIC VIABILITY*

Solar energy encompasses a rather wide range of technologies. Heating and cooling of buildings can be accomplished by converting solar energy incident on a collector surface to thermal energy in a working fluid which transfers heat energy to a storage system and used directly for heating (or hot water) or used to operate a heat-operated refrigeration equipment for cooling. Solar thermal conversion systems collect solar radiation and convert it to thermal energy for use as process heat or electric power generation. Wind energy conversion systems are composed of a rotor devise to absorb kinetic wind energy to produce mechanical/electrical energy. Bioconversion converts plant matter and solid wastes directly into heat energy by combustion, to other forms of fuels by pyrolysis, fermentation, etc. In ocean thermal conversion mechanical power is derived from a heat-operated power plant using the temperature gradient between the surface water and the cold water underneath. Photovoltaic electric power uses semi-conductor and photo-chemical devices to convert sunlight directly into DC electricity or fuel gas.

The technical feasibility of several of these applications has already been demonstrated. Solar energy for space heating and/or cooling purposes and windmills have been in use in various parts of the world as early as the turn of the century. Parabolic collectors, similar to those being considered for solar thermal conversion systems, provided steam for irrigation pumping in Egypt in 1913. Current efforts are focused on building reliable, low cost systems that can be installed and used in a variety of ways.

Wind energy systems should be economically viable within a few years. If the aerodynamic technology developed over the last 30 years were applied, the system cost could be dramatically reduced and market applications would be greatly increased.

Photovoltaic sytsems (solar cells) are expected to have applications in major market areas-the dispersed, on-site ("roof-top") uses and the small-to-moderate size (entral-power-station facilities).

Bioconversion of fuels includes both near term and long term applications. Recycling of urban and agricultural wastes is now providing energy in some areas, while large biomass forms, both terrestial and marines, are longer range propacts.

The economic viability for these different applications will occur in different stages, but cost reductions will depend more on market volume than on technological breakthrough. Indeed, economic viability for much of the dispersed market could be achieved by 1980 without any technological breakthroughs. However, considerable R & D would be required to achieve economic viability or photovoltaics for central power stations by the mid 1980's or early 1990's.

Solar thermal systems and ocean thermal systems require either substantial research or engineering developments.

With the exception of bioconversion and ocean thermal conversion, all solar energy systems require some storage capability. Conventional backup systems must be utilized to the extent storage is inadequate during periods of no insolation or wind.

Full utilization of solar energy technologies could significantly reduce pollution levels. The environmental impacts of solar energy systems should be lower than those of conventional energy sources because solar systems are, by nature, essentially clean environmentally. There are, however, some land use and aesthetic problems associated with solar collectors.

V. *DIRECT RADIATION*

Referring again to Fig. 1, direct solar radiation conversion may be used to heat an object directly, as with a home water heater, or to heat a working fluid that may be used to develop power in a heat engine or to transfer heat to the ultimate receiver (Figures 2 & 3), or direct radiation falling on photovoltaic cells directly converted to DC electrical power.

V-1. Solar Collectors

Table 2 shows classification of solar collectors according to ranges of temperatures usually obtainable.

TABLE 2. *Classification of Solar Collectors*

Category	*Example*	*Temp. Range °F*	*Efficiency*
No concentration	Flat Plates	150-300	30-50
Medium concentration	Parabolic Cylinder	500-1200	50-70
High Concentration	Parabodial	1000-4000	60-75

The type of device used to collect solar energy depends primarily on the application. Flat plate collectors are used for low temperature application such as heating water, building heating and cooling with absorption refrigeration. The flat plate collector consist of a black

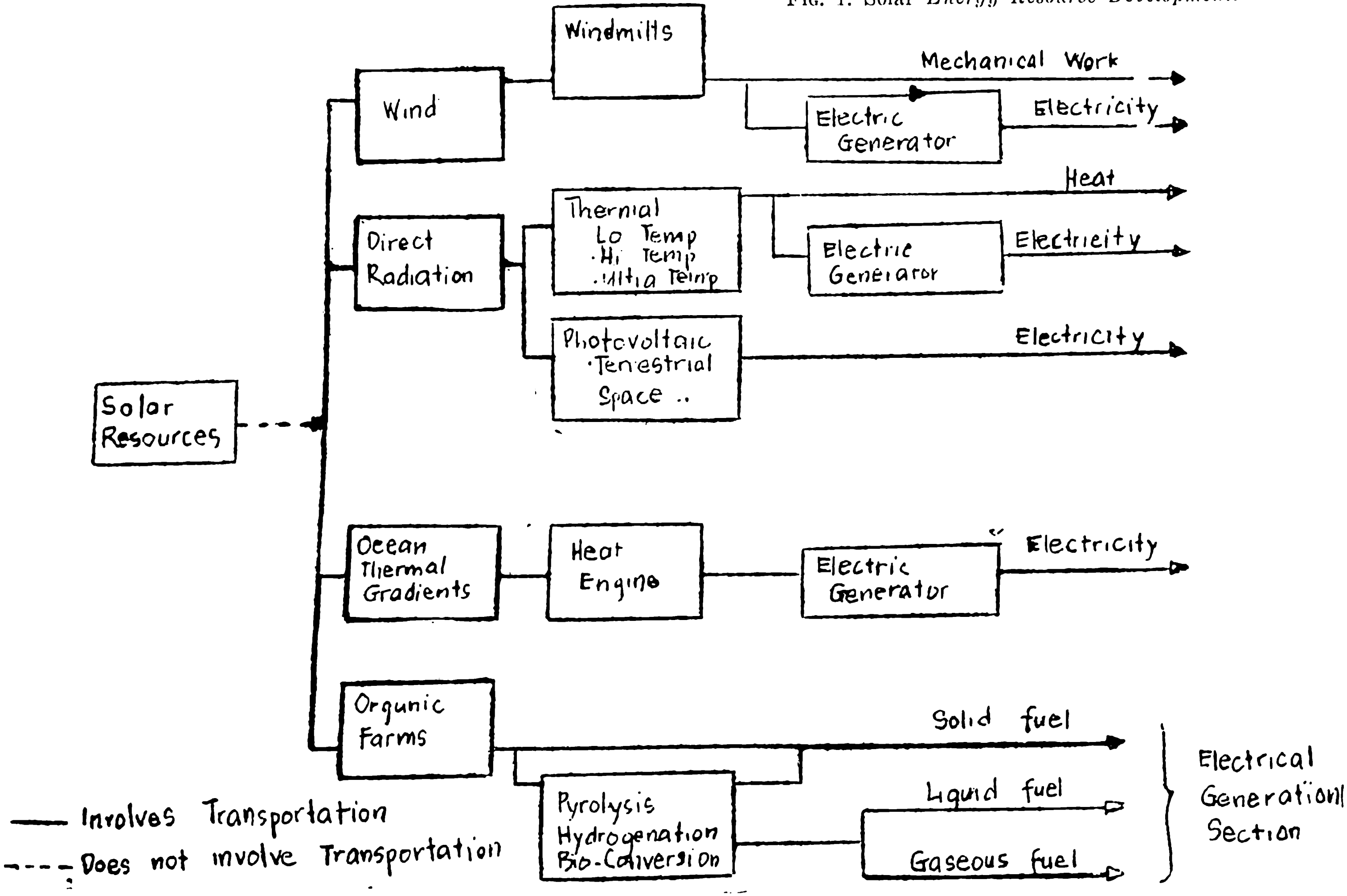


FIG. 1. Solar *Energy Resource Development.*

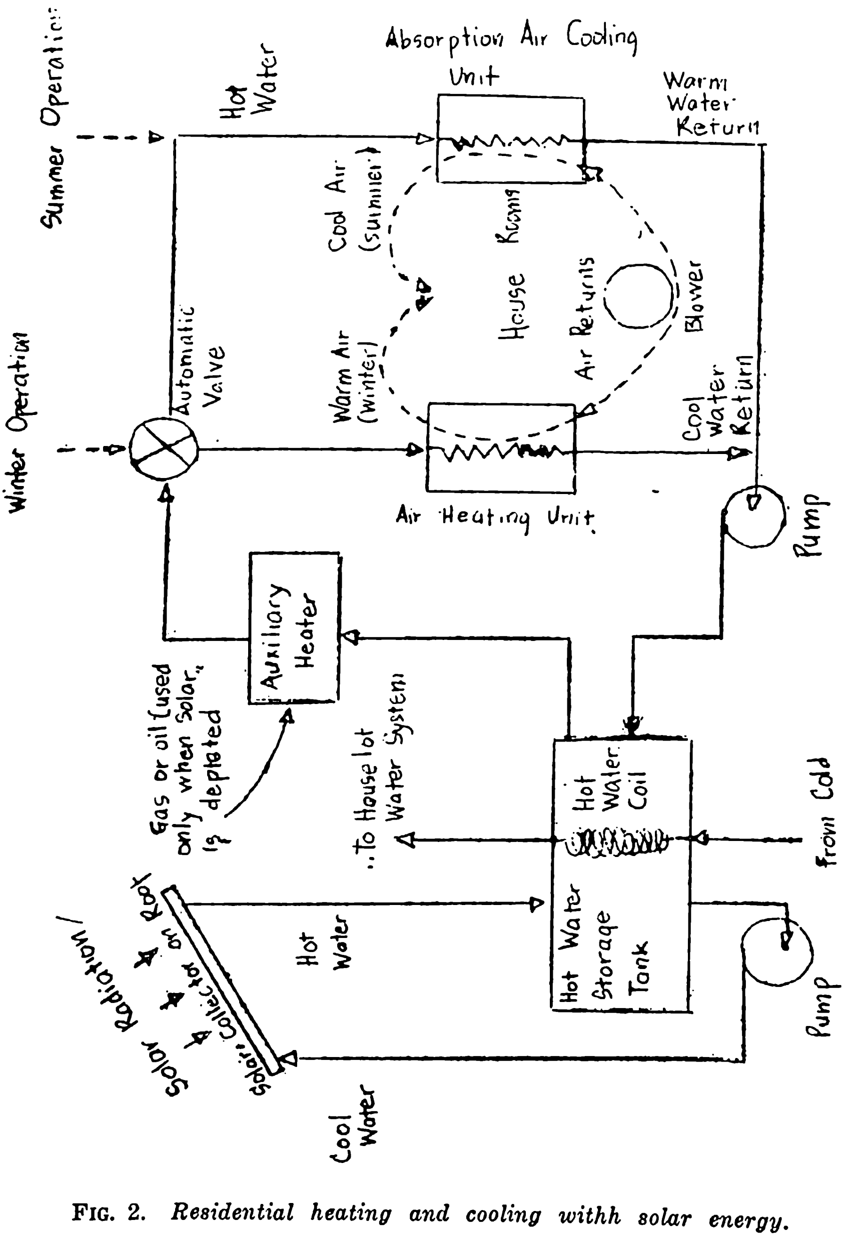


FIG. 2. *Residential heating and cooling withh solar energy.*

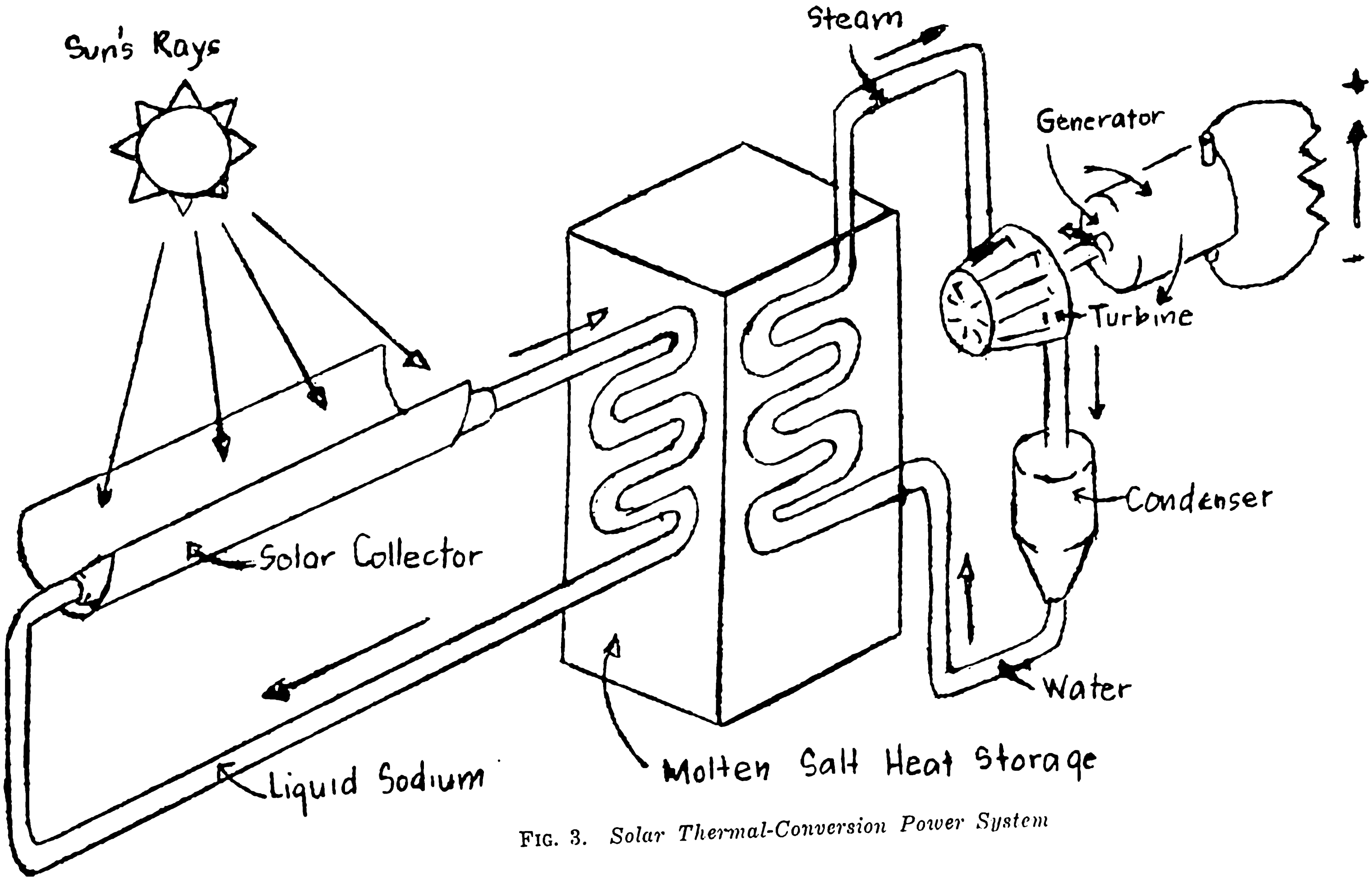


FIG. 3. *Solar Thermal-Conversion Power System*

plate covered by one or more transparent cover plates of glass or plastic, and the sides and bottom of the box are insulated. Sunlight is transmitted through the transparent covers and absorbed by the black surface. The covers are usually transparent to solar radiation but tend to be opaque to infrared radiation from the place and also minimize convective heat transfer from the plate. Water is commonly used as the thermal medium but air is also used directly for heating residences. Generally, collection efficiency decreases with increasing fluid temperature. Some improvements have been claimed when a selective coating was applied to the collecting surface, instead of flat black paint.

One of the earliest uses of low-temperature solar radiation was to distill salt from the brackish water to produce potable drinking water.

Another potential use of low-temperature solar collectors is for drying agricultural products. Our farmers have been using this method in its crudest form.

Solar Concentrators may be used to produce temperatures in excess of 300°F for efficient electrical power generation, for agricultural and industrial drying, and for other applications where high temperatures are needed such as solar furnaces which are at present primarily used for research on high-temperature refractory materials. The major advantage of extremely high temperature solar concentrators is their potential for high conversion efficiencies for thermal conversion power systems (see Figure 3).

V-2. Photovoltaic Cells

The photovoltaic convertor, a silicon solar cell, was developed in 1954 by Bell Laboratories as an outgrowth of previous work in the transistor. It converts solar radiation directly into electrical current. Used first on an American satellite in 1958, solar cells have now become the major source of power for space vehicles which are required to operate reliably for long periods of time. Their high cost has limited their use for terrestial power generation and results from the fact that individual silicon cells must be made from single crystals. It has been estimated that solar cell costs must be reduced by a factor of 1,000 before they become economically feasible for large-scale generation.

Figure 4 shows cost projections for solar cells as a function of total production. Recent successes in the growth of continuous crystals and the abundance of the silicon base material give some hope for achieving appreciably lower costs in the short-term future.

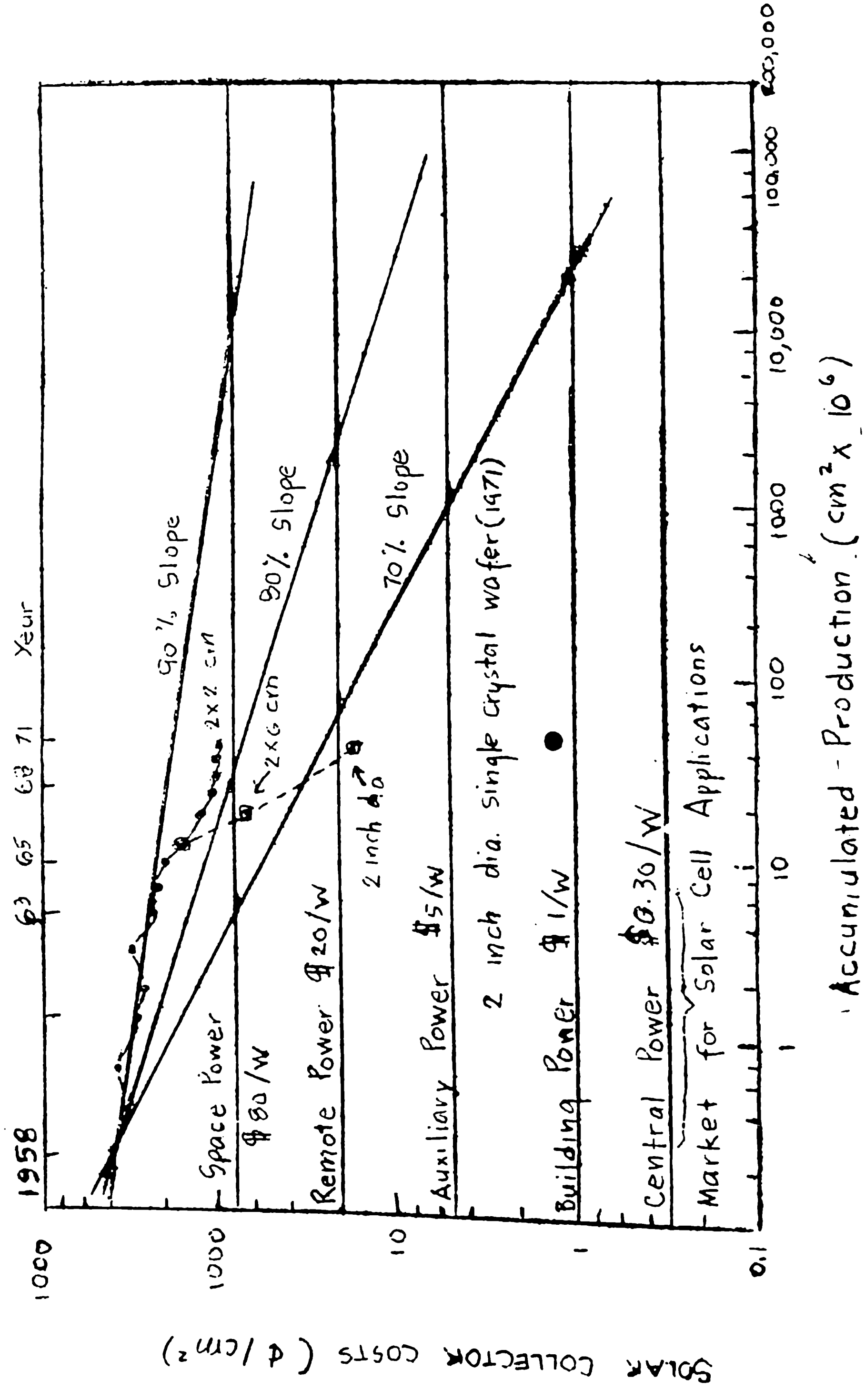


FIG. 4. *Silicon Solar Cell Cost Projections.*

To avoid losses due to atmospheric attenuation and the nighttime outage, proposals have been made to place large arrays of solar cells in a near-equatorial synchronous orbit where the sun would shine on them nearly 100% of the time. The direct current power obtained from the photovoltaic arrays would then be converted into microwave power, beamed to large receivers on the surface of the earth, and there converted back to DC power. The concept envisions 32 sq. km. of solar cells in each satellite station and an area of 55 sq. km. for each ground receiver. It has been estimated that a satellite system of this size would provide 10,000 mega-watts-electric (M_{we}). The principle is illustrated in Figure 5.

The technical developments required to make this power stations feasible are so formidable that such stations are not likely to play any part in supplying energy for the forseeable future.

V-3. Energy Efficiencies

In discussing efficiency for solar-related energy sources, it is important to recognize that the input energy is free and essentially inexhaustible. Thus the conversion efficiency has less effect on direct operating costs than it does for conventional fossil fuel plants. Conversion efficiency does, however, influence the size of the facility required to produce a given amount of energy. As a consequence, it has a great deal to do with capital investment and overhead costs. When solar energy is used for direct heating, conversion efficiencies can be relatively high, with a maximum between 60 and 70%. When solar radiation is used to generate electricity, the combined efficiency of collectors, storage, heat engines, and the associated electrical equipment is not likely to exceed 20%. The overall efficiency of photovoltaic generators is not likely to exceed 10%.

It is predicted that research on advanced thin film technology will establish the feasibility of producing thin-film solar cells of 10% efficiency at $100/peak kw by the late 1980's. Such cells could be used in arrays with some light concentration, to produce systems efficiencies of 16% to 20%.

V-4. Environmental consideration

The residuals associated with solar space heating are negligible. The net heat residuals for solar electrical power generation are also negligible, but solar heat will be removed from the collection area and transferred to the generating plant in the form of heated wastewater and electrical output. As a result, there may be some localized thermal pollution as in fossil-fueled electric generation plants.

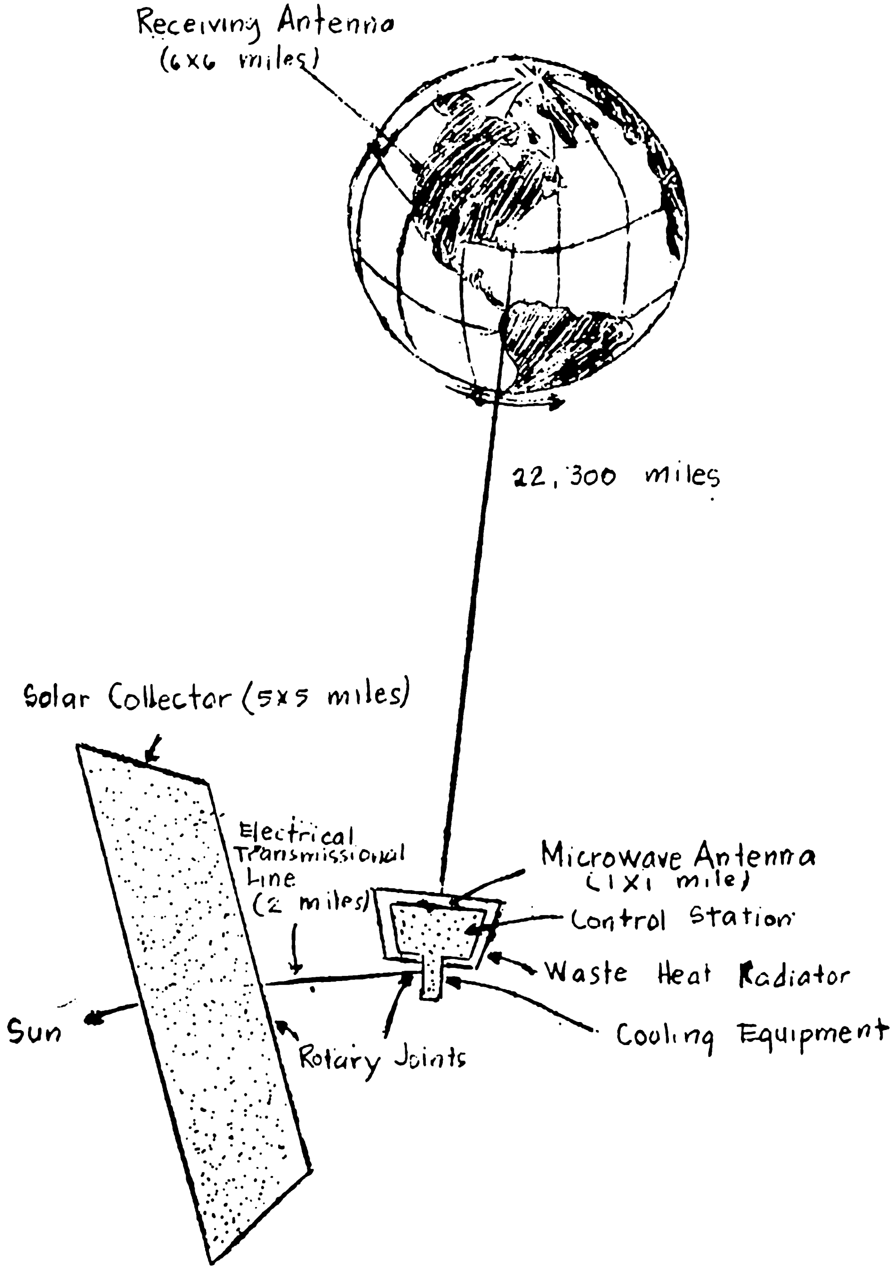


FIG. 5. *Satellite Solar Power Station.*

The development of land into solar forms will involve some damages to the local ecosystems as a result of road-building, grading, and the installation of the facilities.

V-5. Economic Considerations

Two factors that greatly affect the economics of direct solar conversion are its relatively low density and its intermittent nature. The former imposes a need for large collection area with a correspondingly high capital investment. The latter requires either large scale storage subsystem or sufficient back-up capacity to meet the energy demand when solar radiation is low or nonexistent.

For a given output, the capital investment required for a conventional fossil-fueled plant is determined largely by system efficiency and load factor. For fossil and nuclear plants, load factors of 50 to 85% are common. Solar plants, restricted to daylight use, operate at load factors on the order of 20 to 25%. Thus, capital investment in a solar plant is likely to be relatively high.

As a consequence of intermittency, the installed capacity of a solar power plant must be somewhere between 3 to 6 times the capacity of an equivalent fossil-fueled power plant for a given annual output.

Although operating costs are expected to be low, the authorization of capital investment will represent a major share of generating costs. Installed costs are expected to compare favorably with breeder nuclear power plants.

For photovoltaic conversion systems, it is expected that by 1985, a 1 kw sytsem will cost $4000 producing electricity at 40 to 80 mills/kwh. This will substantially reduce to 20 to 46 mills/kwh by 1995. Also by 1995, central photovoltaic conversion statons with average power of 10,000 kw requiring 4.2×10^6 ft^2 area at a system cost of $1400/kw average will produce electricity at 22 to 43 mills/kwh.

VI. *WIND ENERGY CONVERSION SYSTEMS (WECS)*

At the most general level about two percent of all solar radiation to the earth is converted to wind energy in the atmosphere.

Although the conversion of solar energy to wind energy takes place at all levels, 30% of the wind energy is generated in the lowest 3,000 ft of the atmosphere. Only a small part of the energy flux in the lower level is available for conversation to a form of power directly useful to man.

As energy is removed from winds close to the ground kinetic energy is transferred downward from higher altitudes through the energy transfer mechanism of the earth's boundary layer. Thus, the lower atmosphere from which energy is removed is continually replenished by natural meteorological processes.

Wind energy systems should be located where strong but constant wind velocities are found. Locations frequented by strong typhoons should, however be avoided.

In the case of conventional windmills, the output from the rotor is directly proportional to the square of the blade diameter and the cube of the wind velocity. The potential range of the output is thus relatively large for modest changes in size or operating conditions.

Conventional rotor-style windmills retain the basic configuration that has been used for thousands of years of pump water and grind grain. A schematic diagram of a typical modern windrotor system is shown in Figure 6.

Although a windrotor's output is proportional to the wind velocity cubed, it is often not economical to design the electrical generating equipment to absorb all the rotor power at maximum possible wind speeds. Since high winds occur infrequently, it is more cost effective to use a smaller generator which maintains a constant output at all speeds above it designed wind velocity. This is known as flat rating.

Windpower generators operate at their installed capacity only when the wind is blowing at or above their flat-rate wind speed. As a consequence, a typical windpower generator operates at an overall load factor between 15 and 25%, only about 1/4 that of a typical fossil-fueled plant. Thus, for a given annual power output, the windpower generator will need approximately four times the installed capacity of a conventional steam plant.

Wind variability affects the rotor speed which in turn affects the output frequency of the generator. Since existing power networks and many machines and appliances operate only at constant freqency AC, some means for regulating the output frequency is required.

In general, the components of a WECS have relatively modest technical requirements. Many are available as the off-the-shelf items. The integration of these components into an efficient system will require engineering and development but the design problem is largely of demonstration rather than research.

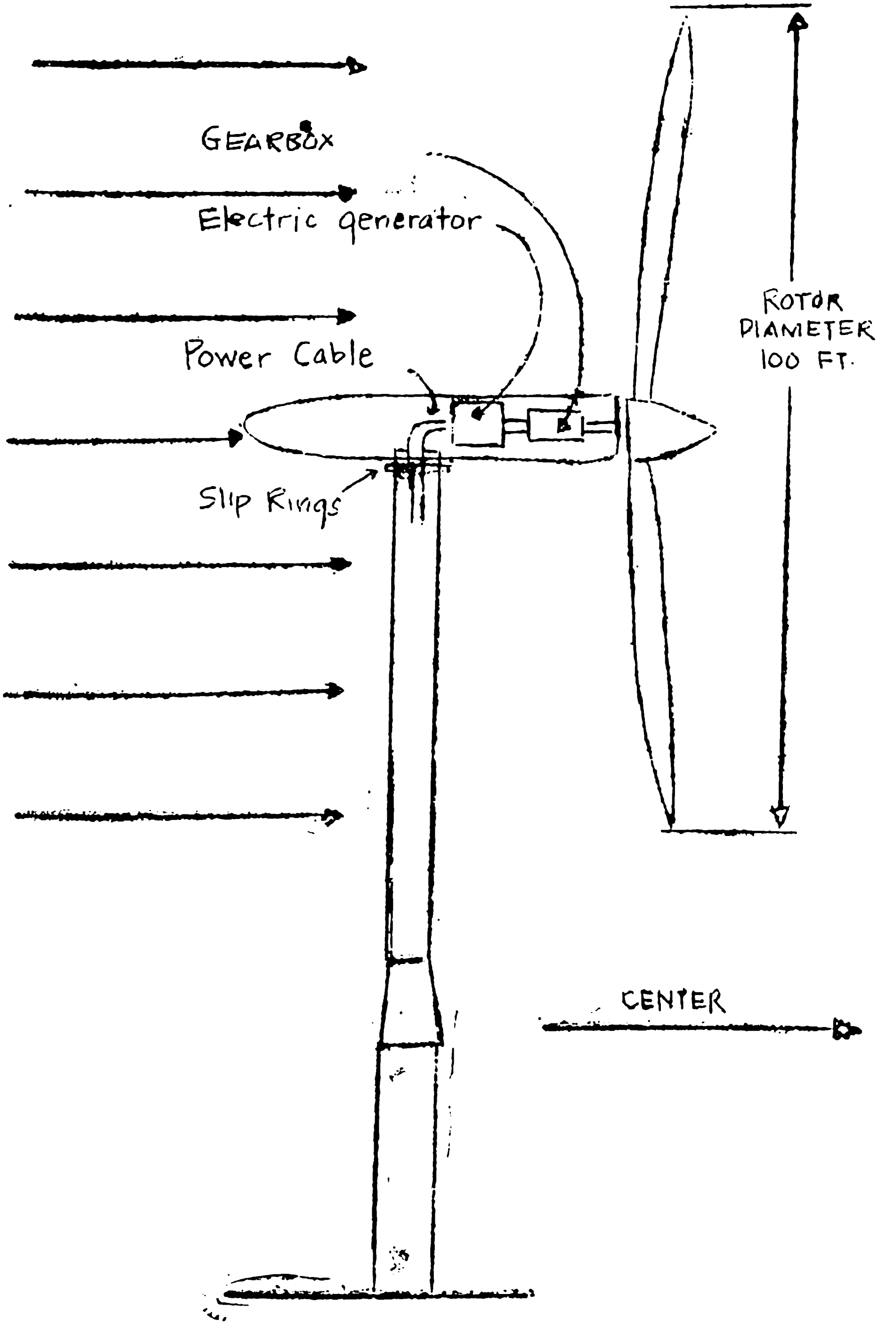


FIG. 6. *Typical Wind Rotor System.*

For large scale, central power application, there is much to recommend straight forward energy farms, each covered with a grind of identical wind generating units. Aside from the relative simplicity of the concept, it takes advantage of mass production economics and simplifies the development and demonstration of basic windpower units.

Small scale applications are also promising. A ten-foot rotor will recharge a small electric car overnight. A 25-foot rotor will provide enough energy for an all electric single family home.

VI-1. Energy Efficiencies

The maximum theoretical energy recovery for any wind-driven device is about 60% of the energy contained in the air stream intercepted. Blade inefficiencies and mechanical losses reduce the theoretical recovery to a maximum of about 40%. The overall wind efficiency of an individual rotor generating system is not likely to exceed 35%, and may be less. As noted before, efficiency has very little effect on direct operating costs but does influence capital investment and overhead costs.

VI-2. Environmental Consideration

Windpower has no significant environmental residuals. It produces no waste heat and, for most part is compatible with multiple land uses, including farming.

Windpower has no significant environmental residuals. It produces no waste heat and, for most part is compatible with multiple land uses, including farming.

On the matter of aesthetics, some people may find the prospect of giant towers across the landscape to be distasteful no matter how great their dedication to non-polluting energy system.

VI-3. Economic Considerations

The initial unit costs for wind power generators is high as with any new technology. Until the inevitable bugs are worked out of prototype systems, the operating costs will also be high. Assuming that these early hurdles can be passed successfully, it has been estimated that windpower generating systems can be built for about $150 to $200 per installed KW. This compares with today's cost of $200 to $250 for conventional fuel plants and $500 for conventional nukes (1974 prices). For the same annual output, the windpower system will require 3 to 4 times the capacity of the other two systems. Initial capital investment will therefore roughly in proportion.

Figure 7 shows the expected selling price of wind turbine as a function of rated KW. Figure 8 shows breakeven costs between wind turbines and price of oil.

VII. *ORGANIC FARMS*

A pound of dry plant tissue will yield about 7,500 Btu's of heat when burned directly. A ton of dry biomass, when heated in the absence of air will produce 1.25 barrels of oil, 1,200 cu. ft. of medium Btu gas, and 750 pound of solid residue with heat content roughly equal to that of coal. By adjusting the process temperatures and pressures, the relative amount of solid, liquid and gass generated can be varied to meet end-use requirements.

Although attractive from many standpoints, the growing of plants for energy generation is relatively inefficient. The solar conversion efficiency of the photosynthesis process is seldom over 3% during the growing season. A year-round average of just over 1% is typical for most high yield crops. As a result, the land required for a given energy output is very high relative to other solar power sources.

Based on an NSDB-Supported "Feasibility Study of the Utilization of Forests of Generating Electricity", conducted by Forest Products Research and Industries Development Commission (FORPRIDCOM) few years ago, around 280 sq. km. of forest is needed to support a 100 M Wc. generating plant using fast growing Ipil-ipil on a 3-year rotation.

In the United States, farm productivity per acree has tripled for the same area since 1934 and the output per man-hour has increased seven-fold. Machines have replaced farm animals, hybridized and generically manipulated seed have replaced the best of the "natural" grains, and modern forestry practices have increased productivity dramatically. It is this change which has made it possible to seriously consider the development of energy plantations as partial substitutes for fossil fuels. The equipment required for energy production is well developed and in continual state of improvement.

High yield agriculture demands high insolation, adequate water supplies, and availability of nutrients, either through natural soil conditions or the use of fertilizer.

The similarity of energy forest technology to existing fossil fuel generating system could be expected to reduce the problems

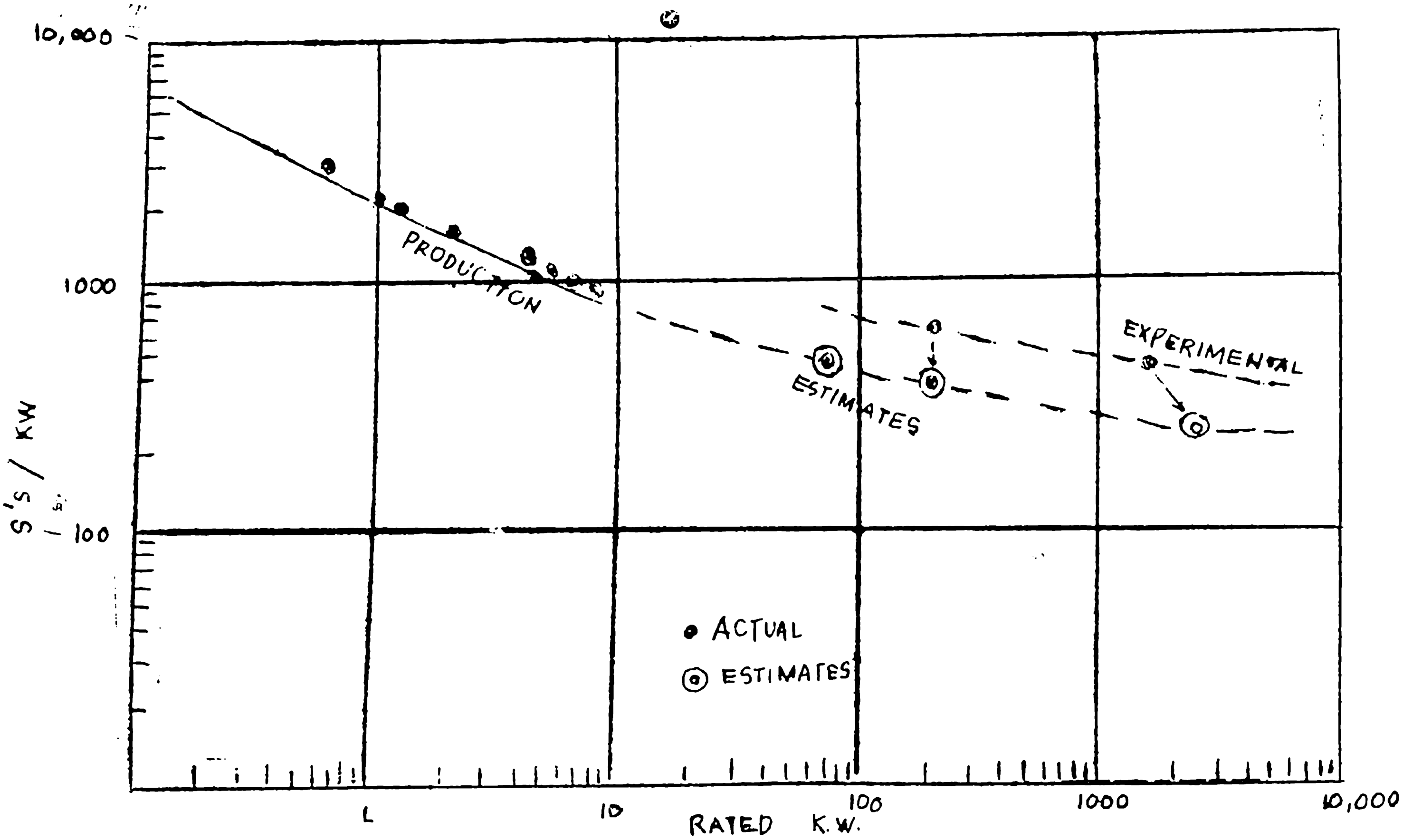


FIG. 7. *Expected Wind Turbine Sell Price 1973 Dollars.*

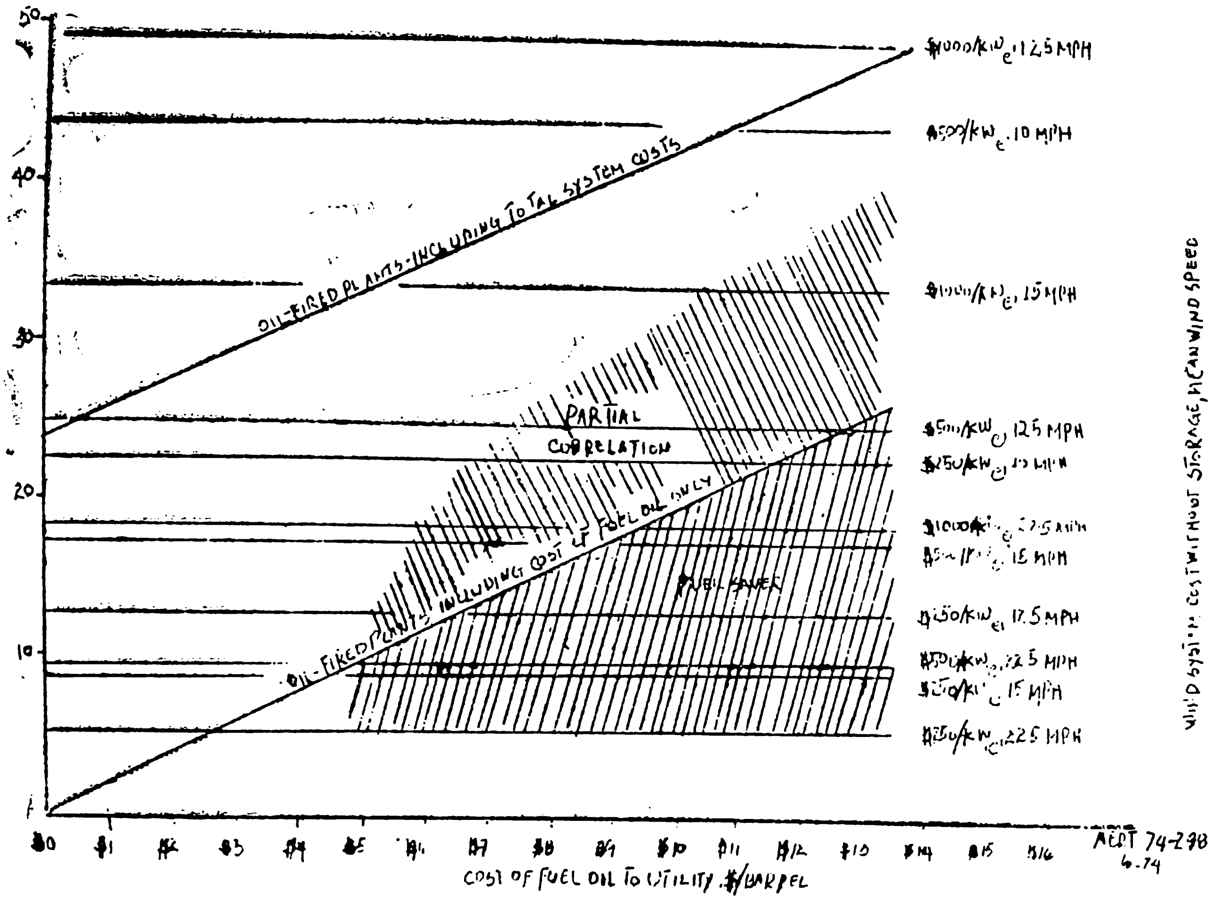


FIG. 8. *Breakeven Costs, Windturbines versus price of oil.*

associated with introducing a new source of power. Bagasse, the residue of sugar cane, has been used for years as fuel for process steam and power for sugar making.

VII-1. Environmental Considerations

The oxygen now in the atmosphere is almost entirely of biological origin, produced through the decomposition of water.

Non-point source pollutants associated with agricultural operations may present some problems especially with regard to fertilizers and pesticides. The large-scale use of irrigation water may present salination problems.

The conversion processes will have two environmental consequences. Conversion of urban solid waste and some agricultural residues will reduce many of the problems associated with disposal of these materials. Additionally, the residues from conversion of agricultural waste and energy crops may prove to be useful as organic fertilizers, soil conditioners, or as animal supplements. On the other hand, conversion of urban solid waste may produce waste water and filter cake with little utility and some potential disposal problems. The original volume of these wastes will, however, be reduced by the conversion process, thus reducing the problems associated with the disposal of the original refuse.

VII-2. Economic Consideration

Economies of the scale can be expected to apply to energy plantations as they do to most industrial and agricultural processes. The FORPRIDECOM initial study came out with rough estimates amounting to about ₱225,000 total investment requirement (not including the value of the land) for a 75 MWc capacity arriving at a unit production cost of ₱0.17/kwh compared to ₱0.21/kwh on a typical oil-fired steam power plant.

VIII. *OCEAN THERMAL ENERGY CONVERTION (OTEC)*

The objective of the OTEC program in the U.S. is "To establish the technical, economic and geopolitical feasibility of large-scale floating power plants capable of converting ocean thermal energy into electrical energy, leading to the commercial utilization of such plants and the production of significant amounts of energy." This renewable energy source provides a possibility for a large scale energy payoff with minimal impact on the environment. OTEC also provides the options of producing products such as protein, fresh water, minerals, chemical fuels, and fertilizers.

The amount of continuous energy available from ocean thermal thermal gradients is many times more than that consumed throughout the world today. How much more depends on a number of factors, including the depth from which the cold water must be obtained, the conversion efficiency of the system, and the transmission losses in getting the electrical energy to shore. As with the wind, an accurate assessment of the resources base is probably less important than the knowledge that the potential greatly exceeds the existing demand.

The ocean thermal power plant is essentially a Rankine cycle operating over a very narrow range of temperature. Warm surface water at around 77°F is used to boil a secondary fluid (working fluid) at about 68°F in large heat exchangers (see Figure 9). The vapor then expands through turbines to produce mechanical/electrical power. The exhaust vapor is condensed to the liquid state in heat exchangers cooled by deep ocean water.

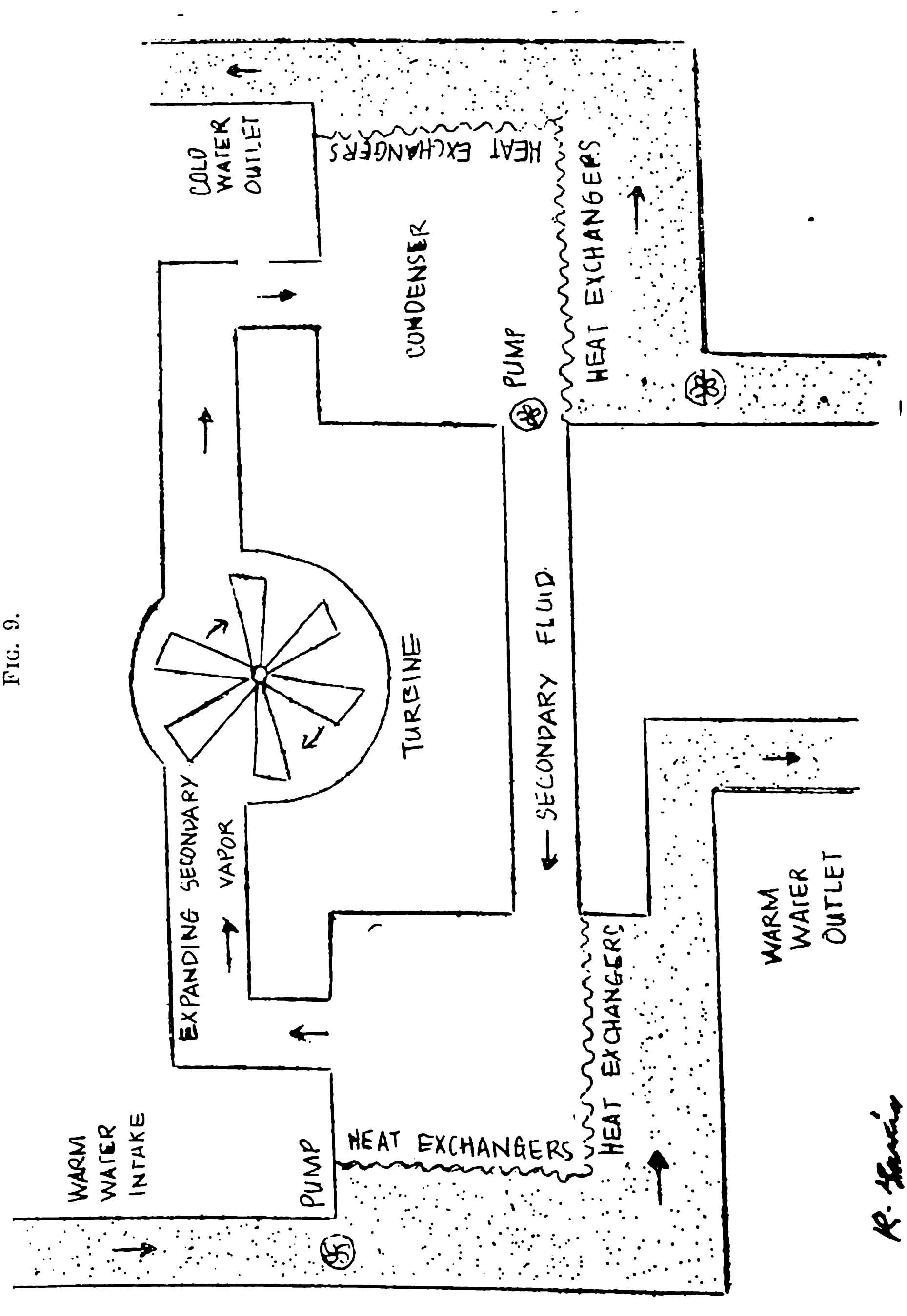
The technology required for OTEC system is relatively low-level technology. No scientific or technical breakthroughs are required, though some are expected, and the basic technology is presently available to support the achievement of program goals. However, the state-of-the-art within this body of technology needs to be advanced in order to adapt the technology for this application, especially with a view to providing economically viable systems.

Without actual experience in assembling an OTEC plant, the degree of technological complexity cannot be accurately estimated. Engineers envision the naval architecture as involving technological problems comparable to those already solved by the shipbuilding and oil-drilling industries. The most critical ocean engineering problems are the emplacement and maintenance of the deep-water pipe, extending to a depth of 1000 ft. or greater. However, such problems are regarded as being surmountable at reasonable cost.

In the power technology area, there is the key problem of the extensive amount of heat exchanger surfaces required, and the intertwined problems of bio-fouling and corrosion. These problems are amenable to research efforts presently underway and represent a significant factor in the cost and material requirements for OTEC plants.

Thus the principal question is the cost at which reliable systems can be provided. Present plans in the U.S. are to initiate construction of a proof-of-concept (POCE) experiment very early in the 1980's resulting in the generation of net power output of the order of 10 to 30 MWe. This POCE is expected to lead to a demonstration

FIG. 9.


WARM WATER INTAKE
PUMP
HEAT EXCHANGERS
HEAT EXCHANGERS
EXPANDING SECONDARY VAPOR
TURBINE
SECONDARY FLUID
WARM WATER OUTLET
PUMP
CONDENSER
HEAT EXCHANGERS
HEAT EXCHANGERS
COLD WATER OUTLET

plant delivering about 100 MWe before the middle of the 1980's and a total production capacity of 100 MWe by the mid 1980's.

The maximum theoretical efficiency of a.power plant working with a temperature gradient of 36°F is about 6.7%. The actual efficiency is not likely to exceed 3% and because of this, OTEC plants will be capital-intensive. These power plants will be "fuel-free" operating by circulation of large quantities of water. They will not require land area. Unlike some solar energy applications, resources for providing technological thermal collectors and thermal storage and thermal storage devices are not needed since the ocean provides them naturally.

VIII-1. Environmental Consideration

The degree of implementation will probably determine what, if any, environmental and ecological alterations might occur on a regional or global basis. Compared to other energy alternatives, the ocean thermal option would appear to be relatively environmentally benign, and any possible adverse effects should be controllable and/or reversible.

There are siting limitations associated with the availability of the thermal resource and of suitable ocean conditions. Also, the problems of outflow of warm and cold water will impose a limit to the number of such power plants that can be permitted per unit area of ocean. Regulatory problems, such as freedom-of-navigation and law-of-the-sea considerations, may also impose certain limits to the availability of ocean areas for this application.

IX. *SUMMARY*

All solar energy sources are characterized by low power densities and low conversion efficiencies when used to generate electricity. As a consequence, the land area requirements (with the exception of OTEC) for a given output are relatively large.

Figure 10 shows the land area requirements as a function of overall conversion efficiencies and intensifies the range of specific solar technologies.

Offsetting the overhead costs due to the high initial investment in solar power systems are the economic benefits associated with free energy and lower operating costs. This relative advantage is likely to increase in the future, since fossil and nuclear fuels require extensive and energy-intensive exploration, extraction, transportation, and processing before they can be converted to usuable energy.

Finally, energy from the sun is practically inexhaustible.

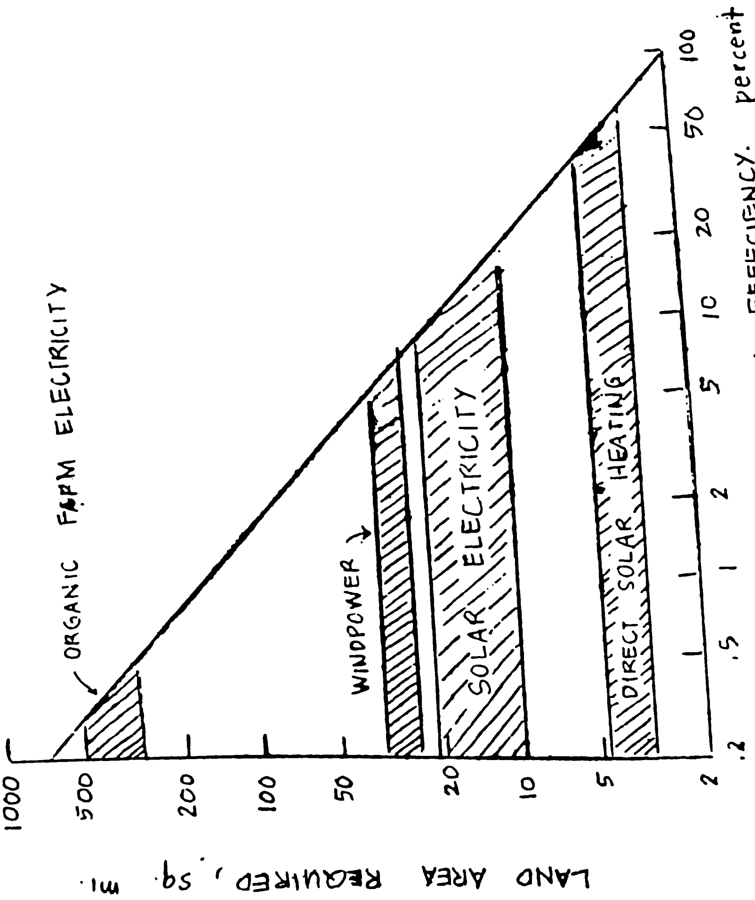

ORGANIC FARM ELECTRICITY
WINDPOWER
SOLAR ELECTRICITY
DIRECT SOLAR HEATING
NET SOLAR CONVERSION EFFECIENCY. percent
.2
.5
1
2
5
10
20
50
100
LAND AREA REQUIRED, sq. mi.
1000
500
200
100
50
20
10
5
2

FIG. 10.