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A Feasibility Study Concerning the Use of Alternate Energy Sources in Taiwan

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A FEASIBILITY STUDY CONCERNING THE USE OF ALTERNATE ENERGY SOURCES IN TAIWAN

by

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Li-Juan Lee

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I. INTRODUCTION

Taiwan is an island situated off the southeastern coast of the Chinese mainland and separated from Fukien Province by the Taiwan Strait which has a width of from 90 to 120 miles. The southern tip of the island is 225 miles north of the Philipines and the northern tip 665 miles southwest of Japan. South-Central Taiwan is bisected by the Tropic of Cancer (Figure 1).[1]

The main island lies between 21°45' and 25°38' north latitude and 119°18' and 122°6' east longitude. It is 250 miles long and from 60 to 90 miles wide. The area is 13,885 square miles. The island shape is roughly that of a tobacco leaf; long and tapering to the stem end in the south.

The climate is subtropical in northern and central Taiwan, tropical in the south. Summers are long and humid, with an average temperature of about 80°F. The winters in the south are confined to January and February, and the average temperature is a mild 65°F. Snow occurs only in the high mountains. Table 1 and Figure 2 illustrate the average seasonal day-time temperature range in selected cities in Taiwan; northern, central, southern and eastern parts respectively.[1] Table 2 and Figure 3 show the average night-time temperatures in these cities.[2]

Table 3 and Figure 4 illustrate the average seasonal wind speed and direction for selected cities in northern, central, southern, and eastern parts of Taiwan respectively.[2] In general, the wind

Figure 1. Map of Taiwan

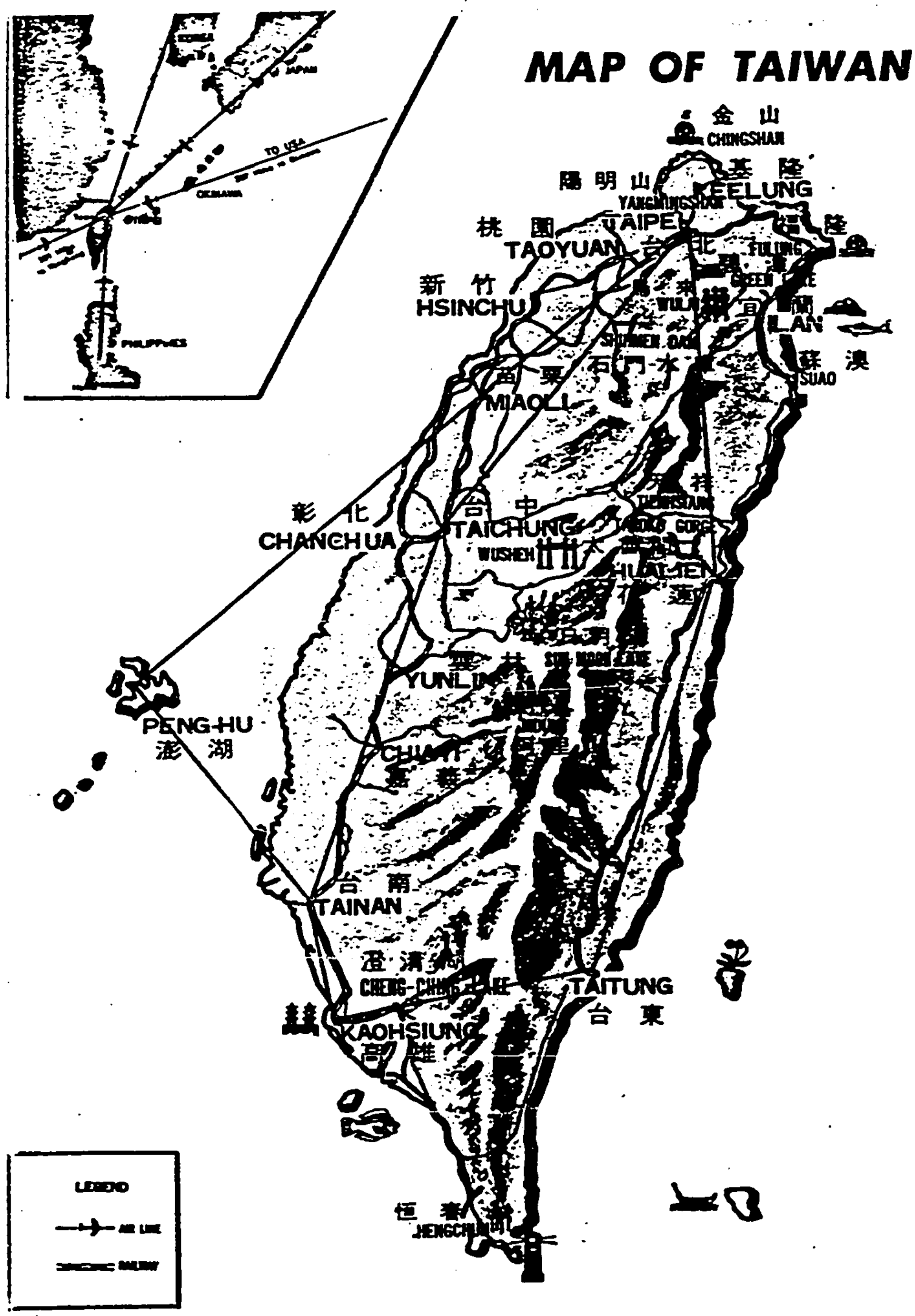


Table 1. Average Seasonal Day-Time Temperatures (°C) for Selected Cities in Taiwan

(Data from Central Weather Bureau of R.O.C.)[2]

Location	March	June	September	December
Taipei (———)	17.9	28.4	27.3	18.9
Tai-Chung (— —)	20.5	29.0	28.7	19.8
Heng-Chun (------)	24.2	29.4	29.2	23.8
Tai-Tung (—··—)	22.3	28.7	28.4	21.2

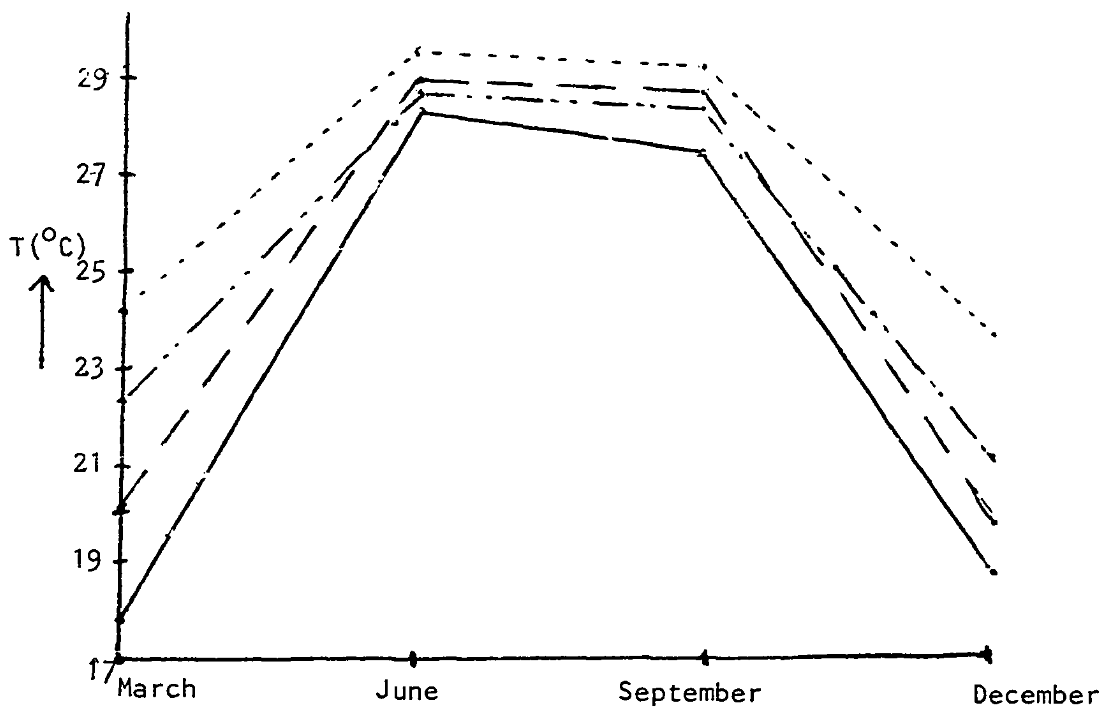


Figure 2. Average Seasonal Day-Time Temperatures (°C) for Selected Cities in Taiwan

Table 2. Average Seasonal Night-Time Temperatures (°C) for Selected Cities in Taiwan

(Data from Central Weather Bureau of R.O.C.)[2]

Location	March	June	September	December
Taipei (———)	16.1	25.1	24.5	16.8
Tai-Chung (— —)	17.1	25.2	24.3	15.4
Heng-Chun (------)	20.7	26.1	25.5	21.6
Tai-Tung (—··—)	19.6	25.8	25.3	18.9

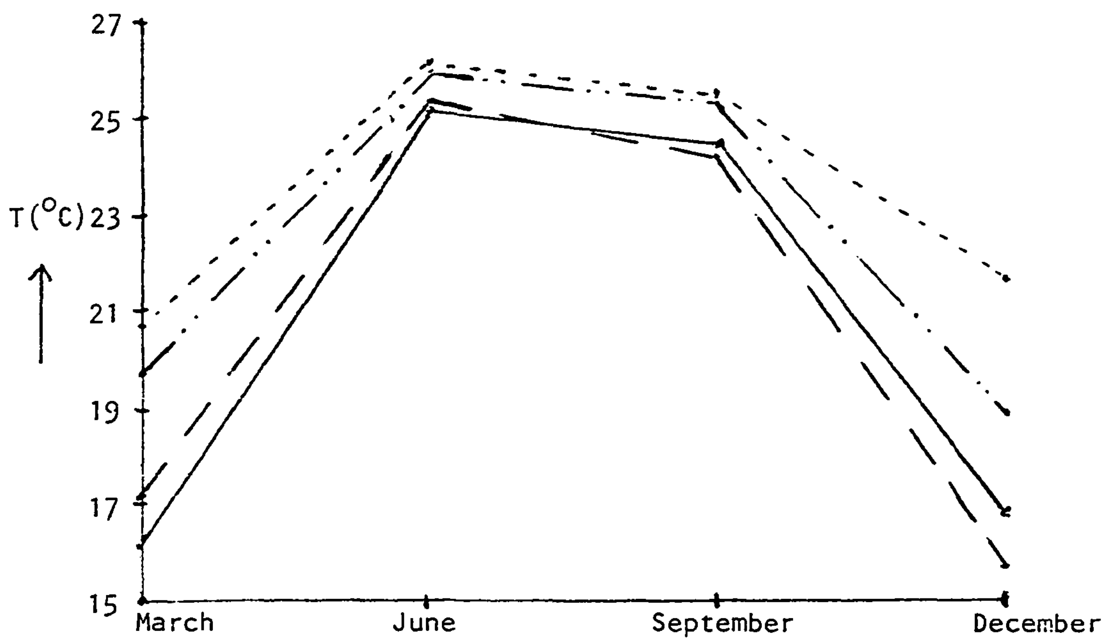


Figure 3. Average Seasonal Night-Time Temperatures (°C) for Selected Cities in Taiwan

Table 3. Average Seasonal Wind Speed and Direction for Selected Cities in Taiwan

(Data from Central Weather Bureau of R.O.C.)[2]

	Taipei		Tai-Chung		Heng-Chun		Tai-Tung	
Month	Speed ($\frac{m}{sec}$)	Dir.	Speed ($\frac{m}{sec}$)	Dir.	Speed ($\frac{m}{sec}$)	Dir.	Speed ($\frac{m}{sec}$)	Dir.
March	2.6	W	1.9	S	4.2	SW	3.1	SSE
June	1.7	NNW	1.3	N	2.4	E	2.9	SE
September	3.9	W	1.8	S	3.1	SW	2.5	SE
December	3.2	W	2.0	S	4.7	SW	2.6	SE

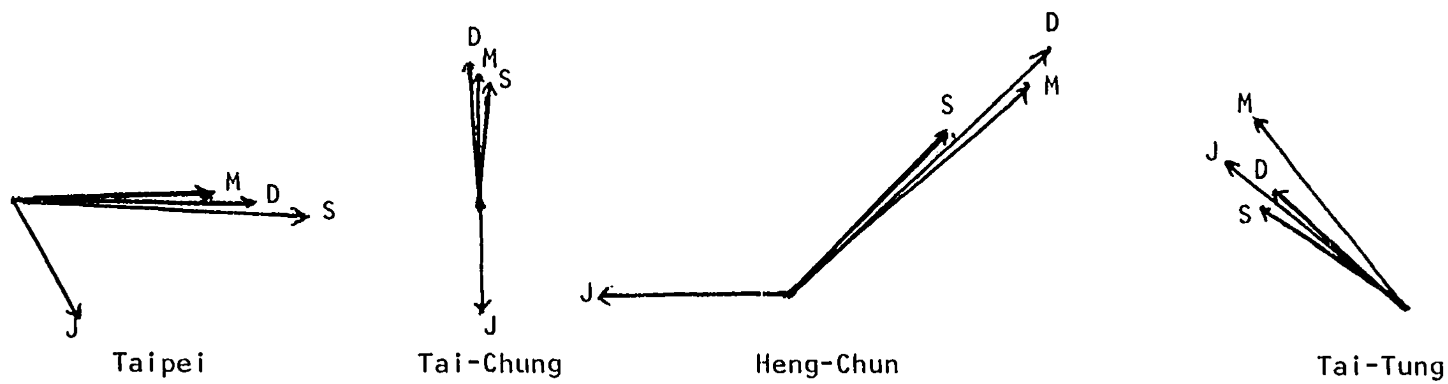


Figure 4. Average Seasonal Wind Speed and Direction for Selected Cities in Taiwan

speeds in Taiwan tend to be greatest in December and least in June. An overall average of wind direction for Taiwan tends to be from the south.

Taiwan's population exceeded 17 million at the end of August, 1978.[3] The population density is more than 1255 persons per square mile, highest in the world. Since the land area of Taiwan is approximately one-quarter the size of the entire state of Michigan, while the population of Taiwan is almost double that of the entire state of Michigan, the population density is 7.7 times that of Michigan, and 20 times that of the United States (Table 4).

The major types of energy used by the people of Taiwan are gas, oil, coal, hydroelectric and nuclear.

The installed electric power capacity was 7,020 million watts at the end of 1977. A little over 19 percent is from hydro plants, 9.1 percent from a nuclear plant and the rest from fossil fuel-fired generators.[5] Fossil fuel-fired generators include both coal and oil burning generators (Table 5 and Figure 5).

Taiwan is not rich in natural resources. Those available have been exploited with increasing success in recent years. Production of minerals (including coal, crude oil and natural gas) has tripled since 1952. Coal reserves are estimated at more than 220 million metric tons. Production was a little less than 3 million metric tons in 1974 (Table 6), a little more than 3 million metric tons in 1975, and 3.2 million metric tons in 1976. This was insufficient to meet demand and 170,000 metric tons of coal were imported. Coal seams are becoming thinner and extraction costs have risen. Oil has not

Table 4. The Population, Area and Population Density of United States,[4] Michigan,[4] Kalamazoo County[4] and Taiwan[3]

	Population (persons)	Area (mi^2)	Population Density (persons/mi^2)
United States	214,659,000	3,536,855	60.7
Michigan (entire)	9,104,000	56,817	160
Kalamazoo (County)	202,200	562	360
Taiwan	17,009,328	13,885	1225

Table 5. The Electrical Generating Capacity and the Relative Percentage Generating Capacity of Various Taiwan Power Sources[5]

Installed Type	Capacity (M.W.)	Composite %
Hydro	1.365	19.4
Nuclear	636.000	9.1
Fossil Fuel	5,019	71.5
Total	7,020	100.0

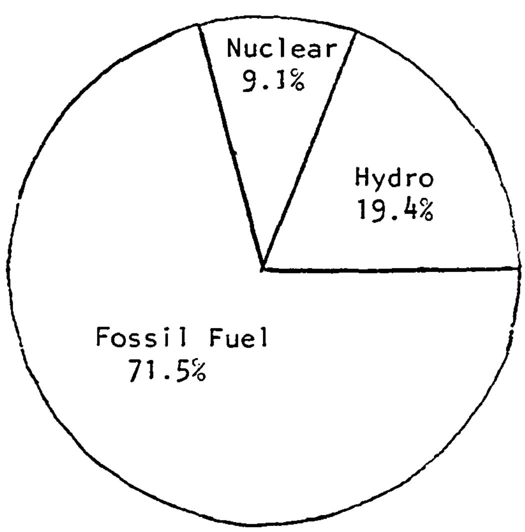


Figure 5. Relative Capacities of Taiwan Power Sources

Table 6. The Industrial Production of Energy Resources in Taiwan[6]

(Note: M = million)

Contents	Unit	Industrial Production	
		1974	1975
Coal	1000 MT	2934	3141
Natural Gas	Mm^3	1587	1575
Crude Petroleum	1000 KL	210	215
Electricity	M KWhr	20536	22894
Manufactured Gas	Mm^3	30	28

yet been discovered in commercially important quantities, although exploration continues on both land and sea. Natural gas, however, is a major resource. Reserves found on land exceed 32 billion cubic meters. Sizable deposits have been discovered off the southwest coast but are not yet tapped. Natural gas production from land wells was nearly 1.6 billion cubic meters in 1974 and more than 1.8 billion cubic meters in 1976.

Power sources in Taiwan cannot meet the existing energy crises, so most of the supplies are imported. Tai-power (Taiwan Power Company) which transports oil from the Middle East in its own tankers, has signed supply contracts with Saudi Arabia and Kuwait.

II. USE OF WIND AS AN ENERGY SOURCE

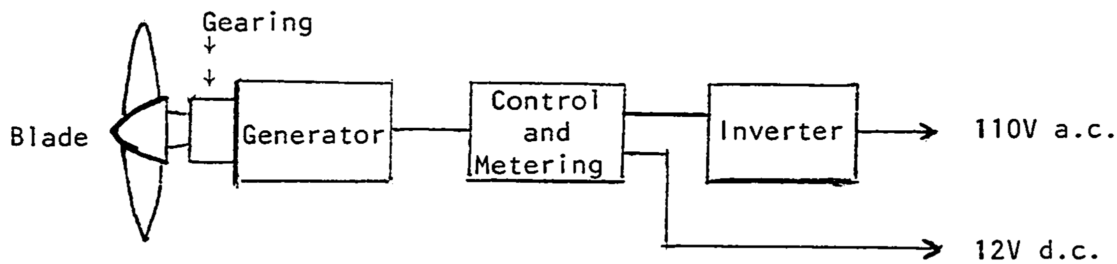
The even-shifting differential heating of the earth by the sun's warmth causes the motion of the winds. The conversion of the tremendous force of wind motion to electricity is a source of nonpolluting energy. The world is struggling to meet the demand for electrical energy and is consuming fossil-fuel sources at a devastating rate while only lackluster impetus is given to the use of the vast quantity of nonpolluting energy available from the wind.

A basic function diagram is shown in Figure 6.[7] There are three usual classes of windmills (post-mills, smock-mills and tower-mills)[8] The initial step in the conversion of wind energy to mechanical motion can be accomplished by a variety of wind blades and rotors. Electrical generators make the conversion from mechanical motion to electricity. Either d.c. or a.c. generators can be employed with various voltage and power capabilities as required by the system. Popular values are 12V, 24V, 36V, 110V d.c., and 110V, a.c.

When the wind velocity is too high, an intervening belt and/or gear system can be used to make an appropriate conversion between the rotational speed of the wind-driven rotor and a suitable speed of rotation for the generator.

During periods of calm and low wind velocity, generators become inactive. Electrical energy must be stored by batteries or

Figure 6. Basic Plan of Wind-Generating System[7]



other energy-storing methods. Presently the secondary battery is popular and serves as a reservoir of electrical energy.

Wind electrical-generating systems must be planned according to the average wind velocity conditions of an area, with an added safety factor that would acccomodate a reasonably long wind-quiet period. An average yearly wind velocity of 9-10 miles per hour is adequate for installation of a practical wind-generating system.[7]

The average seasonal wind speed and direction in selected cities of Taiwan, as shown in Table 3 and Figure 4, are taken from the records of the Central Weather Bureau of the Republic of China.[2] According to these data, the average wind speed is less than 4 meters per second, except at Heng-Chun in December. Since the minimum practical wind speeds of 9-10 miles per hour are equivalent to 4.02 - 4.47 meters per second, it is evident that Taiwan cannot expect to utilize the prevailing winds in any extensive manner as a feasible energy source. No doubt this lack of sufficient wind velocity is the primary reason that there are currently no windmills in Taiwan.

The fundamental equation that determines the wind power, in watts, that impinges on a slim two-blade propeller is[7]

$$P = 0.005\ AV^3$$

where A is the area in square feet covered by the blade as it rotates (equivalent to πr^2),

V is the wind velocity in miles per hour,

P is the power in watts.

Table 7, which follows, is quite practical and presents an approximation of the usable power that can be derived from an efficient two-blade windmill in terms of blade diameter in feet at a wind velocity of 10 miles per hour (or 4.47 meters per second). An approximate overall efficiency of 30% has been assumed.[7]

The following example will illustrate the use of the wind power equation $P = 0.005\ AV^3$.

Assume a blade with a 10-foot diameter at wind velocity 10 miles per hour and determine the wind power striking the two-blade windmill. The calculation is as follows:

$P = 0.005 \times 3.14 \times (5)^2 \times 10^3 = 392$ watts.

The theoretical efficiency of converting wind energy to propeller-turning energy is 59.3%.[7] The propeller-turning energy is converted into electrical energy (by the propeller generator) with an efficiency of 50%.[7] The overall efficiency then approximates 30% (59.3% x 50% ≈ 30%). Note that 30% of the previous wattage figure is about 117 watts (392 x 0.3). So a windmill with a 10-foot diameter blade is needed to provide electricity to light one 100-watt light bulb.

In Taiwan, the electricity production is estimated to be 33,608 million kilowatt-hours this year (1978). (See Table 8.) If windmills with a 20-foot diameter blade were used to supply 10% of Taiwan's electrical energy, 815,700 windmills would be required.

$$\frac{33608 \times 10^9 \text{ Wh} \times 10\%}{470\text{W} \times 8766\text{h}} = \frac{33608 \times 10^8}{470 \times 8766} = 815{,}700 \text{ windmills.}$$

That is equivalent to approximately 60 windmills per square mile.

Table 7. Output Capability in Watts for Efficient Two-Blade Windmill[7] at a Wind Velocity of 10 Miles Per Hour

Blade Diameter (feet)	Output (watts)
6	40
7	57
8	75
9	95
10	117
11	142
12	169
15	264
20	470

Table 8. Estimates[5] of Taiwan Electrical Needs and Capabilities for the 12-Year Period 1978 Through 1989

(Note: MKWhr - Million Kilowatt hours)

	Predicted Electrical Energy Need		Predicted Electrical Energy Capability		Predicted Average Power Load Per Day	Predicted Peak Power Load Per Day	
Year	MKWhr	Yearly Growing Rate (%)	MKWhr	Yearly Growing Rate (%)	Kilo KW	Kilo KW	Yearly Growing Rate (%)
1978	31,114	12.30	33,608	13.34	3836.5	5570.6	13.69
1979	34,599	11.20	37,344	11.12	4263.0	6215.0	11.57
1980	38,439	11.10	41,457	11.01	4732.5	6927.8	11.47
1981	42.975	11.80	46,324	11.74	5288.2	7772.9	12.20
1982	48,089	11.90	51,809	11.84	5914.3	8729.6	12.31
1983	53,763	11.80	57,897	11.75	6609.2	9795.2	12.21
1984	60,000	11.60	64,586	11.55	7372.8	10972.2	12.02
1985	66,900	11.50	71,990	11.46	8218.0	12279.3	11.91
1986	74.460	11.30	80,099	11.26	9143.7	13715.6	11.70
1987	83,990	12.80	90,322	12.76	10310.7	15535.9	13.27
1988	94,573	12.60	101,680	12.58	11607.4	17566.2	13.07
1989	106,395	12.50	114,366	12.48	13055.5	19844.8	12.97

Note that the calculation of the number of windmills is based on a wind velocity of 4.4 meters per second. The typical averages of Table 3 are substantially below 4.4 m/s velocity, so the actual requirements of Taiwan would be closer to 100 windmills per square mile (to produce 10% of Taiwan's energy requirements).

Although windmills do not provide a feasible energy help for the entire Taiwan country, they might be of some help in some rural or isolated areas which are not easily served by hydro, fossil fuels, or nuclear generating plants. Windmills with large diameter blades, (for example, 100 ft or 200 ft) will increase power output per windmill by 100 to 400 times over a 10-ft diameter windmill. Also, of necessity, such windmill blades would operate at a higher elevation above the terrain where the wind velocity is significantly higher than the surface winds.

III. USE OF WAVES AND TIDES AS ENERGY SOURCES

Power is the rate at which energy is developed. The amount of potential power in a wave train breaking upon the shore, therefore, depends upon the energy in a single wave and the rate at which the waves arrive; that is, their frequency. The energy in a wave consists of two parts; one is the potential energy from the height of the wave, the other is the kinetic energy locked up in the orbital movements of the water particles. Once this energy has been determined for a wave train of a specific wave height, it is then necessary to multiply it by the number of waves that arrive per hour to estimate the horsepower or number of kilowatts generated per foot of coastline. To take a concrete example, a 6-foot swell with a period of 16 seconds could generate along every yard of oceanfront about 40 kilowatts. A mile of oceanfront would generate 70,000 kilowatts.[9]

There are a number of reasons why there does not exist any large-scale power plant in Taiwan using wave energy. Among the prime reasons is that wave energy is not reliable. It rarely continues to dispense power of the same magnitude day after day in any one place all year long. Another is that, except in exceptional gales, the energy is thinly distributed and to be of practical value it must be concentrated. Still another is that where the power generated is greatest it is not easily controllable; that is, it is not feasible in those areas to erect a machine in which the available power could be easily used to turn a dynamo.

The long waves of the tides offer a more practical source of power. The difficulties in utilizing tidal power are less than those encountered in trying to harness waves.

Tidal electric power is a special kind of hydroelectric power, depending on the alternate filling and emptying of a demand basin rather than on the one-directional flow of water. The amount of energy available at a site depends on the range of the tide and the area of the enclosed basin, and can be calculated if these values are known.

The practical tidal power plant is the two-basin system, as illustrated in Figures 7 and 8.[10]

In the two-basin system, the two basins are separated from each other by a dam with gates and are closed off by other gates from the sea. One is operated as a high-level basin and the second as a low-level basin. The power plant is placed between the two basins and arranged to discharge at will either into the low-level basin or directly into the sea. By proper timing of the gates, operation of the power plant can be made continuous. With the two-basin arrangement, some firm power can be developed, but it would vary in amount with neap tides. (Firm power is power developed when needed.) Only a costly system of storing energy in some form, utilizing auxiliary pumping systems and reservoirs much like a storage battery that is charged when power demand is low and discharged when demand is high, can gear the power supply to the fluctuating power demand.

Figure 7.[10] Possible Ranges of Level Variation in Basins, as Compared with Seaward Tidal Range

T indicates turbine flow; P indicates pump flow.
Sluice flows and pump-aided sluice flows not shown.

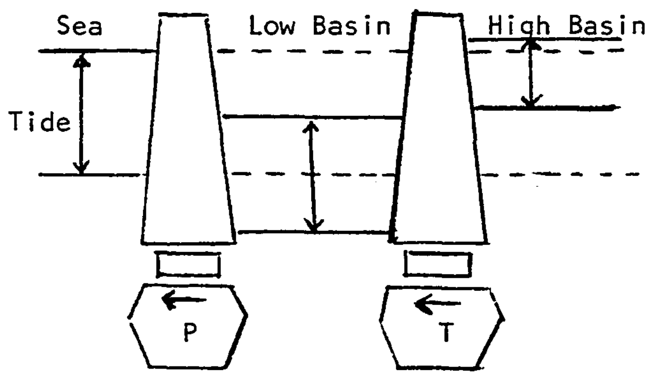
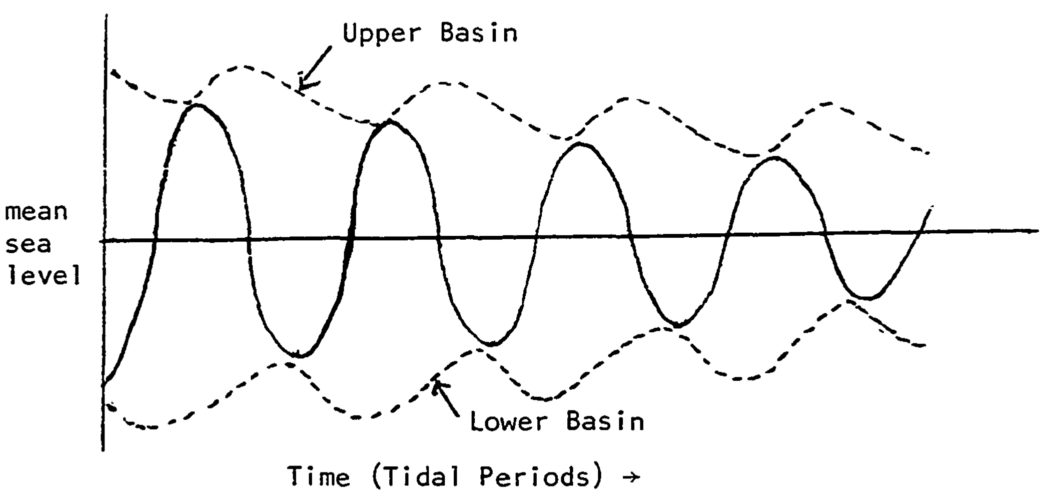


Figure 8.[10] Relative Water Levels in the Upper and Lower Basin Compared to Sea Level

(Double basin system with pumping between sea and basins)



When the earth, moon and sun are all approximately in line, the condition of full and new moon, the tidal bulges of the moon and sun are additive in these two cases, so that the high tides so produced will be extreme, the so-called "spring tides." (Their occurance has nothing to do with the season "spring.") When the sun and moon are in quadrature, the tide-generating forces are 90 degrees out of phase and operating at right angles to one another. This produces the minimum tidal range - the "neap tides." Spring tides are about 20% greater than the average tidal range. Neap tides are about 20% lower than average. This variation occurs fortnightly.[11]

Consider an observer at point A on the equator in Figure 9. As the earth rotates daily he would see two high tides as he passes under the bulges, separated by two low tides. An observer at point B would similarly see two high tides, but the height would be somewhat lower than seen by A. In general, the nearer one is to the equator, the higher the tide one can see; the farther one is from the equator, the lower the tide one can see.

Taiwan's latitude is between $21^{\circ}45'$ N and $25^{\circ}38'$ N. Hence, there may be no doubt about adequate great tides occuring that close to the equator.

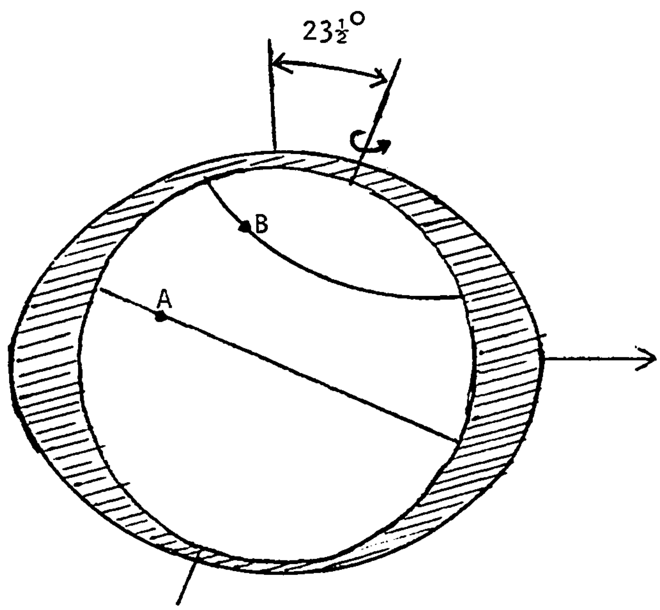
It is possible to derive a formula for calculating tidal power. The potential energy E_p of a body with a mass m kilograms at a height H meters above ground level is given by:

$$E_p = mgH \text{ joules} = 9.8\ mH \text{ joules},$$

with $g = 9.8\ m/s^2$, denoting the gravitational acceleration.

Using one metric ton = 10^3 kg as the unit of mass m, the

Figure 9. The Effect of the 23.5 Deg. Eccentricity on the Tides as seen by Observers A and B



equation becomes:

$E_p = 9.8$ mH kilojoules

Denoting the mass of water flowing down per second as the water flow Q, and assuming that the potential energy is fully converted into useful work, the power - that is, the work done per second - is:

P = 9.8 QH Kilojoules/sec (= Kilowatts).

Since a cubic meter of water weighs one metric ton, the flow Q can also be given in cubic meters per second. By neglecting the small difference between 9.8 and 10, the rule of thumb is obtained that the gross power (in kilowatts) of a water power plant is ten times the product of the water flow (in cubic meters per second) and the head (in meters).

The overall efficiency of the conversion from potential energy of the water to electric power delivered from the plant can be estimated at about 75-80 percent,[12] and therefore (rather optimistically) the rule of thumb for net power is:

Net power = 8 QH (KW)

Assuming a head of tide of 5 meters (about 16 feet), and applying the formula P = 8 QH, a water flow of Q = 250 m^3/sec would be required to produce a power of 10,000 KW. (= 10 MW) That is the same quantity as the practical geothermal power plant Taiwan is expecting to build in 1980.[13]

If this power is 10 MW with a tidal head of H = 5 meters, then a permanent flow of 250 m^3 per second is required. This means that within a tide period of twelve hours about 10 million cubic meters of water flow through the turbines from one basin to another basin. If the level difference between the two basins is not to be decreased appreciably by the loss of this quantity, the capacity of each reservoir must be, say, ten times as great. Therefore, a capacity of 100 million cubic meters is required, and the gates must be wide enough to deliver the whole quantity of 100 Mm^3 within a time of scarcely more than one hour.

Therefore, significant contributions from tidal power can be made only by means of large reservoirs and with dams, gates, and turbines for handling great quantities of water.

IV. USE OF WATERFALLS AND STREAMS AS ENERGY SOURCES

When power needs were far smaller, the energy contained in the flowing water of a nearby stream was often enough to satisfy those needs. For more power, however, the energy of falling water is needed.

If there is flowing water, but no drop, to produce hydroelectric power, a dam must be built on a river, with turbines and generators at its base. The water behind the dam stores energy that would otherwise have been dissipated as the water descended over the river bed. When tunnels through the dam are opened, water pours through with great force, spinning turbines which drive generators to produce electricity.

Taiwan's 30 hydroelectric plants have a total capacity of about 1.4×10^6 kilowatts.[14] They make up more than 19 percent of the total installed electric generating capacity (Table 5 and Figure 5). A contemplated project at Sun Moon Lake would add nearly 1.5×10^6 kilowatts.[14] Other sites offer additional potential of more than 5×10^6 kilowatts. The Tseng Wen Dam and Reservoir was dedicated in 1973. It stores 708 million cubic feet of water and generates 5×10^4 kilowatts of electricity.[14] More than 850 kilowatts of hydroelectric power will be coming from the Tachia River in central Taiwan. The Chingshan power plant with capacity of 3.6×10^5 kilowatts is Taiwan's biggest.[14] The Tachi plant, also on the upper reaches of the Tachia, added 2.34×10^5 kilowatts in 1974.[14] Other plants in the complex include Kukuan at

1.8×10^5 kilowatts and Teinlun at 7.9×10^4 kilowatts.[14]

Hydropower has some definite advantages. It operates entirely without fuel, the original energy comes from the sun. Thus, there are no combination products, or any other wastes. The overall efficiency of the conversion from potential energy of the water to electric power delivered from the plant is about 75 to 80 percent.[12] Because of this high efficiency, very little waste heat is generated and the electricity produced in this manner is usually cheaper than that of any other method.

From the preceding chapter, we know a water flow of Q in cubic meters per second and a head H in meters will deliver a net power of 8QH (KW). The velocity of the free jet impinging on the generator, or turbine, can be computed by setting the potential energy of the water at the top equal to its kinetic energy at the bottom.

$$mgH = \tfrac{1}{2}mv^2 \qquad v = \sqrt{2gH}$$

Table 9 uses $v = \sqrt{2gH}$ to predict the water flow velocity at the bottom of the waterfall for various waterfall heights.

Solving $v = \sqrt{2gH}$ for $H = \frac{v^2}{2g}$ and substituting this expression into the net power equation yields:

$$\text{Net power} = 8QH\ (\text{KW}) = 8Q\,\frac{v^2}{2g} = 4Q\,\frac{v^2}{g}$$

or net power $\approx 0.4Qv^2$ kilowatts.

Hence, the amount of power generated by a hydroelectric system depends upon the volume of water flow (in m^3/s) and the square of the velocity of the water (in m/s).

Hydropower cannot be a long-term solution to Taiwan's energy

Table 9. Variation of the Exiting Water Flow Velocity with the Height of the Waterfall

Head (m)	Velocity (m/s)
1	4.43
2	6.26
5	9.9
10	13.9
20	19.8
50	31.3
100	44.3
200	62.6
500	99.0
1000	139.0

problems, although it has contributed substantially to the growth of Taiwan. The problem is silt. All streams and all rivers carry silt, tiny soil particles that are swept along with flowing water but which settle out in calm water. Thus a river's burden of silt will be dumped into the reservoir at the hydroelectric plant, and the reservoir will gradually fill up. When that happens, the water storage capability will be lost and thereby its usefulness to irrigation and flood control. As to power generation, on the other hand, the full head would remain; the amount of power generated would depend on the run of the river. The energy of the waterfall available at the dam site will generally be smaller in amount, and subject to fluctuations in the river flow.

V. USE OF GEOTHERMAL ENERGY AS AN ENERGY SOURCE

Geothermal energy is derived from the internal heat of the earth. This energy is usable at those points where it occurs in concentration in an extractable form (such as hot water or steam) within sufficient proximity to the surface. Concentrations of extractable heat at depths less than three kilometers (about 9900 feet) may be considered an economic resource. With the present technology and economic limits imposed by the relative cost of substitute fuels, drilling can be done profitably only to a depth of between 9,000 and 10,000 feet.[15]

Geothermal areas where heat extraction may be economically feasible are usually, but not always, closely associated with volcanic activity and earthquakes.

The direct output of any geothermal energy system is heat, normally contained in steam or hot water. If its temperature level is high enough, this heat can be used to drive a turbine, or some other type of heat engine, producing mechanical energy that can be used to generate electricity or do other useful work. At similar or lower temperatures the heat can be used directly for space-heating, air-conditioning, distillation and chemical processes, and a multitude of other uses. Multiple use systems, in which the high-temperature heat is used to generate electricity and the rest is used directly as domestic or industrial heat, are particularly attractive.

Because of the costs and inefficiencies associated with piping low-temperature steam over long distances, the natural unit size of a geothermal power plant is small, the largest units operating are at Wairaker "B" station (New Zealand) being single-flow 30 MW machines running at 1500 rpm with an inlet steam pressure of 50 lb/in^2 and back pressure of 0.74 lb/in^2.[16]

In Taiwan, exploration has centered at the Tatun volcanic complex at the northernmost end of the island, where exploration began in 1965 and is still in progress. Thirteen fumarole (a crevice emitting volcanic vapors) and hot-springs areas occupy a region of over 50 Km^2. At one locality, the fumarole temperature reaches 120°C.[17]

Exploration has included detailed geologic mapping, geochemistry, and extensive geophysical surveying. Fifty-eight temperature-gradient holes have been drilled,[17] to a maximum of 160 meters. Temperatures to 174°C have been encountered and several holes produce very acid steam. At least eleven holes have been drilled to depths of 300 to 1500 m, with a maximum reported temperature of 293°C. Flow has varied up to 3500 kg/hr of fluid.[17]

The National Science Council of R.O.C. has completed the first experimental-type geothermal power plant[13] in October 1977. Present generation is 700 KW. This is sufficient to show that R.O.C. has the ability of self-design and technical application. The Department of Energy of the U.S.A. announced that R.O.C. is the eleventh country in the world to begin using geothermal power.

The National Science Council of R.O.C. has decided to build a practical geothermal power plant at Ilam (a city in northeastern Taiwan). This plant will provide 10,000 KW (10 MW) after completion in 1980.[13] It is expected that during the first year of operation this plant will produce 8.77×10^7 KWhr of energy. That is 10,000 KW x 8766 hr = 8.77×10^7 KWhr, which is 0.26% of Taiwan's present power use of 3.36×10^{10} KWhr.

$$\frac{8.77 \times 10^7 \text{ KWhr}}{3.36 \times 10^{10} \text{ KWhr}} \times 100\% = 0.26\%$$

and 0.21% of Taiwan's projected 1980 power use.

$$\frac{8.77 \times 10^7 \text{ KWhr}}{4.15 \times 10^{10} \text{ KWhr}} \times 100\% = 0.21\%$$

Taiwan's volcanic mountains are found between Keelung Harbor and the Tamsui River in the north. The whole area once was covered by lava flowing from conical notches rising to 3000 ft or more.[1] There are an average of one hundred weak shocks or more per day in Taiwan's eastern parts.[13] These weak shocks are sufficient to show that "friction" often happens underground between the eastern and western parts of Taiwan, and it might produce substantial heat energy.

It may appear surprising that development has been slow and that so many geothermal fields are still neglected in Taiwan. The reason is that not all geothermal fields are necessarily amenable to economic exploitation, and in order to determine whether a field can be profitably put to use, it is necessary to expend fairly formidable sums of money in carrying out exploration.

Thus, the cost of geothermal exploration may be regarded as "risk capital," such as is associated with petroleum exploration. But with petroleum exploration, if successful, the product can be shipped and sold all over the world regardless of the location of the oil field. In the case of successful geothermal field, however, the energy must be used either locally or within a limited radius. The most probable market is electricity supply. But electricity supply can be developed by conventional means without the need for "risk capital." This is the main reason why, in Taiwan, companies have always eagerly engaged in drilling holes and wells for exploring for oil but not for geothermal heat. Another reason perhaps is that the very acid steam liberated at geothermal holes is severely corrosive to the equipment components needed for the extraction of the thermal energy. The capital losses due to equipment replacement must also be considered a factor in the greater number of oil drillings compared to geothermal drillings.

The total generation of energy in Taiwan in this year (1978) is estimated at about 3.36×10^{10} KWhr; 10% of this is 3.36×10^{9} KWhr. One gram of steam converted into water at the same temperature (say, 100°C) releases about 540 calories of heat, and $1\text{cal} = 6.98 \times 10^{-2}$ watt minutes. Therefore,

$$3.36 \times 10^{9} \text{ KWhr} = 3.36 \times 10^{12} \text{ Whr} \times \frac{60 \text{ min}}{1\text{hr}} = 2.02 \times 10^{14} \text{ watt min.}$$

$$= 289 \times 10^{13} \text{ cal} = 289 \times 10^{13} \text{ cal} \times \frac{1\text{gram}}{540\text{cal}}$$

$$= 0.535 \times 10^{13} \text{ gram of water} = 5.35 \times 10^{9} \text{ kg of water}$$

$$= 5.35 \times 10^{9} \text{ Kg} \times \frac{1\text{m}^3}{1000\text{kg}} = 5.35 \times 10^{6} \text{m}^3 \text{ of water.}$$

Thus the production of 10% of Taiwan's current yearly energy needs by this method would require converting 5.35×10^6 m^3 of water per year into steam. This is equivalent to approximately 600 m^3 per hour.

It has been estimated[16] that if the planet Earth were to be cooled through one degree centigrade, enough heat would be released to keep the whole world supplied with all its electrical power needs at the present level for some forty million years. However, the seismic and climatic consequences of cooling the Earth by one degree, or even by one-hundredth of a degree could be disastrous.

VI. USE OF THE SEA AS AN ENERGY SOURCE

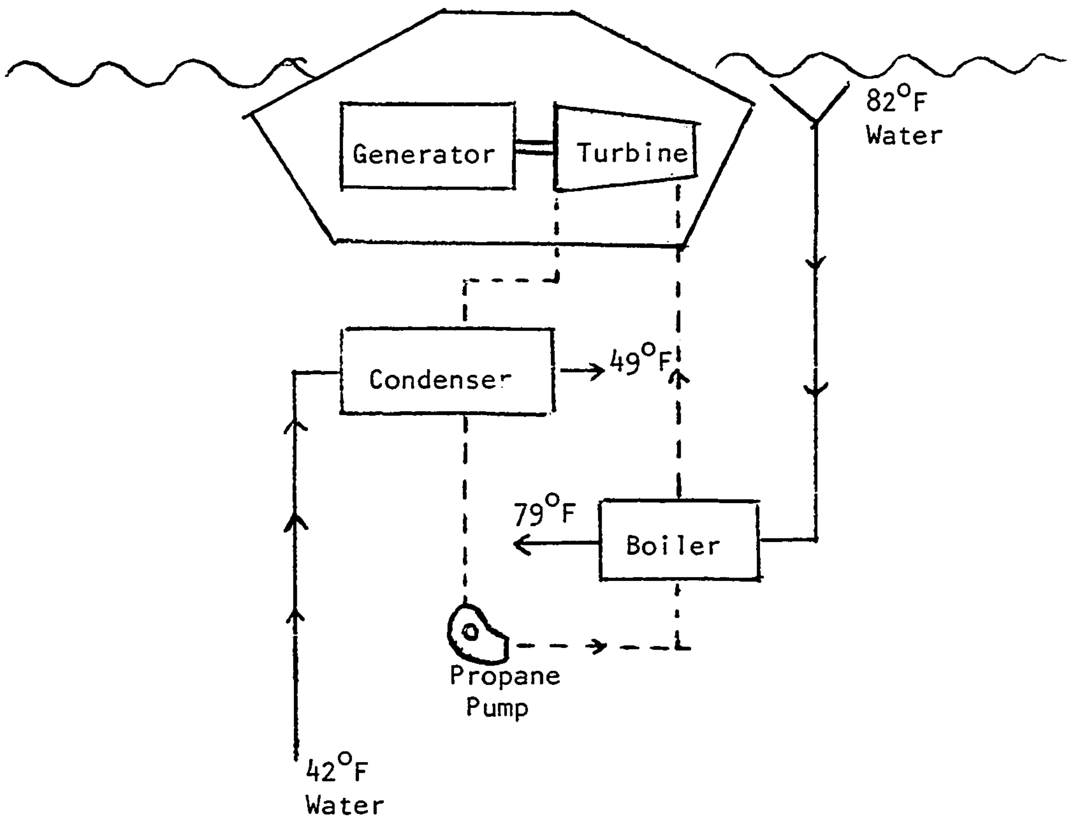
Solar-electric conversion systems consist of direct thermal system, photovoltaic system, wind system, ocean wave system, ocean tide system and ocean thermal gradient system.

The temperature difference between the sun heated upper layer and the deeper cold water of the ocean can be used to power very large heat engines. So long as a sea water temperature difference of at least 15°C exists, it should be possible to operate an ocean thermal gradient system.[18]

A Solar Sea Power Plant (SSPP) located in the (Florida) Gulf Stream is shown in Figure 10. The warm surface waters are passed through heat exchangers which boil a working fluid, such as ammonia, propane, or Ethylene Oxide, to drive huge turbines coupled to generators. The cold water pumped from the ocean depths is circulated through heat exchangers to condense the working fluid. The process relies on heat engines operating over a temperature difference of about 40°F (22°C).[19]

In order to meet the purpose of the expanded ocean study program which was adopted by the 23rd General Assembly of the United Nations,[20] Taiwan's two research vessels, "Ying Ming" and "Chinlein" have taken up exploration activities in the surrounding ocean around Taiwan. These explorations have objectives of benefiting directly the growth of the national economy and of obtaining information required for management and conservation of resources and for making

Figure 10. Solar Sea Power Plant



sound political, legal and socioeconomic decisions.

Six cruises were carried out prior to 1968-69. The seventh cruise took place from September 10 to October 28, 1968. Forty hydrographic stations and fifty-nine B.T. stations were occupied. (A B.T. station is a station where temperature vs. depth measurements are made with a bathy-thermograph.) The itinerary of the cruise and position of stations are shown in Figure 11. The eighth cruise took place from April 12 to May 12, 1969. Forty hydrographic stations and fifty-eight B.T. stations were occupied. The data obtained on the 7th and 8th cruise are similar but the 7th cruise extended over a larger geographical region and, therefore, only cruise 7 data are included in the table and charts which follow.

The cross section of water temperatures for the 7th cruise are given in Figures 12 to 15.

The distribution of dynamic height anomalies[23] at surface, 50 meters, 150 meters and 300 meters layer for the 7th cruise are given in Figures 16 to 19.

The direction of the current flow is indicated and the velocity can be measured with the scale given in the figures.

Because the maximum of the energy potential of an SSPP system is directly related to the magnitude of temperature difference in sea water and the distances and volume of water to be moved through the facility, a site for the prototype facility was sought where large temperature gradients are available. The market for fuel or electrical power and by-products from power production must be near the plant facility for maximum economic benefit to be derived from

Figure 11. Station Locations of Seventh Cruise

⊙ Serial Oceanographic Station

● B. T. Station

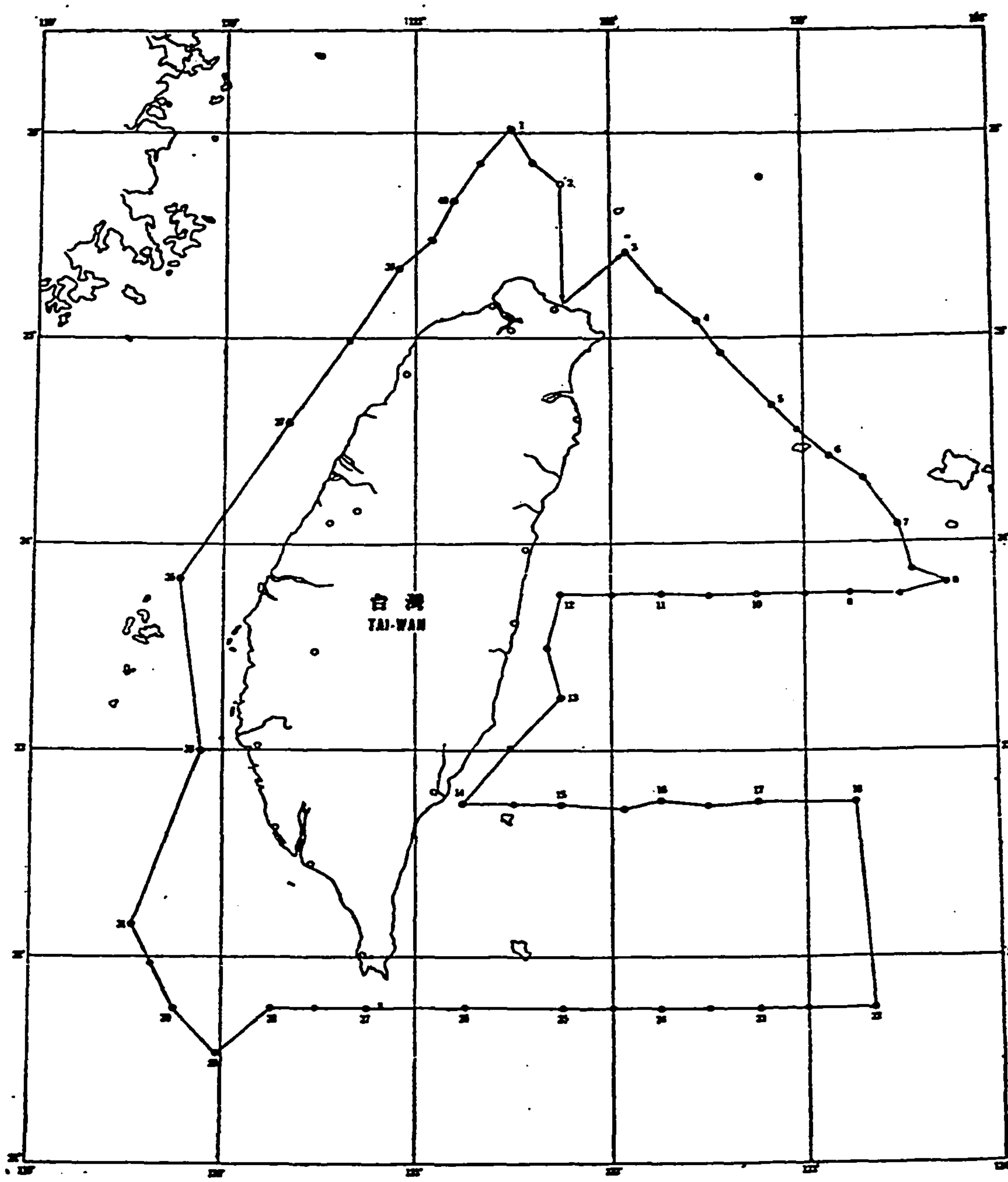


Table 10. Oceanographic Observation Data[21]

Station Number	Latitude	Longitude	Observed Depth(m)	Temp(^oC)	Salin-ity(%)[22]	O_2(ML/L)
004	25-05.0N	122-27.0E	0	26.40	33.21	4.58
			433	9.38	34.56	2.77
			517	7.88	34.39	2.38
			685	5.87	34.42	2.02
			780	5.27	34.48	2.01
			864	4.90	34.50	2.02
011	23-45.0N	122-15.0E	0	27.00	34.38	4.37
			430	11.57	34.51	3.45
			508	9.80	34.54	2.86
			654	7.39	34.34	2.44
			720	6.20	34.40	2.12
			820	4.37	34.43	2.08
			1060	3.40	34.50	1.88
			1234	2.88	34.63	2.02
012	23-45.0N	121-45.0E	0	28.80	33.57	4.15
			336	12.05	34.72	3.34
			421	10.13	34.60	3.02
			506	8.65	34.51	2.62
			576	6.35	34.60	2.34
			738	5.53	34.50	2.08
			846	4.52	34.47	1.79
			1016	3.73	34.58	1.81
013	23-15.0N	121-45.0E	0	28.50	33.98	4.12
			425	10.27	34.27	3.21
			555	7.86	34.20	2.65
			600	7.20	34.21	2.35
			700	6.05	34.27	2.11
			850	4.58	34.58	2.10
014	22-44.0N	121-15.0E	0	27.90	33.55	4.39
			326	12.10	34.64	3.41
			408	10.02	34.56	3.11
			560	7.50	34.50	2.84
			642	6.60	34.45	2.63
			724	5.80	34.48	2.25
			808	5.05	34.50	2.18
015	22-44.0N	121-45.0E	0	28.20	34.11	4.16
			374	12.81	34.49	3.45
			470	10.01	34.61	2.81
			564	7.53	34.33	2.78

Table 10.(cont.) Oceanographic Observation Data[21]

Station Number	Latitude	Longitude	Observed Depth(m)	Temp(^{o}C)	Salinity(%)[22]	0_2(Ml/L)
			654	6.64	34.40	2.48
			744	5.56	34.49	2.40
			936	4.40	34.56	2.36
026	21-45.0N	121-15.0E	0	26.80	34.60	4.37
			384	11.61	34.61	3.10
			483	8.87	34.58	2.85
			581	7.27	34.60	2.47
			678	5.80	34.50	2.33
			776	4.86	34.48	2.20
028	21-45.0N	120-15.0E	0	28.10	34.09	4.33
			250	12.73	34.61	3.30
			374	10.16	34.67	3.20
			466	8.81	34.67	2.73
			560	7.88	34.61	2.67
			650	6.70	34.60	2.54
			746	5.91	34.60	2.20
			937	4.66	34.55	2.14
			1134	3.50	34.50	2.15

Figure 12. Temperature (°C) Section, Station 1-8

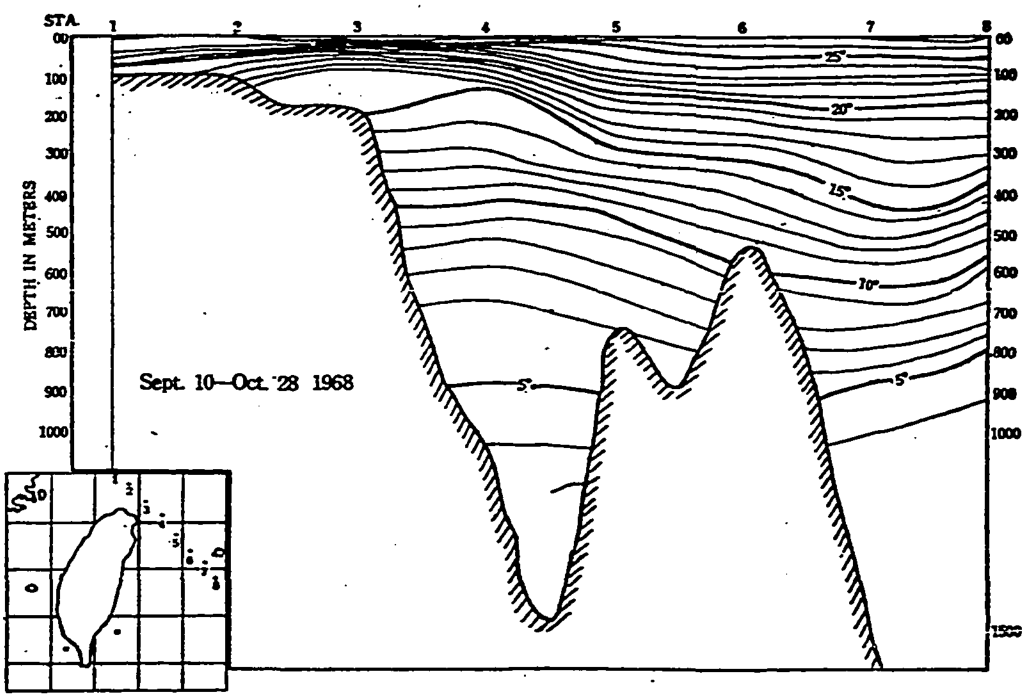


Figure 13. Temperature (°C) Section, Station 8-12

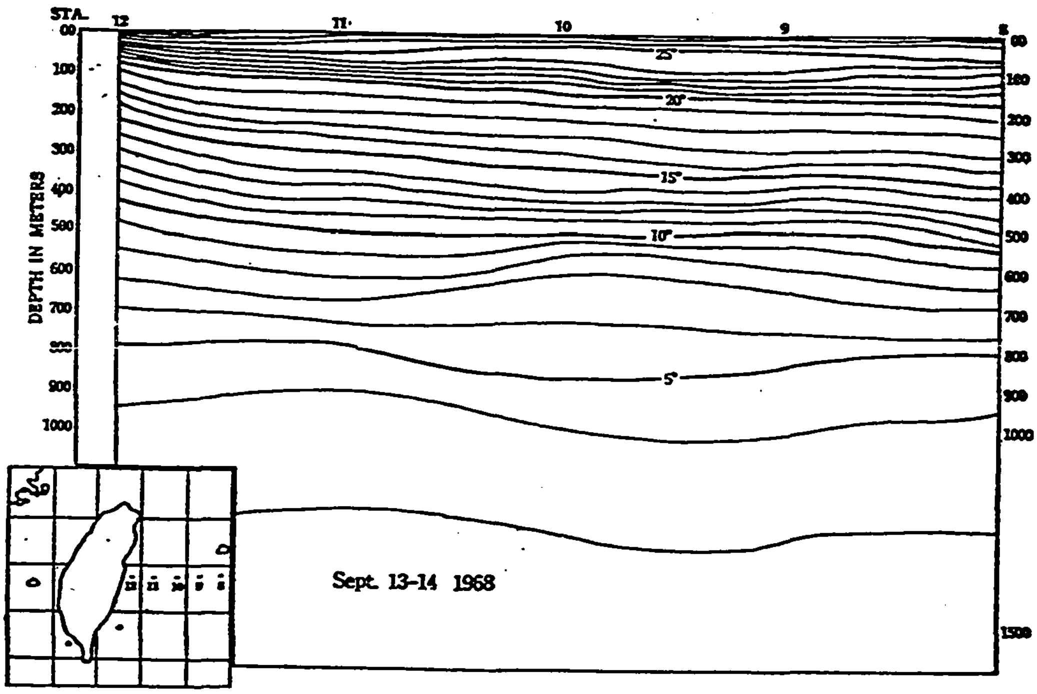


Figure 14. Temperature (°C) Section, Station 14-18

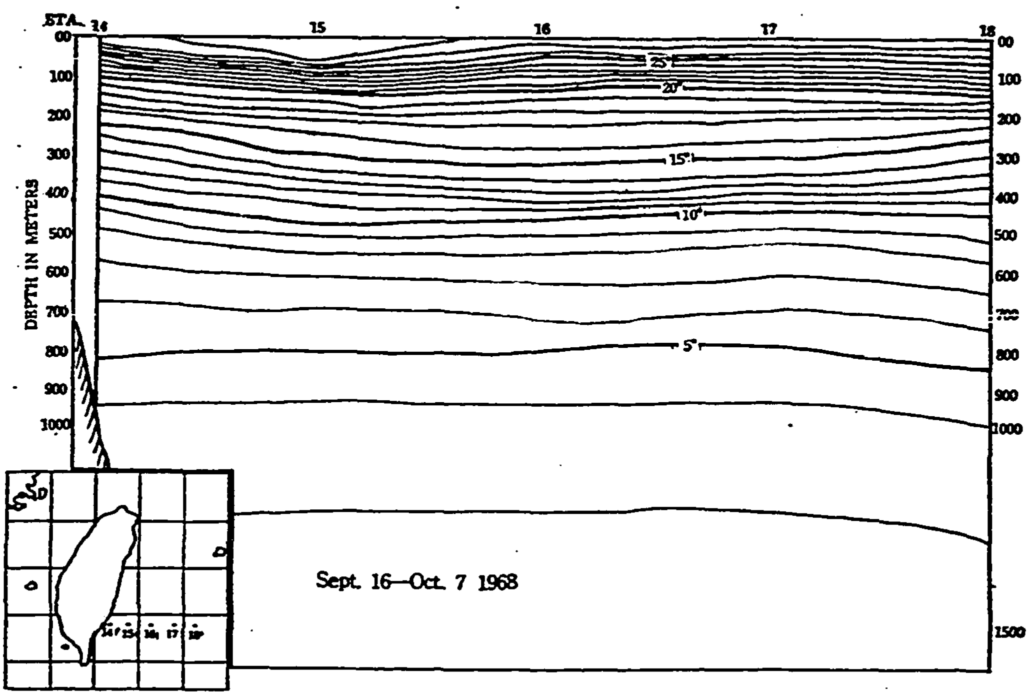


Figure 15. Temperature (^{o}C) Section, Station 22-30

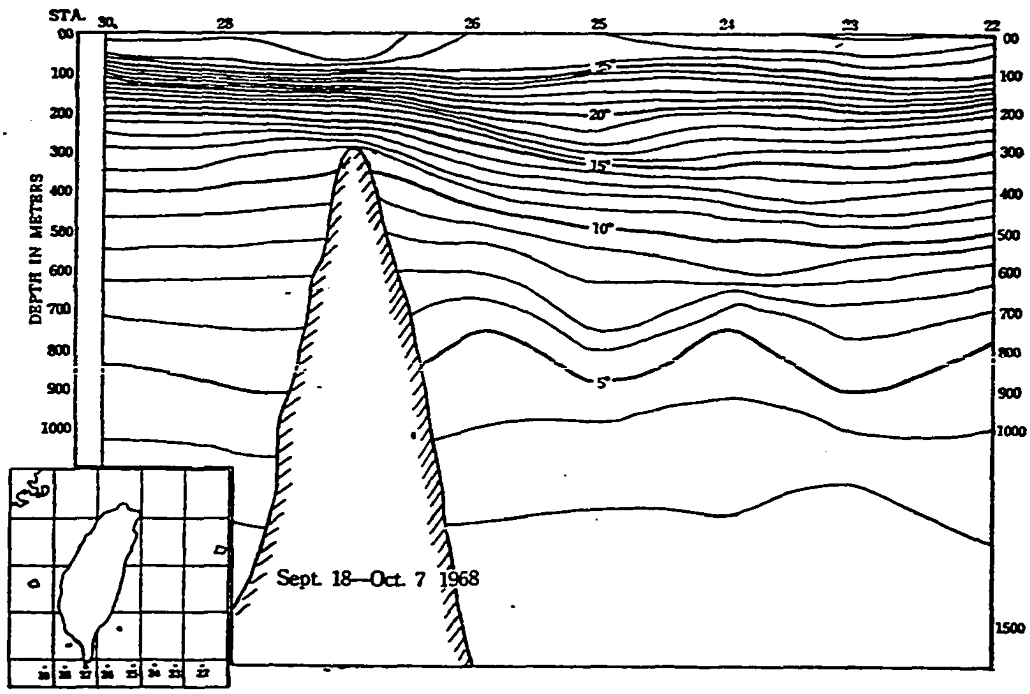


Figure 16. Kuroshio Sea Surface Current Flow
(7th Cruise)

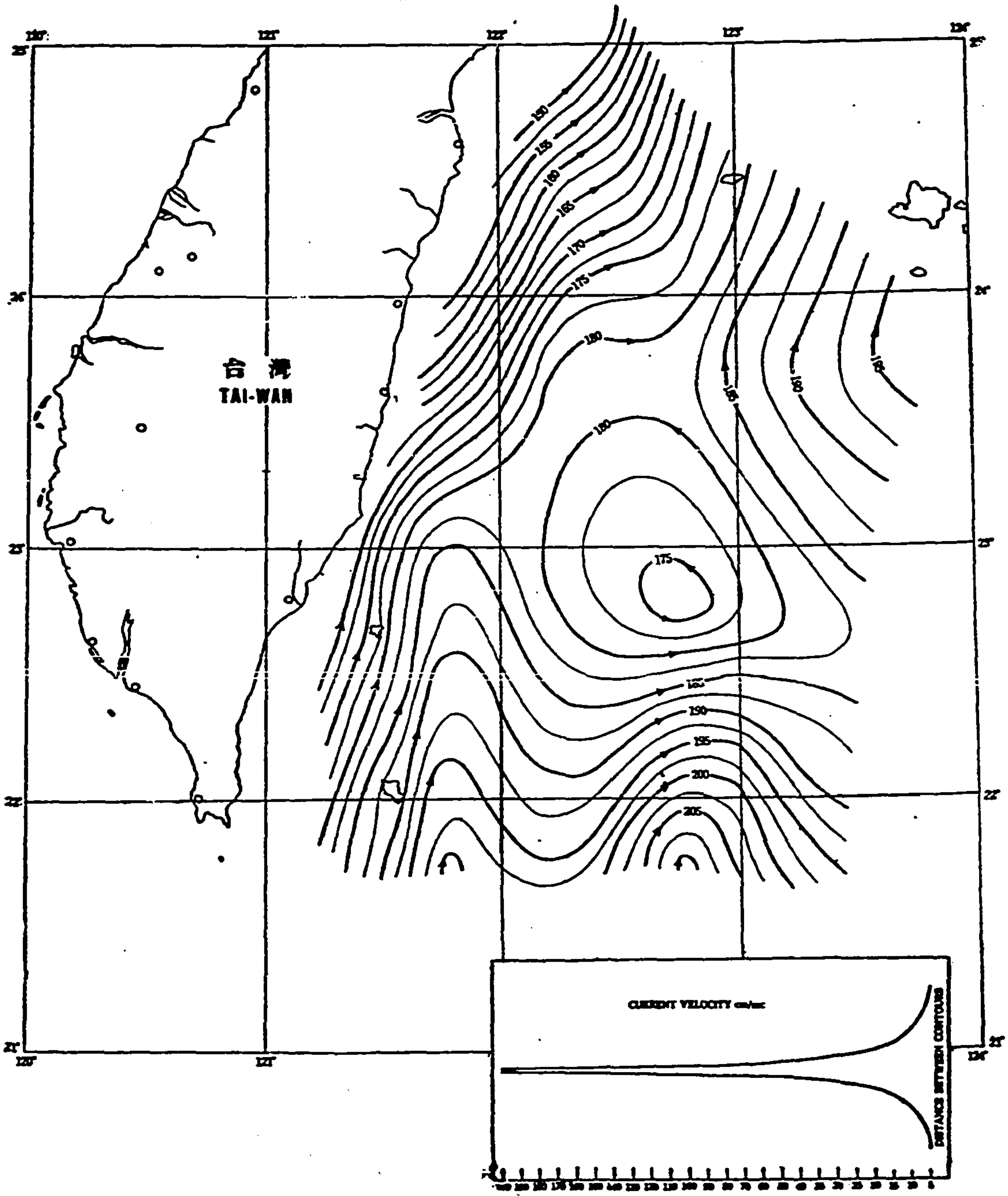


Figure 17. Kuroshio 50 Meter Current Flow
(7th Cruise)

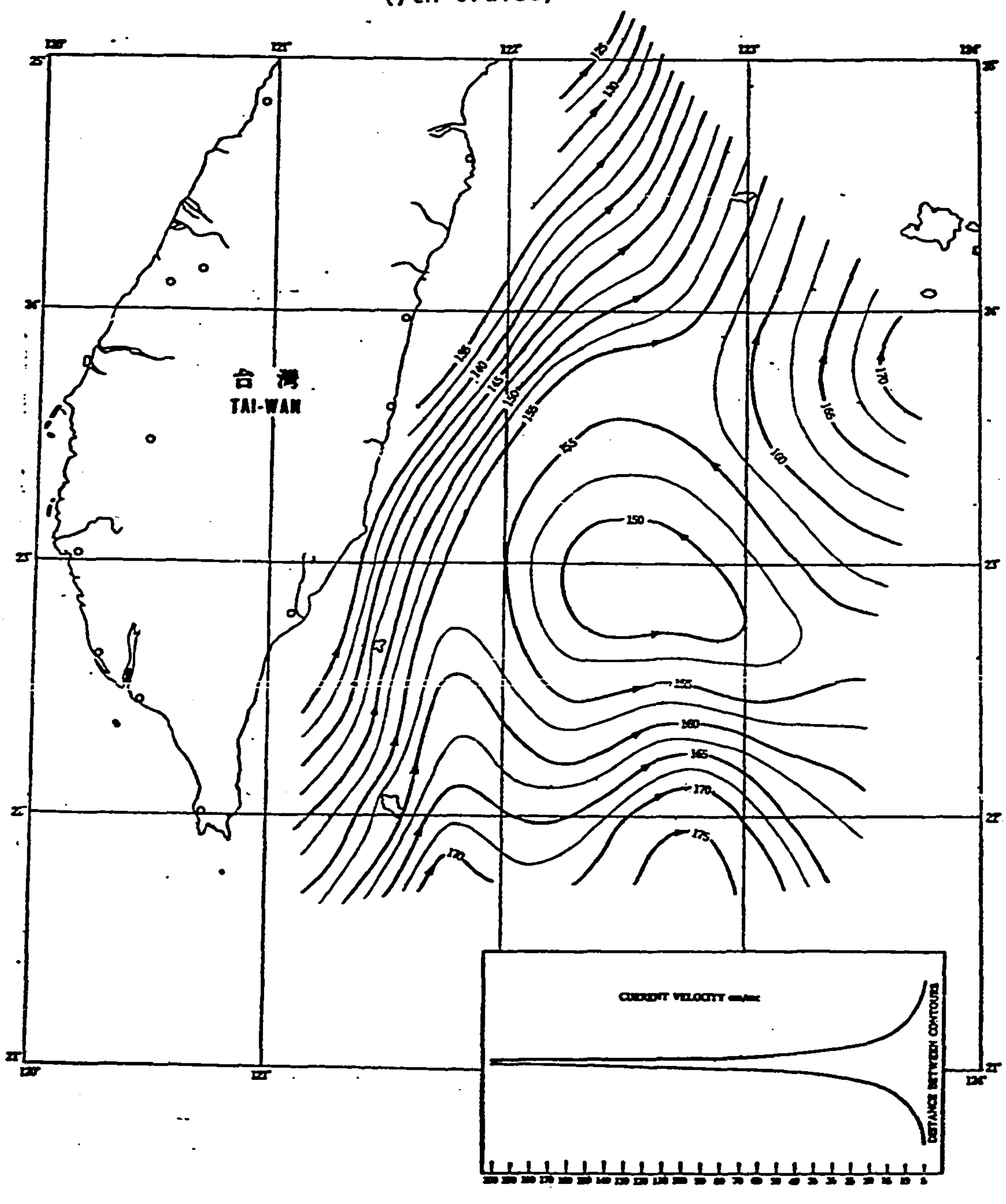


Figure 18. Kuroshio 150 Meter Current Flow
(7th Cruise)

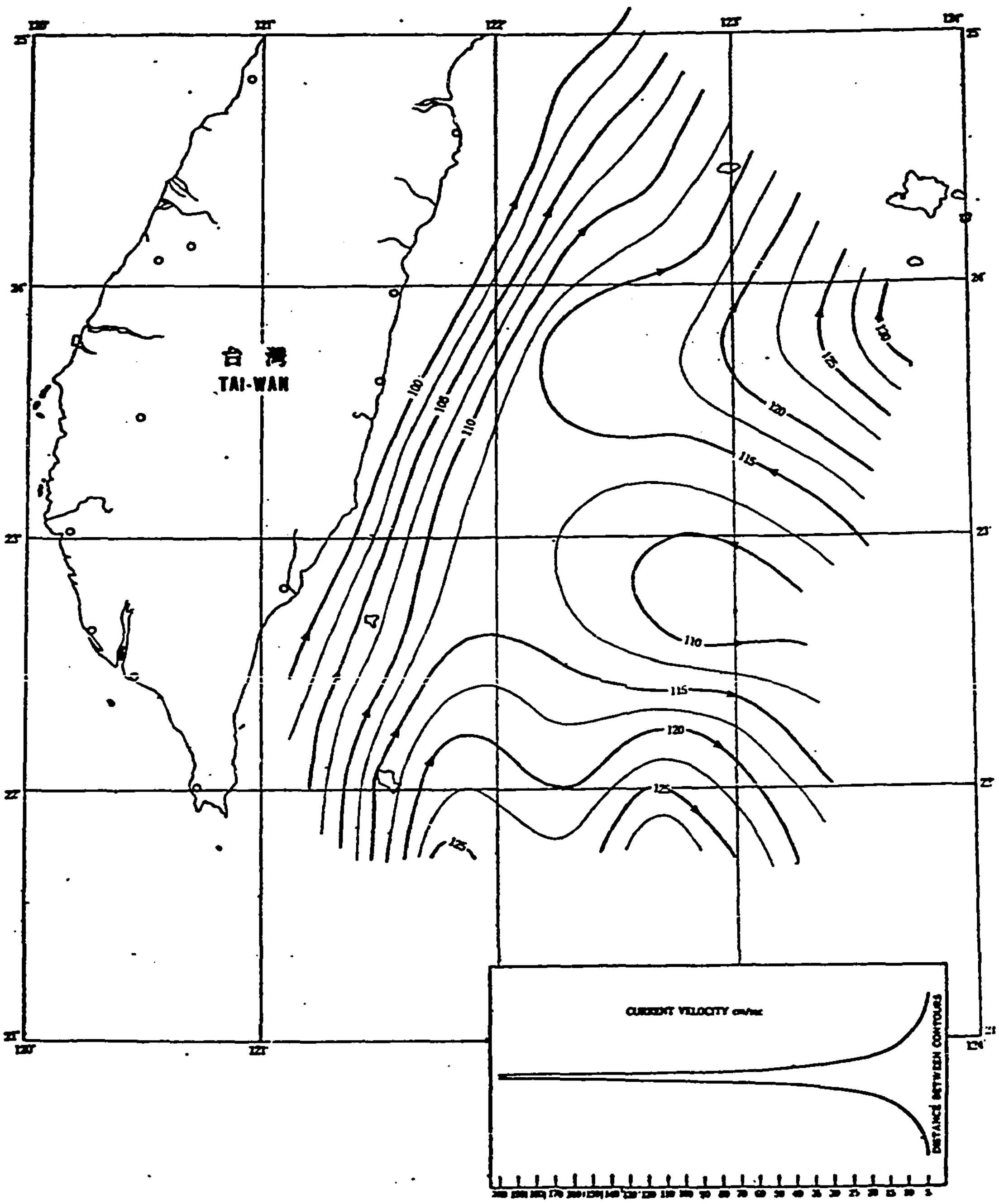
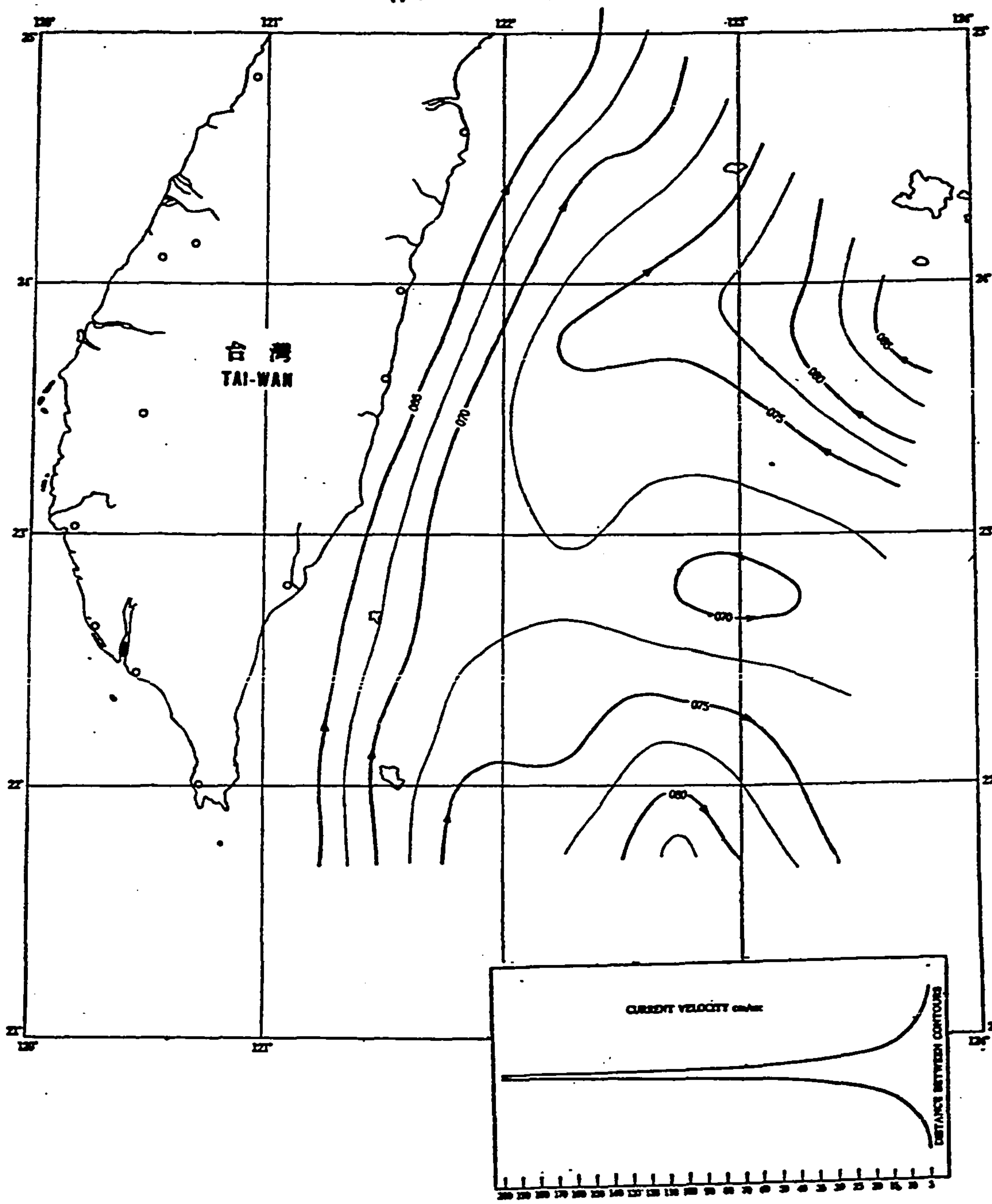


Figure 19. Kuroshio 300 Meter Current Flow
(7th Cruise)



the plant operations.

From the data of Figures 11 through 20 and Table 10, Stations 12 or 14 appear to be the most suitable sites for an SSPP facility for the following reasons: (1) There are maximum gradients of water temperature and maximum difference in water temperature with high volumes of water supply; (2) these stations are quite near the shore; (3) these stations are close to eastern Taiwan's biggest city, Taitung, a ready market for plant products; (4) there would be easy power transfer.

The SSPP installation costs are high ($300 to $500 per KW)[19] and the maximum theoretical thermodynamic efficiency is only 3.3% (actual efficiency only 2% or even less).[18] However, the SSPP "fuel" (water temperature difference) is free and endless. Therefore, this method of energy extraction from the sea is potentially of immense economic value and economic interest. Moreover, there would be some by-products from this process such as fresh water and hydrogen. The electrical energy generated in this manner could be used in an electrolysis process to generate hydrogen gas. This hydrogen gas would be piped ashore as a fuel to local power stations or various industrial organizations. The hydrogen fuel generated in this manner of course would have the great virtue of being "storable" while electricity must in general be considered non-storable. It would also be possible to utilize the solar sea power plant in a manner to produce steam for electrical power production while at the same time producing fresh water as a desirable by-product.

VII. USE OF THE SOLAR POND AS AN ENERGY SOURCE

The NASA/ASTM standard value of the solar constant at the top of the earth's atmosphere is 1353 Wm^{-2}.[19] (This value of the solar constant, is referred to as the NASA/ASTM standard since it has been adopted as the design criterion for NASA space vehicles and has been issued as the engineering standard by the American Society of Testing and Materials). Expressed in other units, the value is:

$$1.940 \text{ cal cm}^{-2} \text{ min}^{-1} = 429.2 \text{ Btu ft}^{-2}\text{hr}^{-1}$$
$$= 125.7 \text{ W ft}^{-2}$$
$$= 1.81 \text{ hp m}^{-2}$$

The solar constant denotes the intensity of solar radiation outside the atmosphere, incident normally upon a unit area in unit time. Therefore, if there were no atmosphere over the earth, every square foot of the earth's surface normal to the sun would receive 125.7 watts. But the exact value is much less than this, and depends upon the weather. On days of clear sunshine the intensity $\frac{\text{energy}}{\text{area}\cdot\text{time}}$ increases from zero at sunrise to a maximum at solar noon and decreases to zero at sunset. At any moment clouds may intercept the sunlight and decrease the intensity to a low value, that due to the diffuse sky radiation. Thus, the yearly average incidence of solar energy intensity on the ground is different at different places. This average value in the continental U.S. is 17 watts ft^{-2}.[24]

Unfortunately, there is no data about the solar radiation at ground level in Taiwan at hand. However, it is possible to compare it with California, because both the weather and the latitude in

Taiwan are similar to California. In this manner a rough estimate of the value of solar radiation at ground level in Taiwan may be established as approximately 24 watt ft^{-2}. (The average distribution of solar energy in the United States is about 1450 Btu's per square foot per day, and in California 2000 Btu's per square foot per day.)[25]

$$2000\ \frac{\text{Btu}}{\text{ft}^2\text{-day}} \times \frac{1\text{day}}{24\text{hr}} \times \frac{1\text{Whr}}{3.412\ \text{Btu}} = \frac{2000}{24\text{x}3.412}\ \frac{\text{W}}{\text{ft}^2} = 24\ \frac{\text{W}}{\text{ft}^2}$$

If the average solar energy incidence were 20 $\frac{W}{ft^2}$, a typical residential roof area of 1000 ft^2 would be exposed to an average of approximately 20 KW of power; this is equivalent to about 180 amperes in a 110 volt circuit $P = IV = 180 \times 100 = 19800W \approx 20$ KW.

Many attempts have been made to utilize the available solar power as a substitute for other sources of power. The solar pond is one of the systems which may be used to extract heat energy from the sun.

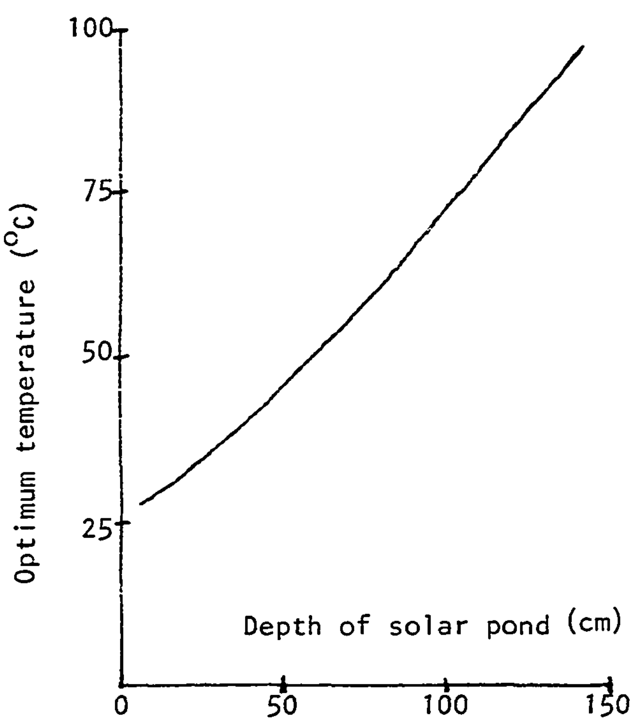
A solar pond is a shallow body of water about one meter deep containing dissolved salts to generate a stable density gradient (fresh water on top and denser salt water at the bottom). Part of the incident solar radiation entering the pond surface is absorbed throughout the depth, and the remainder which penetrates the pond is absorbed at the black bottom. The pond is initially filled with a sufficiently strong salt concentration gradient to eliminate convection. Thermal expansion in the bottom lower layers is thereby insufficient to destabilize the pond. Because of its relatively low thermal conductivity, the water acts as an insulator and permits high temperatures (over 90°C) to develop in the bottom layers.[26] Energy can be extracted from the pond by recycling the water in the hot layers of the pond through a heat exchanger.

Theoretical analyses predict and experimental results confirm that (1) the shallower ponds heat up faster but reach a lower "steady state" temperature.[26] (2) After the initial warm-up period, for a given extraction temperature, there is a particular value of the depth of the pond at which the rate of heat extraction is a maximum.[26] This means the optimum rate of energy withdrawal is equal to the radiation reaching the pond bottom per unit time, and thus in this case the pond is heated only by the radiation absorbed throughout its depth. Figure 20 shows the theoretical optimum extraction temperature as a function of the depth of the pond. (3) High temperatures close to boiling have been developed in the bottom of solar ponds and substantial heat energy has been successfully extracted from these ponds.[26]

A potential method of extracting solar pond energy is by use of thermocouples. If a chromel-constantan thermocouple[27] is arranged in typical solar ponds with one junction at the surface (assume $26^{\circ}C$) and one junction at the bottom (assume $90^{\circ}C$) then the electromotive force developed in the system would be 4.09 millivolts. (That is, 5.646 mV - 1.556 mV = 4.09 mV.)[28]

Because the resistivity of constantan is 44.1×10^{-6} ohm-cm,[29] by using a constantan wire 1 meter long and πcm^2 in cross sectional area, the resistance of the wire is 14×10^{-4} ohm ($R = p\frac{l}{A}$). Therefore, a solar pond, using such a chromel-constantan thermocouple should develop 2.92 amperes of current, and develop 1.2×10^{-2} watt

Figure 20. Variation of the Optimum Temperature with the Depth of the Solar Pond



of power.

$$I = \frac{E}{R} = \frac{4.09 \times 10^{-3} V}{14 \times 10^{-4} \Omega} = 2.92 \text{ amps.}$$

$$P = IE = 2.92 \times 4090 \times 10^{-6} = 1.2 \times 10^{-2} \text{ watt.}$$

One can increase the current or decrease the resistance by using several thermocouples in parallel. For example, with 100 thermocouples in parallel, the current should increase to 292 amps, so the power would reach 1.2 watt, but unfortunately the potential difference would still only be about 4 millivolts.

It is evident that this is not a very practical method of converting solar energy to electrical energy because of the low wattage output and the considerable expense of such long thermocouples. Also, the high salinity of the solar pond would be likely to cause serious erosion of the thermocouple's metals.

VIII. USE OF THE SOLAR CELL AS AN ENERGY SOURCE

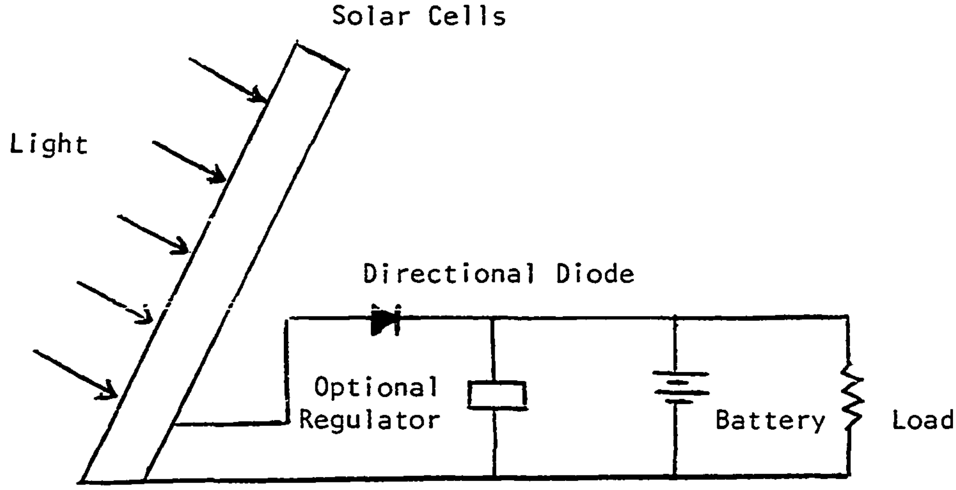
One way of utilizing the energy of the sun is to generate electricity directly from sunlight by the photovoltaic process. The photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by use of the photovoltaic effect are called solar cells.

Most solar cells are composed of crystalline semi-conductors prepared to have solid state characteristics which promote separation of photoelectrons and a resultant flow of electricity in an attached external circuit.

Figure 21 shows a conversion of photons of light energy to d.c. electricity. The d.c. electricity can be used directly, or it can be used indirectly to charge batteries or activate some other type of energy-storing device.

Although some solar cells are made from Cadmium sulfide (CdS), Cadmium telluride (CdTe), gallium arsenide (GaAs), germanium (Ge), and other combinations, the predominant basic material is silicon (Si). The main incentive for investigating the use of GaAs, InP, GaP, CdTe, and other materials as solar cells is to attempt to achieve a higher efficiency than is theoretically possible with Si, and to perhaps achieve better power output and stability at high operating temperatures. Recently, a special gallium aluminum arsenide photovoltaic cell with 16% efficiency was reported.[30] How-

Figure 21. Basic Solar Power Supply (Solar Cell)



ever, it was very difficult to prepare, and is thought to cost 10-100 times as much as the cost of a silicon cell.

In general, it is not expected that the efficiency of photovoltaic energy conversion at ambient temperatures will ever exceed about 25%.[24] The average efficiency of present production silicon cells is 13-14%.[24]

Assume that 20 W/ft^2 is received for one year on a typical residential roof area of 1000 ft^2. If this input sunlight is converted into electricity with 10% efficiency, it would produce 17,532 KWhr of energy. This electrical energy is more than twice the average 7691 KWhr[31] U.S. residential usage in 1972.

$$\frac{20W}{ft^2} \times 1000\ ft^2 \times 0.1 \times 8766\ hr = 17532\ KWhr$$

17,532 KWhr would provide the average amount of electricity for nine people in Taiwan this year; (1978)

$$\frac{33608 \times 10^6\ KWhr}{17 \times 10^6\ persons} = 1975\ KWhr/person$$

$$\frac{17532\ KWhr}{1975 KWhr/person} = 9\ persons.$$

It would take about 70 square miles of solar collectors to provide for all of the consumption of electricity in Taiwan (using 10% efficiency silicon cells under 20 W/ft^2 sunlight).

$$\frac{33608 \times 10^9 Whr}{20 \frac{W}{ft^2} \times 0.1 \times 8766 hr} = \frac{33608 \times 10^9 Whr}{17532 Whr/ft^2} = 191.7 \times 10^7\ ft^2 \times$$

$$\frac{1\ mi^2}{2.79 \times 10^7 ft^2} = 68.7\ mi^2$$

This is almost 0.5 percent of Taiwan's land area.

$$\frac{68.7\ mi^2}{13885\ mi^2} \times 100\% = 0.5\%.$$

Hence, only about 7 mi^2 of land area has to be covered by solar cells to generate 10% of Taiwan's electricity.

Using the current cost of solar cells[24] of approximately $200 per ft^2, 7 mi^2 of solar cells would cost about 400 billion dollars, which is a prohibitive cost. However, using the $1 per ft^2 cost hoped for perhaps in the next decade, the cost for 7 mi^2 of solar cells drops to approximately 200 million dollars which may make this system practical.

IX. USE OF NUCLEAR ENERGY AS AN ENERGY SOURCE

The Taiwan Power Company established the Nucelar Power Research Commission in 1955 to study the suitability of nuclear power plants for a multiple power source development program. Since 1964 nuclear plants have been under investigation for northern and southern Taiwan in order to supplement the electrical energy supplied to the two very large cities of Taipei in the north and Kaohsiung in the south.

Three nuclear plans having 6 reactors have been planned for Taiwan. The first nuclear plant is being constructed in northern Taiwan, with one unit of 636 million watts capacity already completed, and a second unit of the same capacity which will begin operation in December of this year (1978). A second plant is under construction on the coast near the first one and will have a capacity of 1970 million watts. The first unit will go on line in 1981 and the second unit in 1982, each at 985 million watts. Southern Taiwan's first nuclear plant will have two units of 951 million watts each, one to begin generation in 1983 and the other in 1984. (Table 11)[32]

After the six reactors are completed by 1985, the yearly generation will be 35,000 million kilowatt-hours[5] and will replace consumption of about 8 million kiloliters of oil fuel.[5] The total Taiwan energy generation in 1985 (all sources) is expected to be 71,990 million kilowatt hours (see Table 8). Therefore, the 1985 energy

Table 11. Current and Planned Nuclear Reactors for Taiwan[32]

Item	Capacity (MW)	Type	Reactor Supplier	Comment
Northern 1st Nuclear Plant (Unit 1)	636	Boiling-Water	GE Company	Generating
Northern 1st Nuclear Plant (Unit 2)	636	Boiling-Water	GE Company	Will go on line in December 1978
Northern 2nd Nuclear Plant (Unit 1)	985	Boiling-Water	GE Company	Will go on line in 1981
Northern 2nd Nuclear Plant (Unit 2)	985	Boiling-Water	GE Company	Will go on line in 1982
Southern 1st Nuclear Plant (Unit 1)	951	Pressurized Water	Westinghouse	Will go on line in 1984
Southern 1st Nuclear Plant (Unit 2)	951	Pressurized Water	Westinghouse	Will go on line in 1985
TOTAL	5144			

contribution of nuclear reactors should be

$$\frac{35,000\ \text{MKWhr}}{71,990\ \text{MKWhr}} \times 100\% = 48\%$$

Thus the nuclear reactors should increase the percentage composition of actual total power from the current 0.3% (see Table 12) to 48% in 1985.

Taiwan bought uranium from America and South Africa for short-time usage, and has signed a contract with the Paraguay government to investigate and exploit uranium mines in that country.[5] It is estimated that about 1000 metric tons of uranium ore will be needed per year after the three nuclear plants are completed in 1985.

The waste nuclear products will be stored in the nearby scattered islands until the United States has solved the waste products problems. (Now, United States law prohibits the re-use of waste uranium products because of concern for nuclear weapon proliferation.)

Table 12. Generating Method, Generation and Composite in Taiwan, 1977[5]

Generating Method	Generation (M,KW-H)	Composite %
Hydro	3,999	13.5
Nuclear	91	0.3
Thermal	25,634	86.2
TOTAL	29,724	100.0

X. SUMMARY AND CONCLUSIONS

The world population is increasing rapidly and by the year 2000 it will have reached approximately 6000 million people. The estimated world energy demand in the year 2000 is 50×10^{12} KWhr/year.[26] The earth's material resources are not unlimited but finite. Table 13 shows the ultimate resources of energy from all fossil-fuel deposits of the world.[33] These resources will be exhausted at some future point in time - which can be counted in decades for oil and gas and hundreds of years for coal. The inescapable fact is that from now on energy resources will become increasingly scarce and more expensive. Therefore, alternative energy sources need to be developed which at first can supplement the primary non-renewable energy resources and in the future replace them when they have been exhausted.

Taiwan's population[3] is 17,009,328 at the end of August, 1978. It will have reached approximately 23 million by the year 2000 (using a predicted[3] yearly increase of 1.5%). The generation of energy will have reached approximately (total power capacity) 422,000 MKWhr (assuming a yearly growth rate of 12.6% based on Table 8 data). Since Taiwan is not rich in natural resources, efforts should be made to develop new energy sources to provide the minimum energy necessary to maintain a satisfactory life.

Before answering the question, "Which one or two methods of those discussed seem the most practical and economical to increase the energy available to Taiwan?" it is necessary to consider first

Table 13. Ultimate Resources of Energy for All Fossil Fuel Deposits of the World[33]

Item	In hphr x 10^{14}		In KWhr x 10^{14}		In BTU x 10^{17}	
	maximum	minimum	maximum	minimum	maximum	minimum
Coal	750	75	559.27	55.92	1908.75	190.87
Petroleum (liquid)	5	3	3.72	2.23	12.72	7.63
Natural Gas	3	2	2.23	1.49	7.63	5.09
Oil Shale	12	2	8.94	1.49	30.54	5.09
Tar	20		14.91		50.90	
Peat	5	5	3.72	3.72	12.72	12.72
TOTAL	795	87	592.79	64.85	2023.26	221.40

the economic criteria as they relate to the various energy sources. Along with costs and practicality one must also consider the environmental constraints.

The economic criteria concerning costs consists of (1) installation costs (capital costs) and (2) power production costs (fixed charge costs, fuel-cycle costs, operation and maintenance costs).

Costs of wind plant installations are expected to range from about $300 to $600 per kilowatt with electric energy costs ranging from 16 to 21 mills per KWhr.[19] The cost of harnessing 500,000 kilowatts in tidal power plants is $100,000,000,[9] that is equivalent to $200 per kilowatt. The cost associated with a 110 MW natural-steam power plant is $4,165,600 for installation and the total energy cost is 3.35 mills per KWhr,[34] which is equivalent to $37.8 per kilowatt. SSPP installation costs are estimated to be between $300 to $500 per kilowatt and the cost of energy is expected to range from 5 to 10 mills per KWhr.[19] Silicon solar cells with at least a 10 percent conversion efficiency for sunlight are currently very expensive to fabricate. Silicon solar cells cost about $20 per peak watt for moderate quantities of cells[35] or $30 per peak watt for an array.[35] (A peak watt is defined as the maximum power output of an array at normal incidence to the sun in the Zenith at sea level on a clear day. A typical maximum power output is approximately 100 millivolts per cm^2.) For a large power system, with the devices placed in arrays, power would cost more than $30,000 per installed peak kilowatt of electrical capacity.[35] Nuclear plant installation costs are rising above $500 per kilowatt.[19] The cost of heating a solar pond is 1.1 cents per KWhr based upon a pond of 140 m^2 area. By employing a large pond (20 x the above area) to supply heat for 20 houses, the cost is reduced to 0.41 cents per KWhr, which is lower than the cost of heating by conventional fuels.[26] Costs of natural gas during 1971 ranged from about 0.85 mills to 3.4 mills per KWhr.[19] Natural crude oil ranged from about 1.7 mills to 3.4 mills per KWhr.[19] Estimates of the price of fuel derived from pulpwood and chips range from about 3.9 mills to 4.6 mills per KWhr in 1971.[19] Coal and oil costs ranged from about 1.7 mills to 3.4 mills per KWhr at that time.[19]

The comparative costs for the construction of various types of electric power plants are shown in Figure 22.[26]

The electricity cost per KWhr versus the load factor for various means of electricity generation are shown in Figure 23.[26] The capital cost component of energy Ge is calculated from the equation:

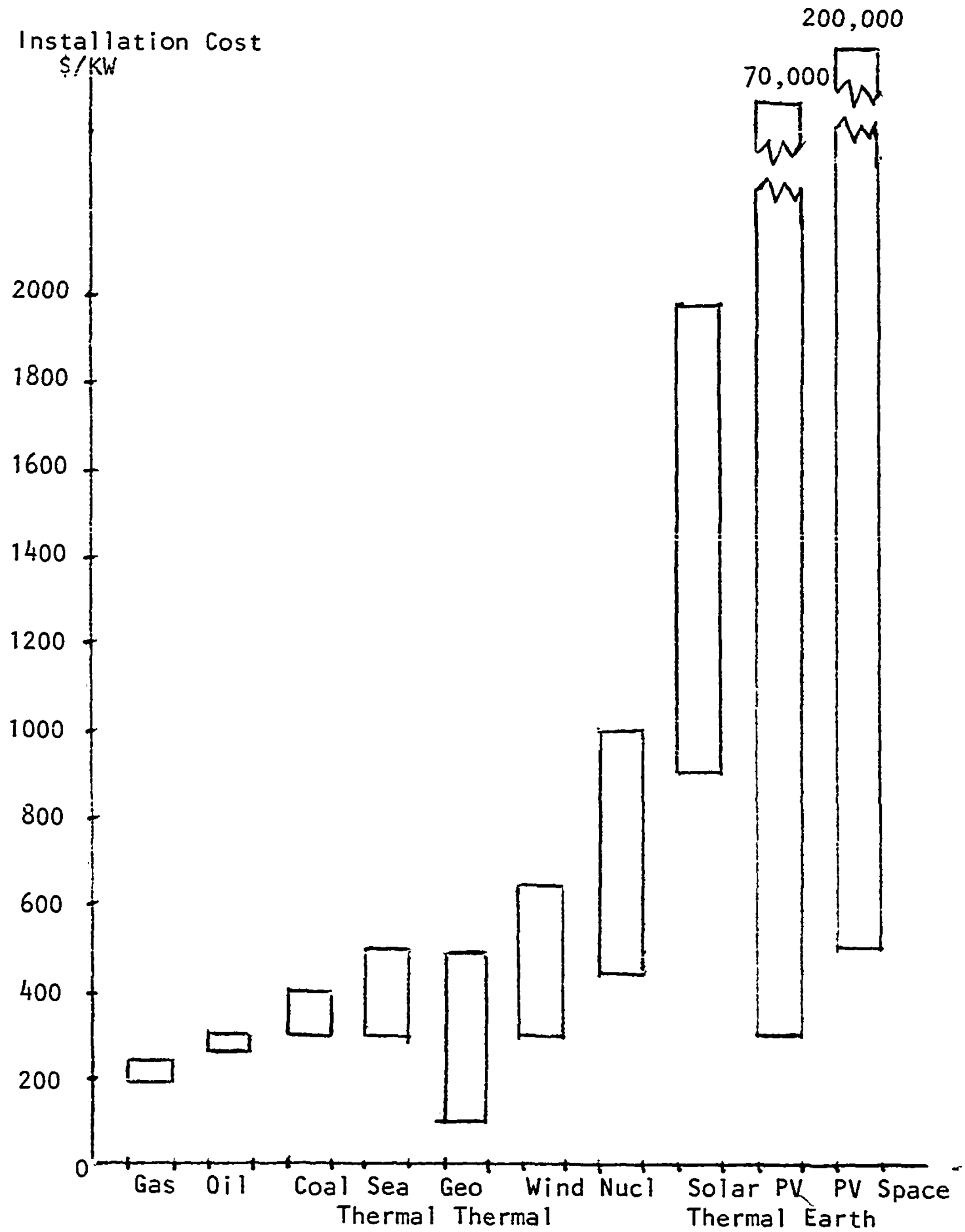
$$Ge = \frac{10^3 R(pc)}{8760L} \quad \frac{\text{mills}}{\text{KWhr}}$$

where R is the total fixed charge rate per year, (pc) the plant capital investment cost ($/KW), and L the load factor (%).

Although low wind speeds make windmills unsuitable energy sources for Taiwan's coastal plains or terrace tablelands, windmills might be feasible for the mountain regions because wind speed is directly related to height. A general equation for determining wind speed at a specific height when the wind speed is known at a reference height is given by[7]

$$V_x = V_F \left(\frac{h}{30}\right)^{\frac{1}{N}}$$

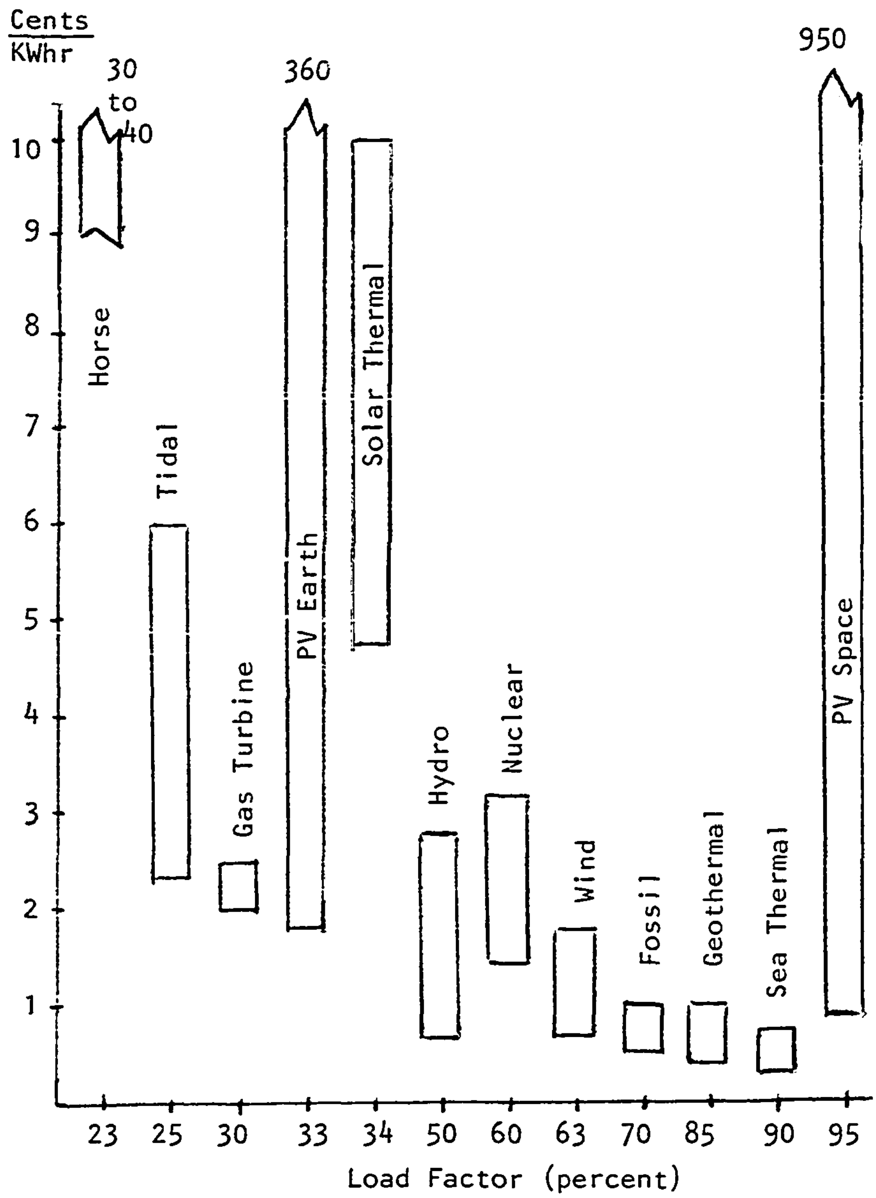
Figure 22. The Relative Installation Costs of Various Energy Sources



Note: PV = Photovoltaic = solar cells

Figure 23. The Relative Costs of Various Energy Sources Versus the Laod Factor

(Note: Load Factor = Average Power/Peak Power)



where V_x is the velocity at the desired height

V_F is the velocity at the reference height of 30 feet

h is the height above ground

$\frac{1}{N}$ is the estimated power law increase, the quantity substituted for N depends on terrain conditions. In open farm country and level for slightly rolling terrain, a factor of 7 can be substituted for N. In level and rolling country with numerous obstructions, the factor is about 5. An estimate of 3 is appropriate for city outskirts and near suburbs and areas with large obstructions.

The central range of high mountains stretches from north to south for a distance of 170 miles and has a maximum width of 50 miles. The area occupied is about half the island. Peaks rise to between 12,000 and 13,000 feet.

Taking h = ½ (maximum mountain height) = ½ (13,000) = 6,500 ft.

$$N = 5 \text{ and } V_F = 2\frac{m}{s},$$

$$\text{then } V_x = 2\left(\frac{6500}{30}\right)^{\frac{1}{5}} = 2 \times (217)^{\frac{1}{5}} = 2 \times 3 = 6\frac{m}{s} = 13.4\ \frac{mi}{hr}.$$

This wind speed is sufficient for installation of a practical wind-generating system.

Moreover, there are some aborigines people living an undeveloped life in Taiwan's mountains. They have no transportation and no electricity. The Taiwan government might profitably install windmills in the mountain regions with higher wind velocities. This would not only solve the problem of transmitting electricity from the hydropower plants or nuclear plants in the coastal plains terrace tablelands, but also lift the standard of living for the aborigines.

Because the wind is free, no charge for the fuel, it requires only a little money to install (capital costs) and very little to operate (power production costs); wind power costs the least and apparently benefits the most.

The well-known English scientist, J. B. S. Haldane has voiced an odd warning about the use of tidal energy.[36] In his opinion, the unlimited exploitation of tidal energy will slow the rise and fall of the tides, which in turn will seriously affect the earth's rotation. As a result, the days would become longer, the moon would approach closer to the earth, and the end result would be the cataclysmic destruction of our planet. Haldane figures that it will take about 36 million years for the earth to be destroyed in this way.

Whether his ideas are right or not, (the theory has not yet been well-received by most scientists), at least it is no doubt true that developing tidal power in Taiwan is not a suitable method, although the energy of the tides is enormous. The reasons are (1) costs, and (2) land availability.

The fact that tidal energy is free does not mean that it will automatically have a low utilizing cost. Actually, the installation costs and the power production costs of a tidal power plant are extremely high (see Figures 23 and 24).

In order to utilize tidal energy, two things are needed: (1) a large mean difference between high and low tide, and (2) a shoreline of suitable geography for the establishment of one or two storage basins. However, in Taiwan there are no natural dams or basins. To construct such a facility would be too expensive both in money and in vital land use. Taiwan's population density is the highest in the world. Agricultural land and residential land are the big problems of Taiwan.

In Taiwan, waterfalls are short and small; the water flow is too small, the head is too low for practical energy extraction. They have usefulness for sight-seeing, but not for power generators. This is the reason that there are no hydroelectric power plants using waterfalls in Taiwan.

Although Taiwan has few long and large streams, it also has several small streams which merge to form big rivers, with dams to hold the water, thereby generating power. So hydropower is an important power source in Taiwan's past, present, and future. Hydropower is one of the better sources of electricity. It requires no mining, processing, transportation, or burning of fuel. In addition, hydroelectric plants are usually part of larger developments involving navigation, recreation, fish and wildlife management, water quality control, water supply, flood control, or irrigation. These features combine to make hydroelectricity very cheap.

Even though Taiwan has volcanic areas available, its development of geothermal energy is too slow. After the completion of the first practical geothermal power plant at Ilan in 1980, it will only produce 0.2% of Taiwan's total power. It is true, however, that to drill a hole or well reaching to several hundred feet in depth, or to several thousand feet in depth is expensive. Geothermal power may not be practical for all of Taiwan but it certainly is desirable for the northeastern part of Taiwan. The first reason is that very few power plants are located in northeastern Taiwan, most of them are located near Taipei (a northern city) and Koohsiung (a southwestern city). Secondly, plenty of geothermal sources are buried deep underground in northeastern Taiwan.

In my opinion, with the dwindling of conventional energy resources, a rising population, and rapid technological advancements, Taiwan should change the present energy conversion system. No doubt solar energy will play a prominent role because of the following facts: (1) solar energy is immense in quantity, (2) solar energy is widely available, (3) solar energy is non-polluting, and (4) solar energy is free for the taking.

Solar radiation at the outer limits of the earth's atmosphere has been estimated at about 5.2×10^{21} Btu's per year. Even with a loss of about 54 percent of this energy at the earth's surface, (35 percent reflected, 19 percent absorbed and re-radiated), the 2.4×10^{21} Btu's per year absorbed at the earth's surface have been estimated at roughly 18,000 times the energy consumed in all man-made devices used throughout the world.[25]

The widely available solar energy uses consist of heating and cooling of buildings, solar thermal energy conversion, photovoltaic conversion, biomass production and conversion, wind energy conversion and ocean thermal energy conversion.

Both the direct form of solar energy and indirect form of solar energy are operating entirely without fuel, since the original energy all comes from the sun, needs no mining, and no transportation.

Hence, there is no pollution or environmental problems.

A solar pond, or solar cell, or light-energy converter can be designed to deliver a certain amount of power in the daytime. However, any solar system, to be worthy, should also be capable of taking care of night-time needs. In terms of electrical energy, this can be handled by changeable batteries. Thus, a 24-hour, all-year-round system requires both the light-energy converter and the energy-storing battery system. Such a system can be combined into a completely self-sustaining and self-maintaining, unattended installation.

Academic Sinica of the Republic of China has estimated[37] that a 160-km^2 solar collector will produce the electricity equivalent to the total energy generated by Tai-Power. That is similar to a "big oil mine." But unlike the oil mine it will not be exhausted within several decades; so long as the sun exists, the energy is endless.

It has been estimated[37] that using less than 3 percent of Taiwan's land area to install solar collectors with an 8% conversion efficiency would generate twice the present Taiwan yearly consumption of energy. It is equal to the energy produced by 48 million kiloliters of oil. If, by successful development and technological advancement the conversion efficiency can be increased to 20% or more, the resultant energy derived would be greater than that from all of the "fossil mines" of Saudi Arabia.

Nuclear energy is one of the most desirable of the feasible energy options of Taiwan. Nuclear reactors may play a vital role in the future of Taiwan for the following reasons: (1) The power needs of Taiwan are increasing rapidly. (2) Taiwan lacks large fossil fuel resources. (3) Nuclear reactor fuel is economically competitive with fossil fuels. (4) Nuclear reactor operation is "clean" with respect to the environment.

Because of the growth of industry and the rising standard of living, power needs have increased rapidly in Taiwan. The average yearly growth rate of electrical generation in Taiwan is approximately 13.5%. Table 14 illustrates the yearly percentage monetary growth rate for manufactured products for principal Taiwan manufacturing industries during the years 1976 and 1977.

The yearly Taiwan electric generation and growth rate for each year during the past ten years (1968-1977) are shown in Table 15.[5]

Taiwan has inadequate fossil fuel resources to meet its current energy crisis so most of the fuel supplies need to be imported. Because of the industrial development dependence on oil, if the oil price rises or if there is a shortage of supply, it will hamper Taiwan's economic development. An increased construction rate of nuclear reactors is a feasible way of reducing Taiwan's dependence on foreign energy sources.

Nuclear power has a considerable virtue in that nuclear fuel requires only a small fraction of the mass and volume of fossil fuels to produce the same quantity of electrical energy. For example, one pound of uranium the size of a golf ball has the same potential energy as nearly 3×10^6 pounds of coal; i.e., about 25 railroad cars full of coal,[38] or as nearly 2.3×10^6 pounds of

Table 14. Percentage Annual Monetary Growth Rate for Manufactured Products During the Years of 1976 and 1977 for Taiwan Industries

	1976	1977
Paper	18.5%	5.9%
Chemicals	20.7	6.7
Petroleum Products	40.5	39.1
Basic Metals	30.1	14.6
Metallic Products	28.0	13.3
Machinery	27.8	11.6
Electrical Apparatus	45.2	20.3
Transportation Equipment	0.3	19.6
Foods	15.4	8.0
Textiles	18.1	9.0
Wood Products	30.0	12.8
Nonmetallic Mineral Products	21.6	26.4
Rubber Products	27.3	4.6

Table 15. Annual Electrical Generation and Electrical Growth Rate in Taiwan for Each Year During the Past Ten Years (1968-1977)[5]

Year	Generation (MKWhr)	Growth Rate (%)
1968	9.802	16.5
1969	11,119	13.4
1970	13,213	18.8
1971	15,171	14.8
1972	17,449	15.0
1973	19,805	13.5
1974	20,534	3.7
1975	22,894	11.5
1976	26.877	17.4
1977	29,724	10.6

1968 - 1977 Average Yearly Growth Rate 13.5%.

petroleum. That means that a very small nuclear source can produce a tremendous amount of power. Also, it is easy to transport as it does not need large oil-ships or tankers. The nuclear generation of 1.25×10^{11} KWhr in the United States[32] in 1974 may be used as an illustration. This amount of nuclear energy was 7.9% of the total energy generation and was equivalent to 185×10^6 barrels of expensive oil or 45×10^6 tons of coal at a cost of approximately 800 million dollars.

Typical fossil fuel power plants will produce 20000 tons of SO_2 and other waste products yearly and these are spread into the air, earth and water. But the same size nuclear power plant only produces 720 lbs. of waste products,[32] and the waste products are under strict control. These nuclear wastes are handled carefully and not allowed to spread into air or water carelessly.

In nuclear power development the fissionable elements used most often are uranium and plutonium. The statistics imply that uranium resources will run out at the end of this century.[32] The use of uranium ($^{235}_{92}U$) to fuel nuclear reactors in Taiwan must be considered a short-term replacement of coal and oil fuels. Although Taiwan does not have resources of uranium, it does have resources of thorium. Therefore, Taiwan needs to develop technology for utilizing thorium for reactors to serve its future needs.

The thorium atom ($^{232}_{90}Th$) is not readily fissionable. But on absorption of a neutron, however, it undergoes changes leading to the formation of an isotope of the element uranium (^{233}U), ^{233}U is fissionable. This process is called breeding, and ^{232}Th is said to be fertile. The nonfission capture of neutrons by a fertile ^{232}Th nucleus results in a series of reactions culminating in fissionable ^{233}U as follows[39]

$$^{1}_{0}N + ^{232}_{90}Th \longrightarrow ^{233}_{90}Th + h\nu$$

$$^{233}_{90}Th \longrightarrow ^{233}_{91}Pa + ^{o}_{-1}e$$

$$^{233}_{91}Pa \longrightarrow ^{233}_{92}U + ^{o}_{-1}e$$

where $h\nu$ = gamma and $^{o}_{-1}e$ = beta.

The following conclusions are indicated:

<u>Tidal Energy</u>

It is not feasible to use tidal power plants in Taiwan because (1) the installation costs are too high, (2) the reservoirs needed are too large, and (3) no natural dams or basins exist in Taiwan.

<u>Waterfall Energy</u>

All waterfalls in Taiwan are too small and too short to satisfy the electrical power generation demands. However, if hydroelectric power plants are installed by the rivers which collect several small streams, the power developed could make an appreciable contribution to Taiwan's needs. Furthermore, water power is very cheap.

<u>Wind Power Energy</u>

In order to raise the standard of living for the aborigines that live on the mountain, Taiwan should establish wind power plants there, because the wind speed is higher than at the ground level. Moreover, it is a step toward a goal of energy self-sufficiency for Taiwan.

<u>Geothermal Energy</u>

By building geothermal energy plants at the volcanic area or earthquake zone, some of Taiwan's problems of electrical distribution could be reduced because the electric power plants are far away from this northeastern area.

Ocean Thermal Energy

Development of energy plants to utilize the ocean thermal gradient seems highly desirable to help to offset the diminishing supplies and increased prices of imported fossil fuels. Station 14 (see Figure 11) which is located on the eastern coast of Taiwan and very close to Tai-Tung city is the most suitable site for a Solar Sea Power Plant facility.

Solar Energy

Solar energy should stand out as an inexhaustable alternative energy source, if it can be harnessed without economic constraint. In Taiwan's southmost part, there is a large land area with a high concentration of salinity making it useless for farming. But the sunlight there is intense, so this is the best place to locate a solar energy plant. Taiwan should begin to establish pilot plant solar cell operation in this area to gain experience with the technology while waiting for lowering costs to make a large scale system feasible.

Nuclear Energy

Nuclear energy has been the bright hope of the future to pick up the electric power generation load from the fossil fuels. The element thorium (^{232}Th) a natural resource of Taiwan, provides the greatest encouragement as the nuclear power plant fuel source of the future. Not only should Taiwan make increased use of uranium fueled reactors to meet the increased energy demands of the present, but Taiwan should also pursue development of reactors which will utilize thorium to meet its future energy needs.

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