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Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment

Volume 4 of 5 Vols.
Annexes 6-10

April 1979

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VOLUME IV

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1.0 OVERVIEW

A two-month investigation was made of the hydroelectric resources of Egypt. Information was obtained from published reports available in both the United States and in Egypt (see section 9.0) and from direct interviews with Egyptian officials in Cairo (see section 10.0). The investigation assessed the potential for hydroelectric power development in Egypt and was the basis for remarks concerning the selection and timing for construction of preferential sites. This report summarizes those investigations and presents observations based on various options of possible development of hydroelectric power generation.

Although Egypt is generally believed to have little potential for further hydroelectric development, there are numerous sites which are practical and feasible for construction. The only existing hydroelectric power plants are on the upper Nile River at the High Dam (2100 MWe) and the Aswan Dam (345 MWe). There are eight sites on the Nile River where it is practical to add hydroelectric generation and, of these eight, four sites, totaling about 350 MWe, are feasible for immediate construction (see figure 1). There are also pumped-storage sites on the Nile River which are not practical to develop at the present time. There is a large potential for pumped-storage generation on the Red Sea: about 20,000 MWe in the Suez area has been investigated and found feasible for development. There is also the Qattara Depression in the Western Desert which can be utilized for conventional, as well as pumped-storage hydroelectric generation, by bringing water from the Mediterranean Sea to the depression by means of an open canal or by tunnels. Preliminary studies have shown that up to 2400 MWe of generation could be developed at the depression.

Each of the potential hydroelectric power generation sites was investigated to see which were feasible and practical for development by the year 2000. Each site was studied for: (a) cost of power developed; (b) impact on environmental, social, economic, and institutional factors; (c) need for the type of power available from the site; (d) policy implications of developing the site such as achievement of national objectives and government policy considerations; (e) transmission additions required and effects on system reliability; and (f) special problems of construction involved. After considering the above factors, a list of options was developed for construction of hydroelectric power generation to meet the electric load growth of Egypt when other forms of energy supply would be integrated into a comprehensive supply pattern.

The options derived range from zero development to maximum development of all the feasible hydroelectric generation potential in the country. Since neither of these two extremes appear practical, options between them, detailing individual development of sites from 1985 to 2000, were chosen. Reasons are given for the selection of some options and the rejection of others.

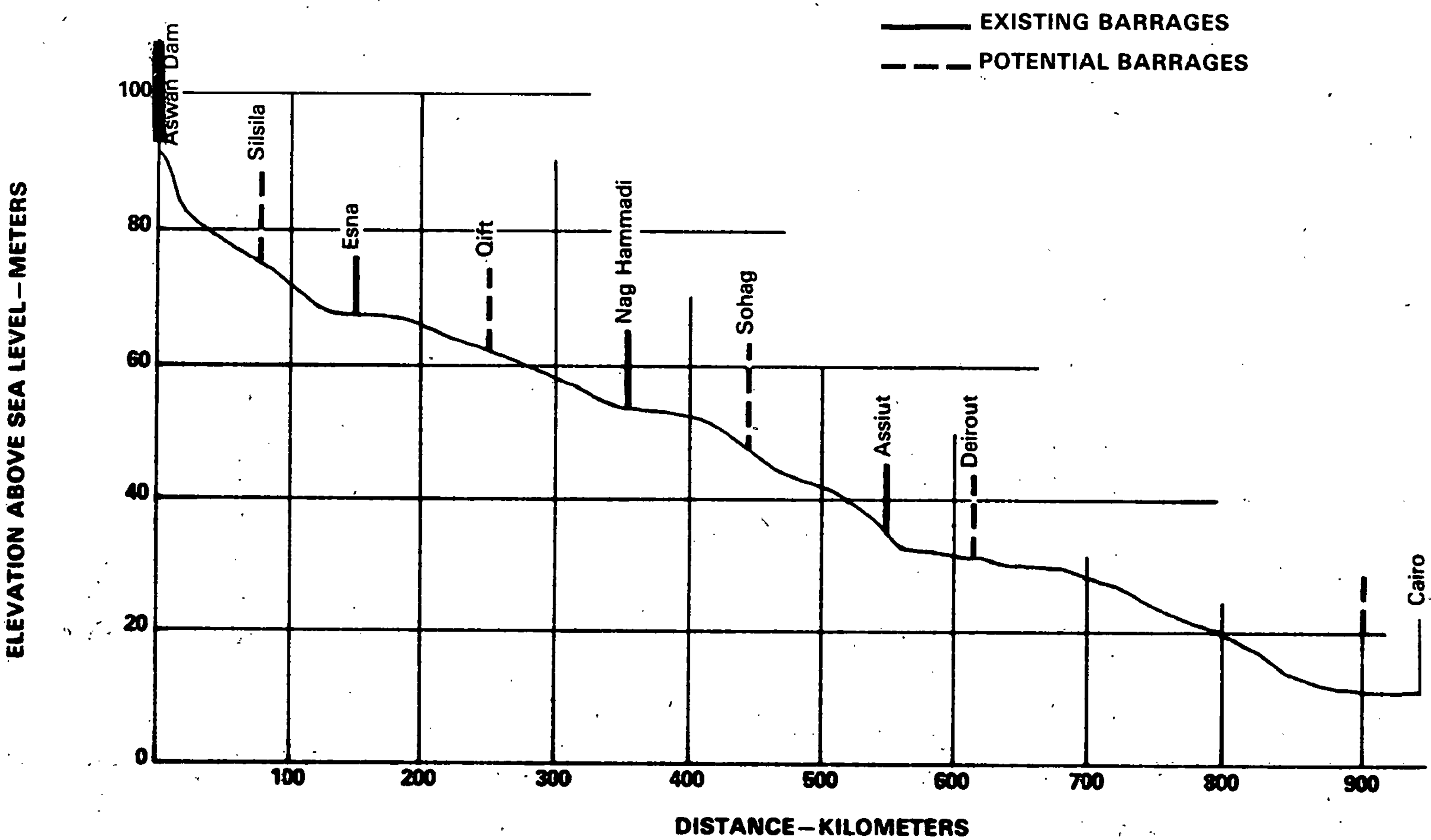

Fig. 1. Nile River Profile

It is clearly illustrated that Egypt should develop its hydroelectric resources as quickly as practical for two basic reasons. Hydroelectric power generation is the optimum method of supplying peaking power to blend with other power supplies to meet total power demand requirements. It is also the most economic source of power supply, because it does not consume expensive fuels which could otherwise be exported; therefore it enhances the country's general economic picture. A progressive plan for early hydroelectric development in Egypt should be initiated immediately.

2.0 SELECTION OF OPTIONS

The criteria for selecting options were basically a matter of whether the option was feasible and practical for construction. An option is feasible if the total capital cost of development and the unit cost per kilowatt and/or kilowatt-hour (kWh) is competitive with other forms of energy generation. An option is considered practical if the development would furnish the type of power which would successfully integrate with other power supplies during a certain time frame, if it met government objectives and did not conflict with established government policies, if the development would not seriously harm the environment, and if there were no insurmountable construction difficulties involved.

Based on the above criteria, the following options were either rejected or retained for further consideration, as noted:

1. No new hydroelectric power development. This option was rejected. Some sites have very favorable feasibility as well as other benefits.

2. Addition of more generators at the High Dam for peaking power. This option was rejected. This option is not practical due to the difficulty of constructing a stilling basin below the dam, the need to maintain a required downstream water flow and the excessive cost of transmission that would be involved.

3. Addition of a second power plant at Aswan Dam. This option was retained. The power plant can be developed at a low cost and would not conflict with the other criteria restrictions.

4. Addition of power plants at the three existing barrages (Esna, Nag Hammadi and Assiut). This option was retained. These sites involve low cost and have a favorable impact when other criteria are considered.

5. Construction of new barrages and power plants at four sites on the Nile River (Silsila, Qift, Sohag and Deirout). This option was rejected. The facilities could not be constructed for power development alone and there is not sufficient justification to construct the barrages for irrigation or to prevent channel degradation.

6. Development of pumped-storage sites along the Nile River. This option was rejected. Existing laws and policies on Nile water use prohibit operation; also, there are more favorable pumped-storage sites on the Red Sea.

7. Development of three pumped-storage sites near Suez on the Red Sea. This option was retained. Favorable feasibility and the need for peaking power after 1990 augment the value of development of these sites.

8. Development of four additional pumped-storage sites near Suez. This option was rejected. Additional peaking power would not be required until after the year 2000 and more favorable sites would be developed first.

9. Development of the Qattara Depression power complex. This option was neither retained nor rejected but used as a possible alternative to some of the Suez pumped-storage sites and some baseload fossil fuel thermal plants because its development must overcome four major impediments: extremely large capital investment, problems of nuclear blasting for construction of the open canal, qualified outcome of the three year feasibility study to be completed in 1979, and unfavorable environmental effects. Only the open canal was considered, since the Qattara Depression tunnel alternative appears too costly to be feasible.

10. Development of all possible hydroelectric power generation. This option was rejected. There would not be a need for this amount of peaking hydroelectric power by the year 2000.

Figure 2 shows the location of the hydroelectric sites discussed above. All the sites are remote from the existing population concentration of the Nile River delta in Northern Egypt. Figure 3 shows more details of the Qattara Depression.

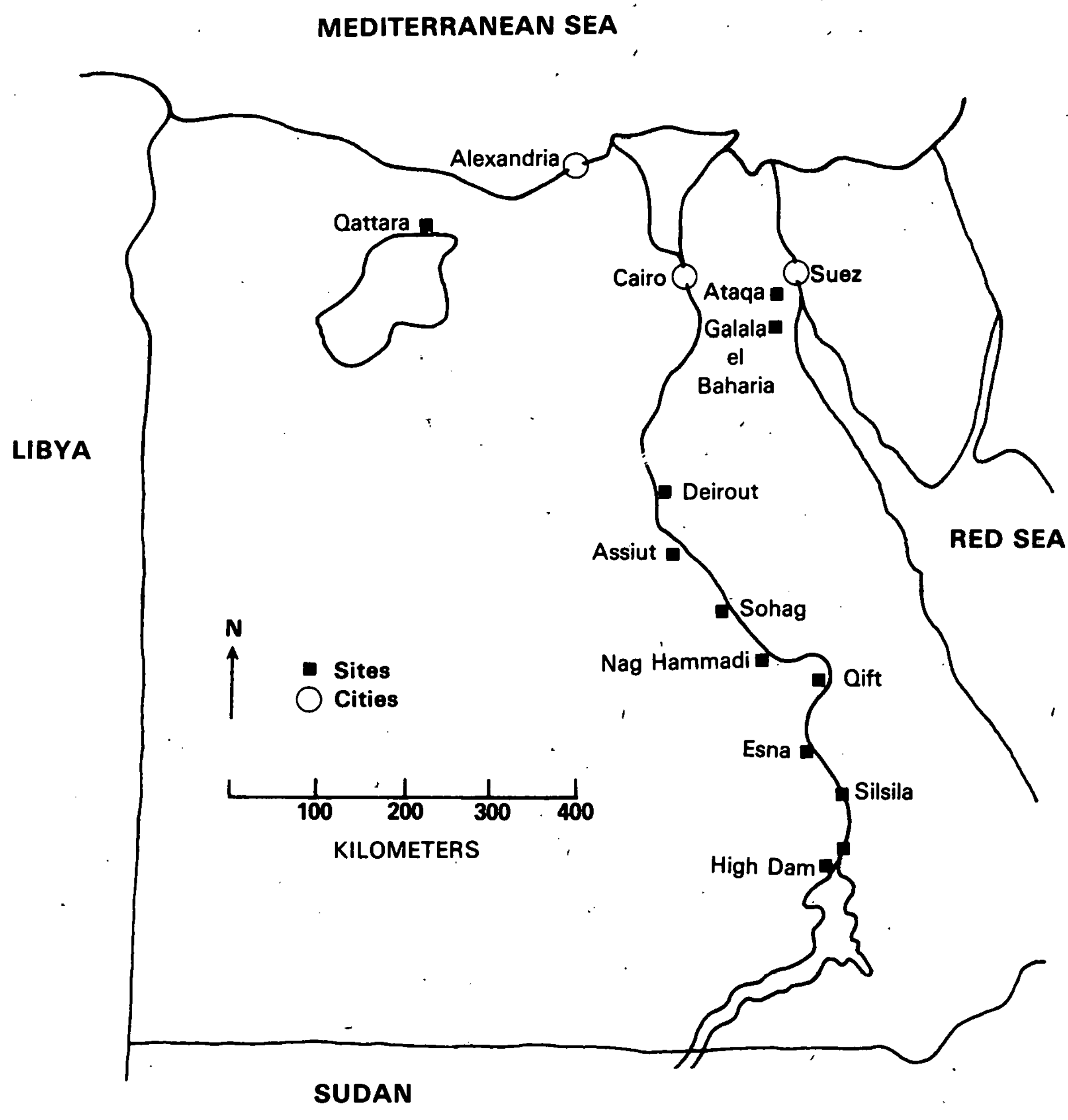

Fig. 2. Hydroelectric Power Sites

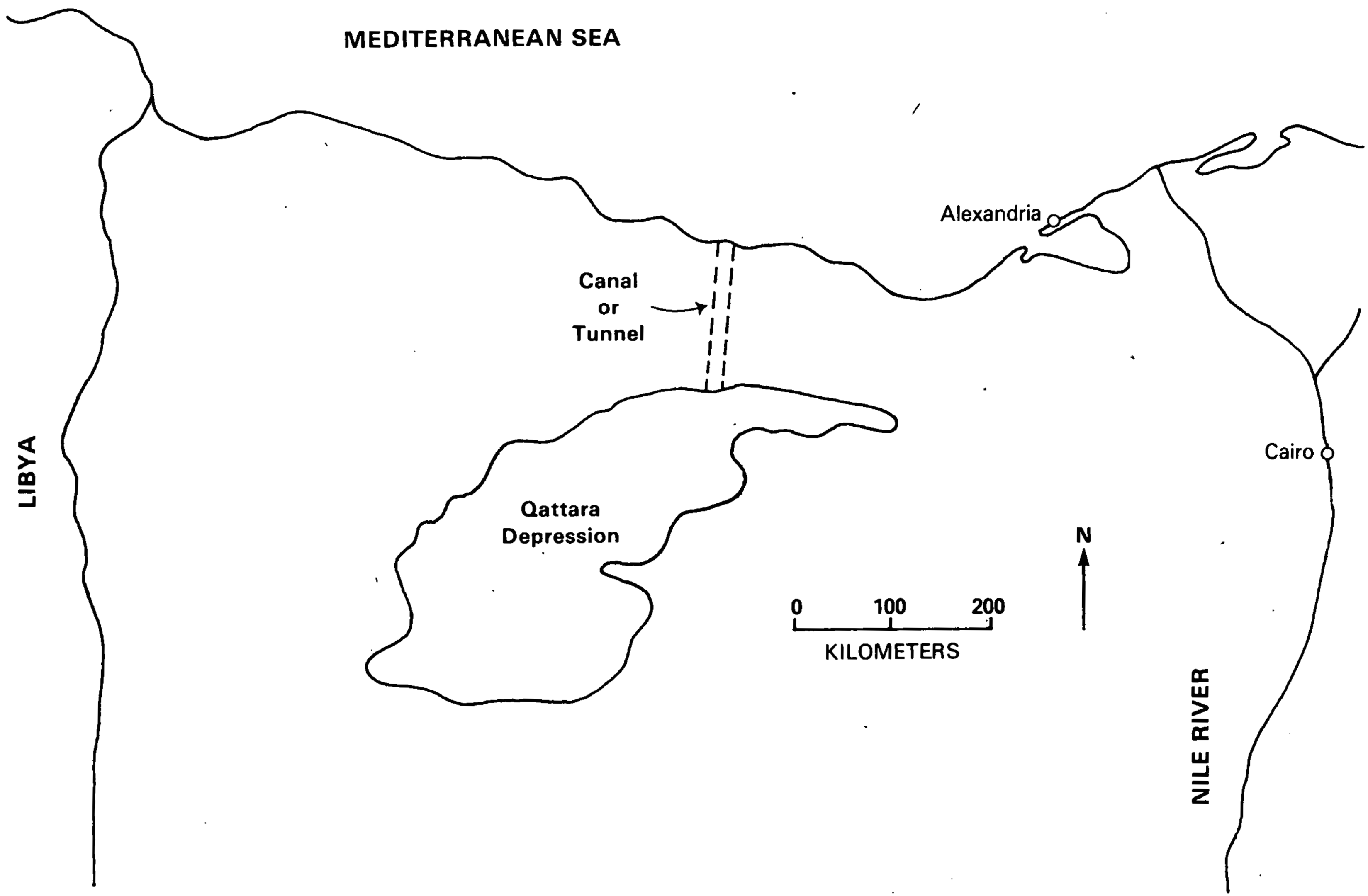

Fig. 3. Qattara Depression Area

The basic functions of a power system are to assist the population in maintaining life and to ease some of the natural difficulties of existence. Assuming the eventual adoption of a balanced national energy policy, the use of electrical energy must increase. The use of economical hydroelectric power in conjunction with baseload fossil fuel thermal and/or nuclear power will provide a power supply system that operates at maximum economy. Therefore, the continued development of hydroelectric power in Egypt is a necessity for the stable growth of the economy of the country.

3.0 RESOURCE ASSESSMENT

Hydroelectric power resources are limited to three broad areas in Egypt. There are the conventional and pumped-storage sites on the Nile River, the pumped-storage sites on the Red Sea, and the Qattara Depression utilizing the water from the Mediterranean Sea.

On the Nile River two power sites have been developed near Aswan: the Aswan Dam and the High Dam. The Aswan Dam powerhouse has a nameplate capacity of 345 MWe, but, because of the lower head caused by the tailrace of the High Dam, now generates only 220 MWe. The High Dam powerhouse has a nameplate capacity of 2100 MWe, but, because two units are on a single penstock and one unit is always down for maintenance, only 1750 MWe can be generated. Long-range generation at the High Dam may be as high as 7 or 8 x 10^9 kWh annually if water conservation in the Sudan occurs and the extra water is not used in-country but is sent to Egypt. However, if only the treaty amount of water is obtained by Egypt, then annual generation at the High Dam would be about 5 x 10^9 kWh. Other Nile river power plants would similarly increase energy production approximately 60 percent if the increased water was utilized.

There are four sites on the Nile that are presently feasible for hydropower development: a second power house at Aswan Dam of 160 MWe capacity, and three power houses at the existing barrages at Esna of 89.4 MWe, at Nag Hammadi of 52.5 MWe and at Assiut of 48 MW. There are four future barrage sites where power could be developed but which must be justified for other than power uses in order for power development to be feasible and not conflict with government policies. The basis for other justifications could be either need for irrigation or need to deter channel degradation but neither appear necessary in the immediate future. These four sites would be at Silsila, Qift, Sohag, and Deirout. They would provide a combined output of approximately 160 MWe and 1.3 x 10^9 kWh annually. The first barrage may need to be at Sohag to protect the existing barrage at Nag Hammadi against future channel degradation, but it is presently impossible to determine when such degradation would occur. There are also some pumped-storage sites on the upper Nile River that, although of marginal feasibility, could be developed if the present law, that water must be returned to the Nile River the same day it is withdrawn, was changed. With the other pumped storage sites available in Egypt, which are more feasible, it does not appear practical to pursue the development of pumped storage on the Nile River.

The option of adding peaking units at the High Dam was discarded because it would be impractical to enlarge the stilling basin below the High Dam and because the construction and age of the existing Aswan Dam prohibit a water level variation of more than three meters (m). During daylight hours, when the ambient temperature is the hottest, a variation of plus or minus one and one-half m is allowed. Presently, due to archeological excavation, plus or minus only one m is permitted.

The additional generation at Aswan Dam would be housed in a separate power house near the center of the dam, rather than in the existing power house which is on the right of the dam. New penstocks would be needed, and four new generators of 40 MWe each are planned. This would add 580,000,000 kWh annually. At the existing barrages new power houses would be built at one end of the dam where bulb-type turbines would be installed. It was noted that the bulb-type turbines have about 25 percent less weight, an efficiency of about 90 percent, and cost about half of what the Kaplan type turbines do. At Esna there would be six units of 14.9 MWe each, generating 551,400,000 kWh; at Nag Hammadi there would be five units of 10.5 MWe each, generating 292,000,000 kWh; and at Assiut there would be four units of 12.0 MWe each, generating 264,000,000 kWh annually.

On the Red Sea there are numerous pumped-storage sites along the western cliffs, which are 200 to 600 m high. The seven most promising sites are a short distance south of the City of Suez. There are three sites at Galala el Bahariya which is about 40 m south of the City of Suez, and there are four sites at Ataga, about 20 m south of the City of Suez. All seven sites would require excavation of an upper holding basin. Drilling is presently being done to determine the characteristics of the soil at the basin sites. The three most feasible and practical sites are two at Galala el Bahariya of 1000 MWe and 1900 MWe, and the one at Ataga of 1400 MWe. Although feasibility studies have shown that all the sites can be developed at costs ranging from 100 to 130 LE per kilowatt, these studies must be updated once characteristics of the soil in the holding basin areas are determined. Size of individual units would be in the 300 MWe range and would be single unit pump/generator design. Efficiency of the pump/generation would be in the 71 to 75 percent range and availability would be high, around 85 percent. It is expected that the units would be operated about 1300 hours a year and would be available for reserves when not in the pumping cycle.

The Qattara Depression is located in the western desert of Egypt about 200 km from Cairo and about 55 km from the Mediterranean Sea. The surface area of the depression at sea level is about 12,500 square km and at its lowest point the depression is about 134 m below sea level. The area between the depression and the Mediterranean Sea reaches a height of about 200 m and either an open canal or tunnels are needed to bring the sea water to the depression. The tunnel option, which consists of two tunnels each of 14.5 m in diameter, is quite expensive, especially when compared to the open canal option, since canal construction is envisioned using clean nuclear explosions. There are three phases considered in the Qattara development. Phase I, lasting for ten years, would be a high plant capacity conventional hydroelectric power plant rated at 670 MWe (315 MWe for the tunnel option). It would take at least the ten years to fill the depression to a level of 60 m below sea level with the open canal option, whereas the tunnel option would never fill the depression to this level because of the enormous evaporation that would occur. Phase II would have a total generation installation of 1200 MWe for either option by utilizing a pumped-storage concept. For this phase, a separate holding basin would be used for the tunnel option, or the canal itself would be used for an upper basin for the canal option. Phase III would have a total generation installation of 2400 MWe by using pumped storage from an upper reservoir located adjacently north of the depression called the Deir Kourayin reservoir site. Development of the Qattara Depression would be a very large undertaking calling for many new industries, a large seaport, and an extremely large capital investment. There are also impediments to the development of the Qatarra Depression, such as environmental problems for both options and international policies of nuclear blasting for the canal option. The Egyptian government has a contract with a group of German, American, and Egyptian consulting firms to prepare a detailed feasibility report on the Qattara project. The report is expected to be completed in 1979.

Table 1 lists the hydroelectric generation characteristics of the existing and the more feasible power developments discussed above. There are additional pumped-storage sites along the northern and eastern borders of Egypt that were not investigated because there is more peaking power available at the sites mentioned than the Egyptian load and load pattern will require beyond the year 2000. These sites may be investigated at a much later date.

4.0 TECHNICAL AND IMPLEMENTATION PRACTICABILITY OF OPTIONS

The "fuel" for hydroelectric plants is water, so the availability of water at all sites considered must be assured. The Nile River, by treaty, is allocated 55 billion cubic m of water annually; this amount has been exceeded each year, as shown in table 2. In the future there will be as much or more inflow to the Nile system at the southern border of Egypt, as changes in the Sudan are made to reduce waste, so the hydroelectric plants are assured of the 55 billion m^3 of waterflow. Water for the proposed plants on the Red Sea and the Mediterranean Sea is always available. Hydroelectric generation on the Nile River must follow the pattern of water use for irrigation. It is unfortunate that maximum irrigation requirements do not follow the pattern of maximum

TABLE 1

HYDROELECTRIC GENERATION CHARACTERISTICS

	Maximum MW	Generation per Year KWhr x 10^9	Pumped-Storage Energy Per 10 Hr. Cycle-GWH			
			Efficiency %	Net Energy Used	Energy Stored	Pumping Energy
High Dam (Existing)	2100	5.01				
Aswan (Existing)	345	1.78				
Aswan #2	160	.59				
Esna	89.4	.55				
Nag Hammadi	52.5	.29				
Assiut	48	.26				
Suez # 1 (El Bahariya)	1000		.73	4.02	10.87	14.89
Suez # 2 (El Bahariya)	1900		.74	6.94	19.75	26.69
Suez # 3 (Ataqa)	1400		.72	4.70	14.33	19.03
Qattara (Open canal)						
Phase I (10 yrs.)	670	5.69				
Phase II (5 yrs.)	530	3.12				
Phase III[1/]	1200[1]	3.12	.71			

1 Combined Conventional and pumped-storage

TABLE 2

DISCHARGES AT NILE POWER PLANTS 1976

(MILLION CUBIC METERS)

MONTH	TOTAL DISCHARGE	HIGH DAM		ASWAN DAM	
		THRU POWER STATION	THRU GATES	THRU POWER STATION	THRU GATES
JANUARY	3,540	3,250	290	3,420	120
FEBRUARY	3,585	3,365	220	3,450	135
MARCH	4,025	3,425	600	3,765	260
APRIL	3,885	3,415	470	3,685	200
MAY	4,825	3,730	1,095	3,745	1,080
JUNE	6,270	3,940	2,330	3,630	2,640
JULY	6,685	4,100	2,585	3,730	2,955
AUGUST	5,880	4,190	1,690	3,715	2,165
SEPTEMBER	4,035	3,930	105	3,595	440
OCTOBER	4,030	4,020	10	3,625	405
NOVEMBER	3,930	3,885	45	3,630	300
DECEMBER	4,030	3,955	75	3,740	290
TOTAL	54,720	45,205	9,515	43,730	10,990

generation requirements. In the past, much water had to be bypassed around the power turbines because of the irrigation release requirements. For instance, in 1976, between 18 to 20 percent of the water was bypassed and not used for generation. (See table 2). The difference between the annual inflow across the Sudan Border as evidenced in figure 4, and the annual release for 1976 at the dams (see table 2) is due to evaporation, seepage, and water retained for storage above the High Dam. Irrigation tells power the amount of water to be released on a daily basis, and power must meet the daily release level while having the option of changing releases hourly. In the future, when sufficient load growth occurs and adequate transmission capacity is available, it is expected that there will be little or no water bypassing the turbines. The irrigation requirements will still take precedence over power generation, but at that time hydroelectric power generation can fit into the whole power system load curve and will not be restricted as at present.

Transmission system reliability has been a problem in the past for the Egyptian unified grid. The problem resulted from lack of a looped high-voltage system, shortage of spare parts, inadequate maintenance, radial feeders to loads, and insufficient generation. In 1975, authority was granted to obtain an adequate supply of spare parts and to give a priority to preventive as well as required repair. There has also been a concerted effort to construct multiple deliveries using two to four feeders for a single load from separate busses and substations, which has greatly improved the reliability of delivery to loads. A contract has been let, in 1978, to provide a completely automated dispatch system with improved carrier current communication and to add an extensive microwave communication system. Present construction and future plans will result in a looped high voltage grid, which, together with the increase of the upper Nile loads, will greatly enhance the high voltage unified grid. The presently planned orderly schedule, if followed, for bringing new generation on line not only assures an adequate supply of power but also assures adequate reserves which are sadly deficient at the present time. The recent changes and planned additions, if carried through, will assure Egypt of a modern, reliable power system supply.

Additional high voltage transmission lines must be added for four of the eight new hydroelectric power plants recommended in this report. Additions will depend on integration with the national grid needed for delivering power from other types of power supplies and on reliability requirements. Therefore, the lines mentioned below are possible additions, which were derived to obtain an estimated total cost for a hydroelectric development. Detailed computer studies must be run to determine actual transmission additions once the location of other power supplies and load deliveries are known.

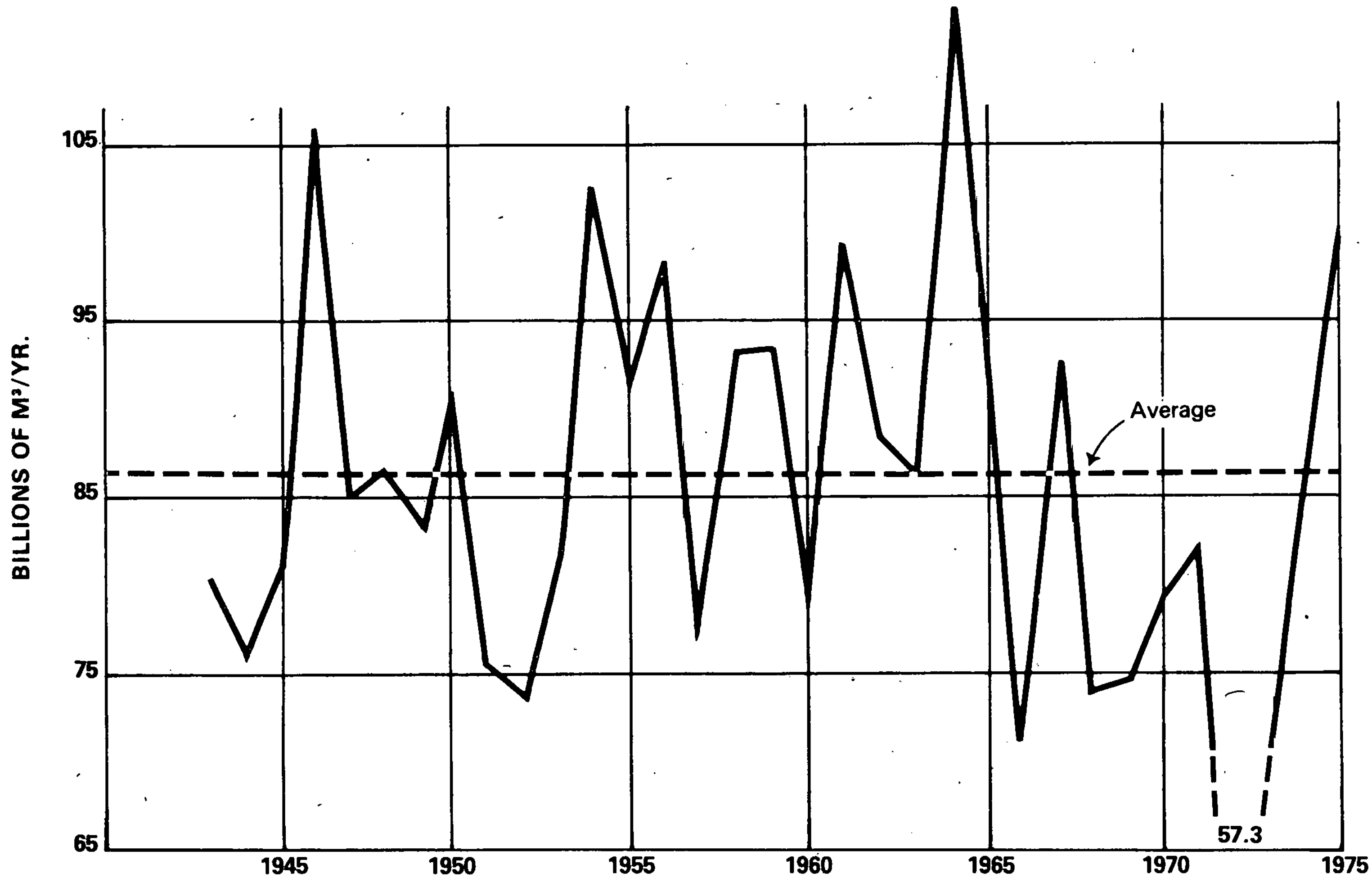

Fig. 4. Nile Inflow Into Egypt

No new lines will be needed for the Aswan #2 power plant or for the three barrage power plants, since their construction will be delayed until local load in southern Egypt has grown to the point that there will be sufficient capacity in the two existing 500 kV lines between upper and lower Egypt to deliver the power generated. At the present time the capacity of the two 500 kV lines is about 1300 MWe at the High Dam and 900 MWe into Cairo. Since there is a capability of about 1970 MWe at present at the High Dam and Aswan power plants, with only a local area load of about 400-500 MWe, the transmission limitation restricts the generation to between 100 and 300 MWe below capability. Load in the upper Nile is expected to grow to the extent that transmission will not limit generation at the present plants in the early 1980's. It would not be feasible or practical to construct a line which would only be needed for a few years. Therefore, the new power developments on the upper Nile at Aswan and the three barrages should be timed to come on the line starting in about 1985 when transmission capacity is assured in the existing lines.

The first pumped-storage development in the Suez area will require only one 50 km 230 kV transmission line from Suez to Bahariya to Ayn Sukhna since there presently exist or are under construction four 230 kV lines from the area into Cairo. The second pumped-storage development will require one 135 km 500 kV line from the Suez area to Cairo and the third development will require one 140 km 500 kV line from Ayn Sukhna to Cairo. There also may be more fossil fuel or perhaps nuclear power plants in the Suez area which would reduce the transmission costs attributable to the pumped-storage projects.

Presently there are no transmission lines near the Qattara Depression area. Two 500 kV lines, one 200 km long to Cairo and one 175 km long to Alexandria, will be required. These two lines would be necessary for reliability for the Phase I development and should be adequate when the other two phases are completed, depending on the local load in the Qattara area. Planning on the Qattara total development has not sufficiently advanced, at present, to refine the transmission requirements further. Figure 5 is a map showing the general location of the transmission line additions associated with the hydroelectric power developments. See table 3 for estimated costs of the transmission lines mentioned above.

Capital investment costs and annual operating costs were estimated for the projects investigated (see table 4). Costs were obtained from Egyptian officials where cost data were available; some costs had to be estimated. All costs are in Egyptian pounds (LE) and are based on 1977 construction. Annual costs, which consist of cost of money, operation, maintenance and replacement, were assumed to be 10 percent of the capital costs. It was estimated that 25 percent of the capital costs would have to be spent outside Egypt for machinery and special materials for the Aswan #2 and the barrage power plants and 10 percent for the Suez pumped-storage plants. For the Qattara project, a reasonable estimate cannot be made until the completion of the feasibility study in 1979.

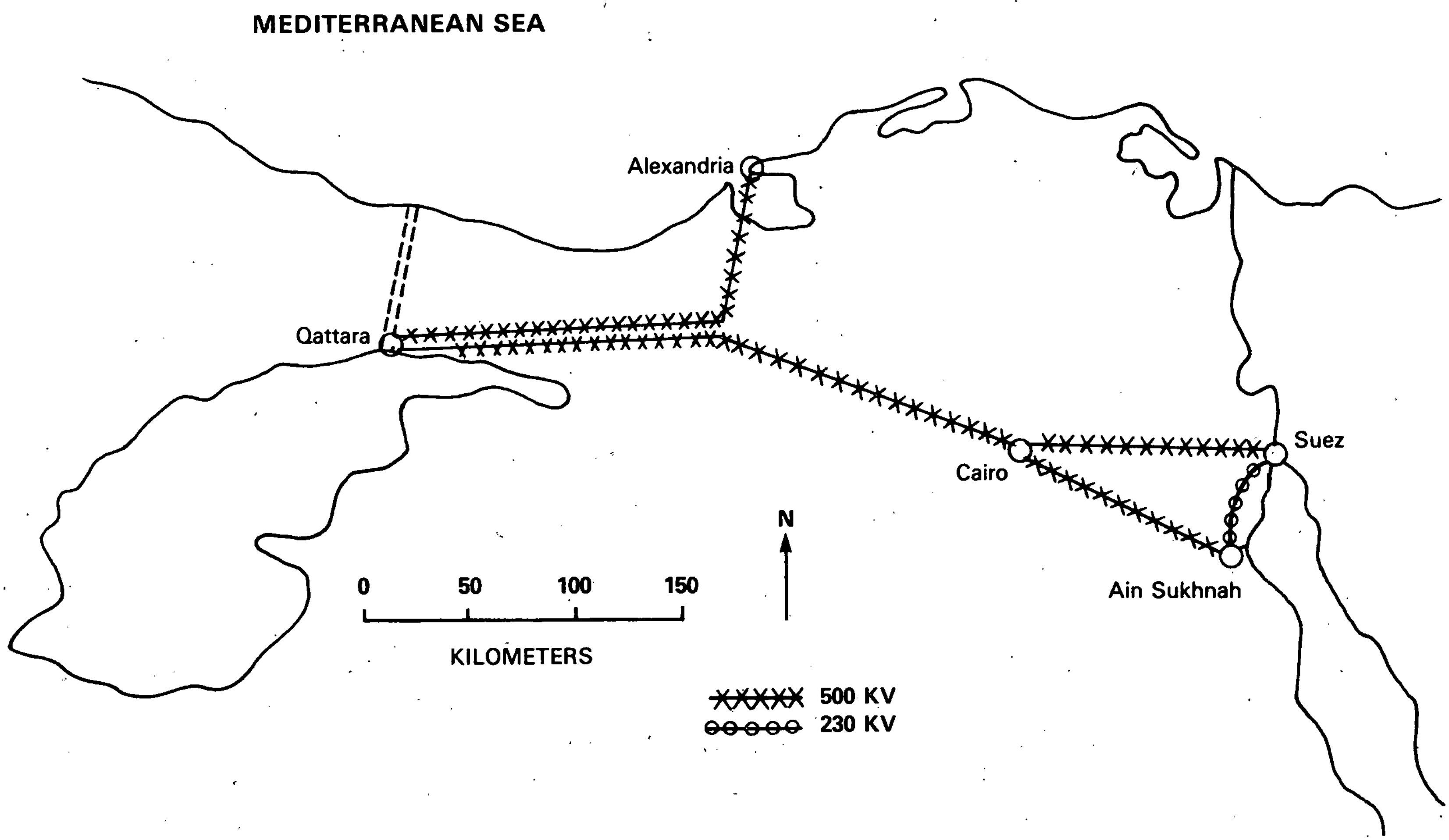

Fig. 5 Map of Transmission Line Additions

TABLE 3

TRANSMISSION LINE COSTS

TRANSMISSION LINE TERMINALS	VOLTAGE KV	LENGTH KM	TRANSMISSION LINE COST 1000 LE	TERMINAL COST 1000 LE	TOTAL CAPITAL COST 1000 LE	TOTAL ANNUAL COST 1000 LE
Suez - Bahariya - Aim Sukhna	220	40	2,400	1,000	3,400	340
Suez - Cairo	500	135	14,850	3,000	17,850	1,785
Aim Sukhna - Cairo	500	140	15,400	3,000	18,400	1,840
Qattara - Cairo	500	200	22,000	3,000	25,000	2,500
Qattara - Alexandria	500	175	19,250	3,000	22,250	2,225

TABLE 4

GENERATION AND PROJECT COSTS

Project	Capacity MW	Annual Gen. 10^9 kWhr	Project Capital Cost Million LE	Trans. Capital Cost Million LE	Total Capital Cost Million LE	Unit Cost LE/KW	Annual Cost Million LE	Unit Cost LE/kWhr[3]
Aswan #2	160	0.59	26.9	—	26.9	168	2.69	.0045
Esna	89.4	0.55	29.6	—	29.6	331	2.96	.0054
Nag Hammadi	52.5	0.29	26.5	—	26.5	505	2.65	.0091
Assiut	48	0.26	21.5	—	21.5	450	2.15	.0082
Suez Pumped-Storage #1	1000	—	108.0	3.40	111.4	111	11.14	—
Suez Pumped-Storage #2	1900	—	190.0	17.8	207.8	109	20.78	—
Suez Pumped-Storage #3	1400	—	147.0	18.4	165.4	118	16.54	—
Qattara (open canal)								
Phase I (1st 10 yrs.)	670	5.69[1]	560	25.0	585.0	873	58.50	.010
Phase II (next 5 yrs.)	530	—	85	22.25	107.25	—	—	—
Phase III	1200	—	218	—	218.0	420[2]	91.02[2]	.029[2]

1 Drops to 3.12 after 1st 10 years.
2 Total of all three phases.
3 Does not include cost of pumping energy.

As can be seen from table 4, the values of LE/kW and the LE/kWh for all projects are quite low when compared with other sources of power supply. Fossil fuel, combustion turbines and even nuclear power have higher unit costs than hydroelectric power from these projects. When other factors such as reliability, life of the projects and absence of harmful environmental factors are considered, the value of and reason for early construction of hydroelectric power plants are clearly demonstrated.

The time frame for development of the hydroelectric power plants depends upon two basic elements - load growth and availability of capital for construction. As far as construction time is concerned, the four Nile River developments could each be constructed and in operation approximately four years after appropriation of money. The three pumped-storage sites near Suez would require approximately 5 years each; the Qattara Phase I, about 10 years. Load growth is a function of the economy of a nation and also of the degree to which the nation is industrialized. It is very difficult to estimate future power demands, and usually there are as many estimates as there are people estimating. For this study, a demand of 1909 MWe in 1976 increases to 5045 MWe in 1985, and then to 17395 MWe by the year 2000. Load factor decreases from 70 percent in 1976 to 60 percent by the year 2000, so that the increase in electrical energy use is a smaller percentage than the increase in electrical power demand. Adequate generation reserve must be added to the load demand to determine the generation capability which must be planned for during the year being considered. Reserves normally should be in the 20 to 25 percent category.

A probable daily load curve (see figure 6) has been drawn to demonstrate a suitable blend of base generation and peaking generation for the peak load day in January of the year 2000. One possible blend of conventional hydroelectric, fossil fuel, nuclear and pumped-storage generation was assumed for illustrative purposes. As can be seen, the fossil fuel, nuclear and conventional hydroelectric generation is used as base load, while the pumped-storage, some hydroelectric and some fossil fuel generation is used for peaking purposes. The shaded area from approximately midnight to 800 hours in the morning is where base load generation is pumping water back into the pumped-storage reservoir for later pumped-storage generation during the peak period 1600 to 2300 hours. The megawatt numbers given on the curve are demand numbers. The capability, which would include reserves, would be much greater. There is a great variety of generation blends that can be used, and such things as economics, capital investment, environmental effects, fuel costs and supply, government policies and international considerations will determine the future generation. Four different blends are shown in tabular form in table 5 giving the capability, load demand, load energy, and energy supply for each. The four blends are for a balanced resource supply, a maximum nuclear, medium nuclear and a minimum nuclear supply, with the first phase of the Qattara development shown in the latter two blends. There are many more blends that could and should be

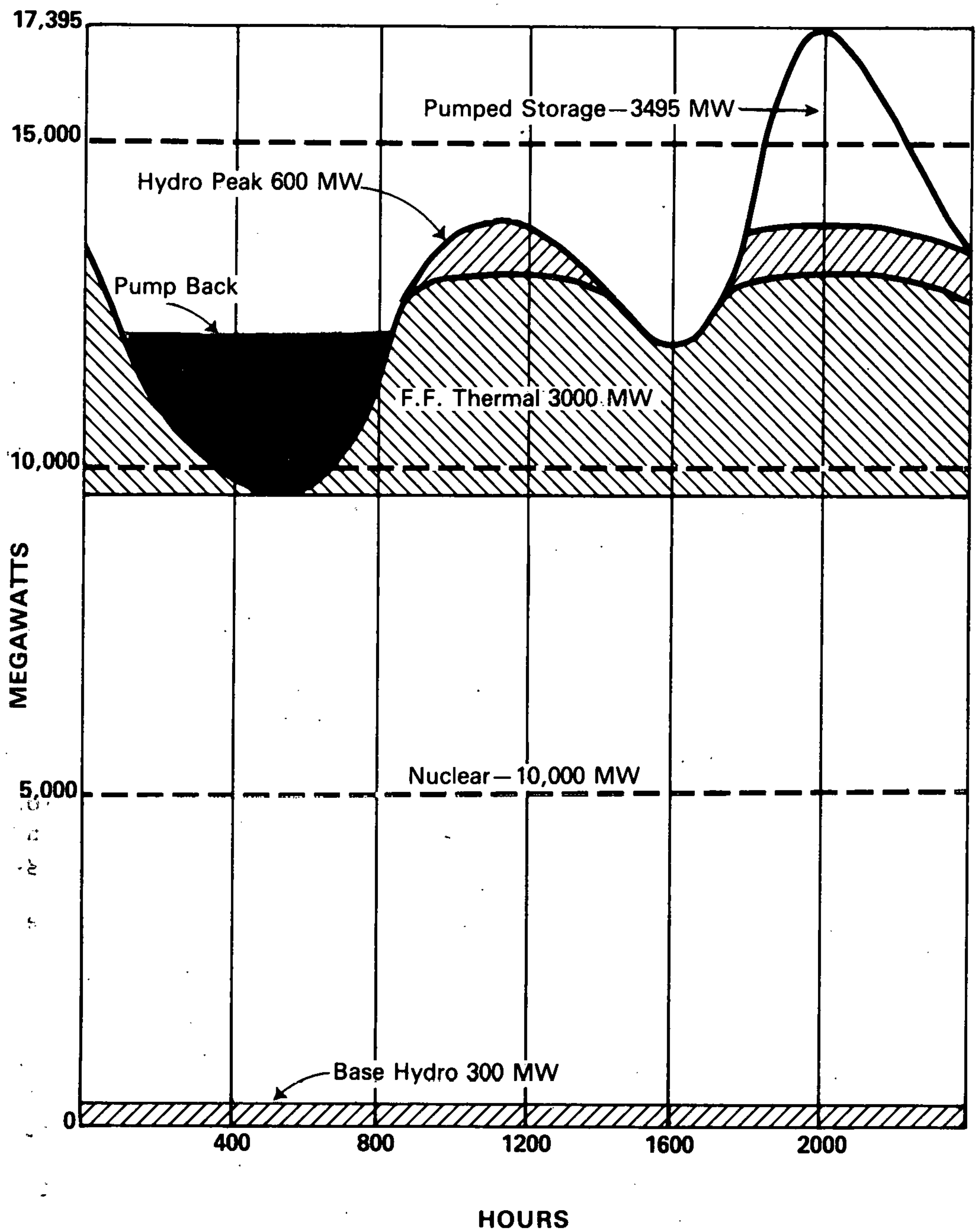

Fig. 6. Peak Day-Load Curve-January-2000

TABLE 5

POSSIBLE FUTURE GENERATION TRENDS

	YEAR					
	1976	1985	2000 Blend 1 Balanced	2000 Blend 2 Max. Nuc.	2000 Blend 3 Avg. Nuc.	2000 Blend 4 Min. Nuc.
Capability (MWe)	3,789	6,670	21,085	21,085	21,085	21,085
Hydro	1,500	2,130	2,200	2,200	2,200	2,200
Pumped-Storage	0	0	4,300	2,900	4,300	4,300
Fossil Steam	2,289	4,540	3,985	3,385	7,615	13,900
Nuclear	0	0	10,600	12,600	6,300	0
Qattara	0	0	0	0	670	670
Demand at Plant (MWe)	1,909	5,045	17,395	17,395	17,395	17,395
Energy Need at Plant (Billion kWhr)	11.64	30.58	105.9	103.3	105.9	105.9
Load	11.64	30.58	97.8	97.8	97.8	97.8
Pumping Energy	0	0	8.1	5.5	8.1	8.1
Energy Supply (Billion kWhr)	11.64	30.58	105.9	103.3	105.9	105.9
Hydro	8.0	7.4	8.3	8.3	8.3	8.3
Qattara	0	0	0	0	5.7	5.7
Fossil Steam	3.6	23.2	19.3	5.0	46.9	91.9
Nuclear	0	0	75.5	90.0	45.0	0

considered which may include other methods of generating electrical energy; however, these four were shown for illustrative purposes and show the method used to obtain an integrated power supply. The daily load curve shown in figure 6 was based on the balanced resource supply blend.

At the present state of electrical generation technology, a mixture of nuclear power for base load and hydroelectric generation for peak load appears to be the ideal solution for a country's long range power supply. Hydroelectric plants can be operated for 60 years or more and have a very low operating cost. Hydroelectric generators have a high load response and a very high availability factor: around 85 percent for pumped-storage units. Although the initial cost of gas turbine peaking units will be less when compared to pumped-storage units, the high cost of gas as well as the availability of gas clearly demonstrates the desirability of using pumped-storage units for generating peaking power.

5.0 IMPACTS FROM UTILIZATION OF OPTIONS

From an environmental standpoint, hydroelectric generation additions at Aswan and the barrages on the Nile will cause no serious effect whatsoever. The existing High Dam caused major environmental changes, such as a reduction of flooding, retention of silt needed downstream, burial of archaeological prizes, and creation of a major reservoir with major water loss by evaporation. The four proposed power plants on the Nile would be installed at existing dams, and would not have a high enough head to cause problems from lack of nitrogen or change in water temperature. No transmission lines would be required for the Nile additions, so there would be no noticeable effect on the environment.

The development of the pumped-storage sites on the Red Sea near the City of Suez would also cause little if any adverse effect environmentally. The three proposed sites will have large upper reservoirs which will increase evaporation and thus humidity in the area, but this will be extremely small in comparison to the evaporation from the Red Sea itself. Major transmission lines will be required and thus mar the scenic beauty of the desert landscape, but it would not be major damage.

Development of the Qattara Depression would cause major changes to the environment, and while some may be beneficial, others would be quite harmful. For instance, the construction of the open canal by "clean" nuclear blasting would certainly cause major environmental problems, since technology has not advanced to the stage where any nuclear blast is clean. The climate of the area would be affected by increased humidity, precipitation changes and possibly temperature changes. The nature of these changes is still largely unknown, and detailed investigations of all should be made prior to requesting authorization for construction of the project.

Construction of any or all of the hydroelectric projects will benefit all of Egypt socially by providing low cost power. The development of the projects on the upper Nile will have a temporary effect on the local area but will encourage the development of local industry. The pumped-storage developments on the Red Sea, by their construction, would invite tourism and could form a basis for fishing and manufacturing industries. Until the feasibility study is completed on the Qattara Depression project, details of its social effects are largely unknown. However, it can easily be envisioned that the project will have major social effects, such as addition of large new industries, development of a major seaport, increased agriculture in the Western Desert, and a considerable shift of population from the Nile Delta area. Highways will have to be constructed or upgraded when the Suez and Qattara areas are developed in order to bring construction material, equipment, and personnel to the sites. Temporary cement batching plants will be required, although, in view of later area development, some of the plants may be permanent.

Hydroelectric projects are typically characterized by high capital costs and such would be the case of the Suez and Qattara developments. However, because the power sites on the upper Nile already have the dams constructed, the investment at Aswan #2 and the barrage power plants will be relatively small. Most of the capital for construction would be spent in Egypt; only the generating equipment and special materials would be obtained from foreign countries. It is estimated that about 25 percent of the cost of Aswan #2 and the barrage developments and less than 10 percent of the Suez pumped-storage and the Qattara construction costs would be spent outside of Egypt. Under an orderly schedule of construction, the expenditure of funds could be distributed in a progressive manner from the early 1980's through the year 2000. The less costly facilities along the Nile would be constructed first, followed by the higher cost Suez and Qattara projects.

The present Egyptian 5-year plan (1978-1982) does not provide specifically for the initiation of any hydroelectric project. In order to meet a proposed 1985 completion date for the Aswan #2 power plant, a small amount of money would have to be available in 1981 and 1982 to initiate construction. It seems reasonable to assume that either the 5-year plan is flexible enough to allow 5 to 10 million LE to be shifted from other proposed expenditures, or that there would be that much capital available from the amount allocated to the Ministry of Electricity to initiate construction. The other power developments could be scheduled in later 5-year plans.

Since total capital costs of the four Nile River developments are about 105 million LE, and since the four projects will be financed separately, the small individual costs should not hinder project implementation. The foreign components of the costs, approximately 25 percent, probably would be financed from foreign institutions, while the remaining costs would be financed internally, for such small projects. For the larger pumped-storage projects near Suez, the foreign components of the costs would be nearer 10 percent of the total and, again, would probably be financed by foreign institutions. The foreign exchange requirements of all the Nile and Suez projects therefore appear relatively small and should not adversely affect the Egyptian government's foreign exchange. Over time, the foreign exchange repayments depend upon adequate remuneration of the productive application of the lower cost power and energy obtained from the projects.

Construction of hydroelectric projects in general requires much unskilled and semi-skilled labor. Large numbers of men and equipment will be needed over the relatively long period of time from 1981 through the year 2000, when all the projects involved are considered. If many of the same workers were employed on all the projects, a trained, skilled work force would be developed for other types of construction. It is estimated that from 500 to 1000 people would be working directly on the projects, in addition to numerous others indirectly involved. For most of the workers, this construction would be only a temporary location, but others will continue to work in or return to the area.

The number of people involved in operations will depend directly upon government policies. For instance, the three barrage power plants and the Suez pumped-storage plants could be operated remotely, but it is expected that those plants will be manned by 50 to 150 people at each plant. The High Dam has approximately 500 people of whom only 200 work directly in operation and maintenance; others work for security, as drivers, in housekeeping, and in administrative tasks. This demonstrates how hydroelectric plants create jobs. There will also be both construction and maintenance people involved in the transmission lines associated with the Suez pumped-storage and the Qattara projects. Although most of the construction people will be housed in temporary facilities, the operation and maintenance people would require permanent housing and would be a nucleus for development of local communities. Wages for construction, operation, and maintenance of the project will be higher than those paid for agriculture or in other local labor markets, and a large amount of this income is likely to stay in the locality.

6.0 POLICY IMPLICATIONS OF OPTIONS

The development of hydroelectric projects appears to be compatible with the Egyptian government's existing policies and long-range objectives. The major objective and policy goals applicable to hydroelectric development, with comments on the role hydroelectric power would play for each, are listed below:

1. Improvement of life and reduction of hardship through the use of low cost energy sources. The low unit cost of hydroelectric power and energy would contribute directly to these goals.

2. Conservation of Egyptian resources used internally, to improve export capability. Hydroelectric energy generation would replace oil-fired thermal plants, releasing the oil for export.

3. Gainful employment of a large labor force of unskilled and semiskilled workers within Egypt. Orderly construction of the hydroelectric projects recommended in this report would give long-term employment to a substantial number of workers both directly and indirectly, through the many new industries that would utilize the low cost power and energy.

4. Dispersal or stabilization of the population in the Nile Delta area. The proposed hydroelectric developments are all remote from existing centers of population. Construction of the projects, as well as the new industries that would be formed, would further this objective. Perhaps the Qattara development should be pushed for construction because of the large benefit it offers in this area.

5. The creation of new industries and the addition to existing commercial resources. Major industrial development, increased fishing and food processing, promotion of tourism, and increased agriculture expansion would all be aided by the construction of the hydroelectric projects and their production of low cost power. Again, the Qattara development would have a major effect in these areas in addition to supporting the large seaport that is envisioned at El Daba, creation of which would relieve the congestion at Alexandria.

6. The development of an adequate low cost energy supply for the future needs of Egypt. As discussed previously, hydroelectric power is not only lower in cost, but also its inherent nature of generation blends ideally into the projected load curve and requirements of the nation.

The only deterrent to hydroelectric power development appears to be the relatively high initial investment required, although in the case of the four Nile River power plants this criteria would not seem to apply. When these projects are viewed over a long-term time period, when the low unit power and energy cost are considered, and the benefits to the country from meeting government objectives are evaluated, the high investment problem is greatly diminished. In the case of the Qattara development, the dispersion of population, the creation of many new industries and jobs, and the development of a major seaport at El Daba would seem to offset most of the negative effects of construction.

7.0 KEY INITIATING ACTIONS

Investigations and planning of hydroelectric power site development is the responsibility of the Qattara Depression Authority which is responsible for all facets of hydroelectric resource development. The Authority first makes a reconnaissance study of all possible hydroelectric sites and makes a study of the economic and practical considerations of development. The more favorable sites are investigated in greater detail, and a feasibility study is then performed. Once the Authority completes a feasibility study which warrants construction, the Authority sends the study to the Ministry of Electricity and Energy with suitable recommendations for construction.

The Ministry of Electricity and Energy evaluates the hydroelectric project as part of an integrated system of power supply, comparing costs of investment, unit power costs, type of power and other such factors with other forms of power generation. If the hydroelectric power project meets the above integration requirements, the Ministry recommends authorization and construction to the Finance Ministry. The Finance Ministry then incorporates the project into the Egyptian budget which is then sent to the Egyptian Congress for approval. Once the project is approved, a foreign consultant is usually selected to oversee the complete construction phase of the project, and local Egyptian contractors are selected to do the actual construction.

In the case of the Aswan #2 power house and the three existing barrage developments, it appears that the existing feasibility studies would be adequate with the possible exception of some of the cost estimates, which should be updated before authorization for construction is pursued. The pump-storage sites near Suez are presently being investigated to obtain more detailed information on soil conditions in the upper reservoir areas. Upon completion of this drilling operation, the present feasibility studies should be reviewed and updated before submittal for authorization. The Qattara Depression development is dependent upon the outcome of the feasibility study presently being conducted and to be completed in 1979. After review of this feasibility study, appropriate action should be taken.

Before seeking authorizations of either the Suez pumped-storage or the Qattara depression projects, detailed computer studies will need to be run to determine the transmission requirements for the developments. Transmission studies are constantly being run and revisions are made as new loads develop, other power generation supplies are authorized, or reliability standards dictate certain changes. Therefore, the most up-to-date study should be used at the time authorization is recommended.

Since the technology is firmly established for the construction and operation of hydroelectric projects, there is no need for research, demonstration, or working models for the Nile River or the Suez projects. Depending upon the outcome of the Qattara Depression feasibility study, it appears that nuclear blasting of the open canal is the only sphere in which new technology may be needed or existing technology must be reviewed. Research will probably be necessary for the Qattara Depression project also, on secondary benefits, and to obtain more information of such things as the industries that can be established along the depression, the effect of evaporation on agriculture development, and the effect of salt water encroachment on the groundwater purity.

Scheduling and priority consideration must be recommended and reviewed by the proper Egyptian government officials. An orderly schedule of the construction of all types of power generating facilities must meet the load growth of the country in the most economic manner. Lead time on hydroelectric projects is similar to or perhaps slightly longer than other power supply options except possibly nuclear power. The higher initial capital investment for hydroelectric power plants must be weighed against the long-term savings of annual and unit costs and other factors considered, such as reliability, the environment, and the balance of trade via the sale of fuels that would otherwise be consumed.

Egypt must take a hard look at its long-term goals and determine as soon as practical which direction to go, where future power supply alternatives are concerned. Choice of this optimum direction must consider constraints such as initial high capital investments, which may overrule a choice which could prove economical in the long run. Regardless of the constraints involved, the development of hydroelectric resources must be done sooner or later because of the inherent advantages of such projects.

8.0 OBSERVATIONS

The earliest practical development and construction of hydroelectric power resources consistent with load requirement and capital investment restraints is in the best interest of the Egyptian government, its people, and the country's economy. Construction of the hydroelectric developments should be initiated in an aggressive and orderly manner.

The low cost of hydroelectric energy and peaking power as compared to alternate forms of supply makes such development essential to the future economy of Egypt. The lack of environmental restraints, the inherent reliability of hydroelectric units, the remoteness from existing population concentrations, the savings of valuable fuel that can be exported, and the capacity to use a high percentage of Egyptian resources and people during construction and operation all contribute to the justification of speedy construction of hydroelectric power plants.

Based on projected load growth and expected load factor requirements, construction of hydroelectric power plants following an aggressive schedule should meet the operational dates given below:

Power Facility	Capacity MWe	Cumulative MWe	Operational Date
Aswan #2	160	160	1985
Esna (Barrage)	89	249	1986
Nag Hammadi (Barrage)	52	301	1987
Assiut (Barrage)	48	349	1987
Suez Pumped-Storage #1	1000	1349	1990
Suez Pumped-Storage #2	1900	3249	1995
Suez Pumped-Storage #3	1400	4649	2000

Development of the Qattara Depression is uncertain at the present time pending the outcome of the feasibility study. However, if the project is feasible, construction difficulties are overcome, and funding can be arranged in time for the large capital investment required to attain operation of the first phase by the year 2000, then some of the fossil-fuel fired or nuclear generation could be delayed or replaced. If Phases II and/or III are completed by the year 2000, then some of the pumped-storage peaking units could be delayed.

When and if the four additional barrages on the Nile must be constructed for irrigation or to prevent channel degradation, then power facilities should be added at the time of construction.

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NUCLEAR ENERGY

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U.S.-EGYPT COOPERATIVE ENERGY ASSESSMENT

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1.0 INTRODUCTION

This annex is prepared to provide specialist input to the Egypt/U.S. Cooperative Energy assessment regarding the prospective use of nuclear energy to meet Egypt's energy needs. The function of the nuclear energy specialist of the U.S. team, working with Egyptian counterparts, was to provide information and data input to the integrated analysis of energy supply options regarding:

- current plans of Egypt for the utilization of nuclear power systems;
- major factors that will enter into the practicality of Egypt's ability to carry through those plans;
- potential effects of the planned use of nuclear energy by Egypt; and
- steps which would need to be taken by Egypt to initiate and implement an effective program for the application of nuclear energy in Egypt.

An important element in consideration of the use of nuclear energy in Egypt is the potential availability of domestic nuclear fuels resources (uranium or thorium ores) for nuclear power plants which Egypt might build and operate. The availability of these fuel ores in Egypt was addressed as part of the fuels resource assessments conducted by the U.S. Geological Survey members of the U.S. Team. (See Annex 1-Energy Resources of Egypt). Use is made in this annex of information reported in the Uranium and Thorium section of Annex 1.

The remainder of this annex is structured along the following lines:

Section 2 (Overview and Summary) summarizes some of the major information in, or observations presented in the remainder of this annex that can be drawn from the information collected by the Nuclear Energy Specialist.

Section 3 (Egyptian Plans for Nuclear Energy) summarizes the current plans of Egypt regarding the prospective use in Egypt of nuclear power systems and sets forth some of the basis for those plans.

Section 4 (Egypt's Resources to Implement a Nuclear Energy Program) reviews briefly the basic resource capability of Egypt to site, construct, operate, and fuel nuclear power systems.

Section 5 (Potential Effects of the Expanded Use of Nuclear Energy) identifies some of the potential impacts that would derive from an extensive use of nuclear power systems in Egypt.

Section 6 (Next Steps) briefly defines some of the near-term steps which Egypt should consider initiating to lay the ground work for effective exercise of the nuclear option.

2.0 OVERVIEW AND SUMMARY

2.1 Overview

Nuclear power plants appear to be a lower cost source of baseload electricity to meet Egypt's increasing electricity demands than are oil-fired power plants. The successful construction and operation of nuclear power plants requires a dedicated commitment by Egyptian authorities to the following four practicability issues:

1. Execution of international agreements and contracts requisite to establishing a framework for obtaining nuclear power systems;

2. Obtaining the funds to finance the full scope of the Egyptian nuclear energy program;

3. Development of a qualified cadre of senior and middle management personnel to plan and carry out the extensive effort involved in the purchase, siting, construction and safe operation of multiple nuclear power plants;

4. Establishing functional quality assurance programs as integral parts of all elements of the Egyptian nuclear energy program.

2.2 Summary of Annex

The following points summarize the content of this Nuclear Energy Annex:

Egypt is faced with an increasing demand for electric energy. A major portion of the hydroelectric generation potential of Egypt has been exploited. Therefore, future increases in electric generation capacity will have to come from other generation systems. Continual high dependence upon oil-fueled electricity generation would significantly reduce Egypt's capability to export oil. This, in turn, affects Egypt's international trade balance which is important to its ability to finance major energy supply capability expansions using imported systems, equipment and manpower.

Egypt's electric system planners have concluded that nuclear power plants are the lowest cost source of future baseload electricity generation, particularly when oil is valued at world oil price levels. Solar power generation has potential, which is viewed favorably by Egypt recognizing that full test of solar technology and related power operation costs is yet to be accomplished.

On this basis, Egyptian projections for the nuclear generation capacity to be operational by the year 2000 vary from 6000 MWe to 12,600 MWe. No firm long-term plan for nuclear capacity additions exists at this time.

Egypt's current attention is focused upon completing arrangements necessary to acquire and initiate construction of a first nuclear power generation plant at Sidi Krier. Key activities include: (1) the negotiation of a bilateral agreement between the Governments of Egypt and the U.S. which would provide a framework for nuclear cooperation including establishing those conditions necessary for U.S. industrial and engineering corporations to provide nuclear power systems to Egypt; (2) arranging for financing of the first plant, (3) finalizing legislative and institutional matters required to support a nuclear energy program, and (4) the finalization of contractual arrangements between Egypt and the Westinghouse Corporation of the U.S. to provide the nuclear power plant. These latter contractual arrangements are near completion, pending negotiation and ratification of bilateral agreements between the Governments of Egypt and the U.S. Egypt has expressed its willingness to accept nuclear fuel safeguards as a part of this bilateral agreement.

It appears that an optimistic earliest date for initial operation of a nuclear power plant at Sidi Krier is 1986. This date was assumed for the analysis conducted in this assessment. Delays in the scheduled operation of the Sidi Krier plant have resulted in alternative generation capacity of shorter lead time (oil-fired generation capacity) being planned for operation by the 1984 to 1985 time period to meet projected electricity demand in Egypt in that period.

Proven reserves of economically recoverable uranium- and thorium-bearing ores are severely limited. Preliminary geological indications for locating potential uranium resources appear favorable, based on limited available information. However, considerable effort must be expended on on-site exploration to develop reliable estimates of proven reserves. Egypt has initiated discussions with private concerns to explore their participation in the proving and possible development of uranium resources. Thorium was not considered in detail due to the judged limited promise of economic recovery from known resources.

Siting of nuclear plants should not be an early limit on nuclear plant applications. Plans call for siting of nuclear plants on the Mediterranean and Red Sea coasts and use of sea water cooling. Seismic activity would not appear to preclude such siting. Weather, site availability and population proximity factors appear non-limiting.

Consideration of placing extensive reliance on nuclear power systems for future electric energy supply introduces the need for careful examination by Egypt of many factors that would be essential to its ability to effectively site, construct, operate, and fuel a significant number of nuclear power plants including the following:

1. There is a need to establish an evaluation process and related organization and staff capability for the review and approval of nuclear plant siting, safety and operational factors using accepted standards and evaluation criteria.

2. The need for a regime governing protection against third-party liability resulting from nuclear damage has been recognized and discussions are in process with the International Atomic Energy Agency regarding implementing legislation to provide such protection.

3. Initial nuclear plants will be built almost totally with foreign plant equipment and engineering services. In addition, a significant fraction of the required construction labor and materials will initially need to be acquired from foreign sources. Egypt's manpower resources could, with proper training, meet most construction labor requirements. A number of items of plant equipment also appear to be suitable for local manufacture. If Egypt is to reduce the need for foreign resources for its nuclear power plant program, it will require a dedicated well-planned, long-term effort by the Government of Egypt to build upon the experience of the first nuclear plant project.

4. There is a need to develop an extensive cadre of well-trained senior and middle management personnel to plan and implement a program involving a significant number of nuclear power plants.

5. Crucial to Egypt's ability to effectively site, construct and safely operate nuclear power plants is a strong emphasis by Egyptian officials and managers of the concept of "a quality product" and the establishment of an effective quality assurance program, staffed with well-trained, competent people.

6. Even if indigenous uranium resources become available, Egypt will need an assured nuclear fuel supply capability involving uranium enrichment, fuel fabrication, spent fuel management and radioactive waste storage. If Egypt is assured such fuel supply capabilities at existing world prices, there is no economic incentive for Egypt to develop indigenous nuclear fuel cycle facilities until about the year 2000.

Financing a nuclear generation capacity of 6000 MWe to 12,600 MWe by the year 2000 may be difficult due to the high capital cost of nuclear plants, the long-lead time for the siting and construction of such facilities and the higher ratios of foreign manpower, equipment and resources that will be involved. Measures to allow Egypt to provide more of these resources, while needed, will not eliminate the financing challenge in the period to 2000.

The cost of nuclear energy in Egypt must consider not only plant construction and fuel costs, but also the cost of all the supporting infrastructure, e.g., establishing a regulatory process and organization, safeguards implementation, providing specialty O&M services, fuel procurement, safeguards, and spent fuel management and radioactive waste storage. During the early phases of an expanding nuclear program, the unit costs of these essential "miscellaneous services" will be significant due to: (a) their high establishment and initial start-up costs; and, (b) the low nuclear capacity level to which these costs can be allocated. In the long-term, the cost of these "miscellaneous services" will not materially alter nuclear generation costs.

To date, there has been no public reaction in Egypt to the planned use of nuclear energy, and no major problems in this regard is foreseen by Egyptian authorities. Nevertheless, public education concerning nuclear energy merits more planning attention based upon the experience of other countries.

Similarly, the other effects of an expanded nuclear energy application program warrants greater attention in the national planning process. Included in these effects are: local environmental impacts of plant construction and operation; employment opportunities; effects upon regional development plans; social/cultural effects of introducing large technically sophisticated systems and related construction and operations personnel in new areas of the country; competition with other developmental issues for limited resources; and the placement of large generation stations with unique safety-related back-up power transmission system requirements at dispersed locations on a national transmission grid.

Next steps which warrant early attention by the Government of Egypt beyond those required for the Sidi Krier project fall into five general categories. They are:

1. Preparing a well-founded plan for expansion of Egypt's nuclear generation capacity which recognizes the full scope of the challenge that would be involved and the measures available to Egypt to address those challenges.

2. Bringing into place a project management and quality assurance capability commensurate with extensive application of a sophisticated technology with its associated stringent safety related requirements.

3. Establishing a nuclear regulatory infrastructure which includes well-founded evaluation criteria, standards, and processes, an ably staffed and functionally effective regulatory organization, and a regulations enforcement capability.

4. Initiation of efforts to more clearly ascertain the availability of indigenous uranium resources and the potential role exploitation of these resources could have upon Egypt's commodity exports and international balance of trade.

5. Evaluation and selection of those materials and equipment supply or service areas which Egypt can develop as domestic supply capabilities. Programs should then be initiated by the Government of Egypt to bring into being in these selected areas, domestic materials and equipment supply capabilities which meet or exceed established standards.

3.0 EGYPTIAN PLANS FOR NUCLEAR ENERGY

Egypt is faced with an increasing need for electric energy which can be supplied by hydroelectric, fossil-fired, solar or nuclear power generation plants. Considering projected growth rates in the demand for electricity, the availability and relative generation costs of alternative generation systems and fuels, and alternative uses for fossil fuels, Egyptian officials have decided that nuclear power plants should provide a significant portion of Egypt's future electric energy. However, detailed long-term plan for nuclear capacity additions to Egypt's electric grid exist. Various Egyptian projections call for 6000 MWe to 12,600 MWe of nuclear generation capacity to be operational by the year 2000. The following sections provide more details on the basis for this projected utilization of nuclear energy.

3.1 <u>Growth in Electricity Demand</u>

Table 1[1] summarizes historic and projected growths in the demand for electric energy and peak demand for electricity both in actual values and annual growth rates over intervening periods.

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[1] Historical data from Egyptian Electricity Authority (EEA) Annual Reports, future projections provided by EEA as part of joint activities.

TABLE 1

Growth in Electric Energy Consumption and Peak Demand

	1952	1970	1975	1985	2000
Electric Energy					
Consumption-billion kwhrs	0.8	5.7	9.8	32	100
Peak Demand-MWe	100	1010	1775	5000	17000
Annual growth rates per-cent per year	1952 to 1976	1970 to 1976	1974 to 1975	1975 to 1985	1985 to 2000
Electricity Consumption	11.1	9.4	14.7	12.7	8.0
Peak Demand	12.6	9.8	21	10.9	8.5

These projections are in general agreement with the results of independent studies carried out by the International Atomic Energy Agency[2] and the World Bank[3]. They may be compared with current rates of growth of demand in the U.S., Canada and Western Europe in the range of 6 percent to 7.5 percent per year.

3.2 Availability of Alternative Generation Systems

In considering construction of a first nuclear power plant at Sidi Krier, Egyptian authorities examined the prospect of alternative electric generation systems to provide the projected demand for electric energy[4]. The following quotes from the report on that evaluation summarize their findings.

> "Considering alternative energy sources, the known geothermal resources in Egypt are essentially nonexistent on any suitable scale to be considered for power generation. There are coal deposits in the Sinai, but they are too small to be considered for power production. Importation of coal for this purpose is not considered economically feasible."

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2 Market Survey for Nuclear Power in Developing Countries, Egypt; IAEA 1973

3 Power Sector Survey in Egypt, Sanderson and Porter, Nov. 1976

4 Report on Egypt's Need for its first Nuclear Power Plant, November 1976

"Natural gas deposits do exist in the country; however, the present and projected production of natural gas at the time was not determined to warrant further consideration with respect to the requirements for the large generating unit necessary at that time, in addition to those already committed for gas. The two remaining indigenous energy sources, hydro and oil, are the only significant alternatives which should be considered further."

"Potential hydroelectric power resources are the Qattara Depression Project and the Nile Barrages. Although the Qattara Depression Project is planned to have an installed capacity of about 600 MWe in its first stage and could replace a nuclear generating unit of comparable size, it is not considered a timely viable alternative for this particular nuclear project. This is because of present indications of very high capital costs, uncertainties using clean nuclear explosions with such large amounts for excavations of the intake channel, and the requirement of an extended schedule for completion. It could become an economically feasible alternative for some later nuclear stations, if all technical, and economical problems associated with clean nuclear explosions are solved."

"As stated before, there are three existing barrages on the Nile for irrigation proposes and seven more are being considered. If all ten of these were utilized for hydroelectric power generation, a maximum total installed capacity of 600 MWe could be realized; however, the usable capacity would drop to 300 MWe during the low-water winter season. The fact that the first of these generating units would not be available until after 1985, coupled with the variation in generating capacity due to seasonal water level variations, indicates that this source of energy is not a comparable alternative for the nuclear station under consideration."

"The one alternative energy source requiring further close economic comparison is oil. Present indications are that the fuel oil requirements for a plant of the 600 MWe size could be met by Egyptian production from domestic crude oil. Fuel oil used for power production in Egypt is currently subsidized by the Government; however, for a valid economic analysis, the international price of approximately $75/tonne is going to be considered here."

3.3 Power Generation Costs

This led to an examination of the comparative electric generation costs of nuclear- and oil-fired generation plants. The following quotes[5] summarize the results of that examination of comparative generation costs.

> "Figure (1) shows a comparison by year after the start of the plant commercial operation of the cumulative differential operating cost savings for a nuclear plant versus an oil-fired plant in the 600 MWe capacity size. This exhibit was prepared using capital and operating costs estimated for the Sidi Krier project and cost data on operating oil-fired plants under comparable economic conditions."
>
> "This evaluation was performed for a twelve-year period of plant operation, using present day prices for fuel costs of $75/tonne for fuel oil, nuclear fuel prices as per Figures (1) and (2) and using present work methods to the date of commercial operation. As shown from Figure (1), the cumulative savings in operating costs of the nuclear plant with respect to an oil-fired plant will equal the difference in capital cost of the nuclear plant over the oil-fired plant after approximately 4.5 years of operation. Furthermore, the cumulative savings will equal the total capital cost of the nuclear plant after approximately ten years of operation."
>
> "The sensitivity of power generating cost to fuel price variations has been evaluated under the same conditions described for Figure (1) above and the results are shown in Figure (2). Power generating costs are considerably less sensitive to fuel price variations for a nuclear plant [than] for a conventional oil-fired plant. For example, a 50 percent increase in the fuel price would increase generating costs by 5 mills/Kwhr for a 600 MWe nuclear power plant while a corresponding effect for an oil-fired plant would be an increase of 18 mills/Kwhr in generating costs."
>
> "Cost estimates have been made using a 6 year project design and construction schedule from date of contract signing to commercial operation and a twenty-five-year economic lifetime for the plant.

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[5] Ibid 4.

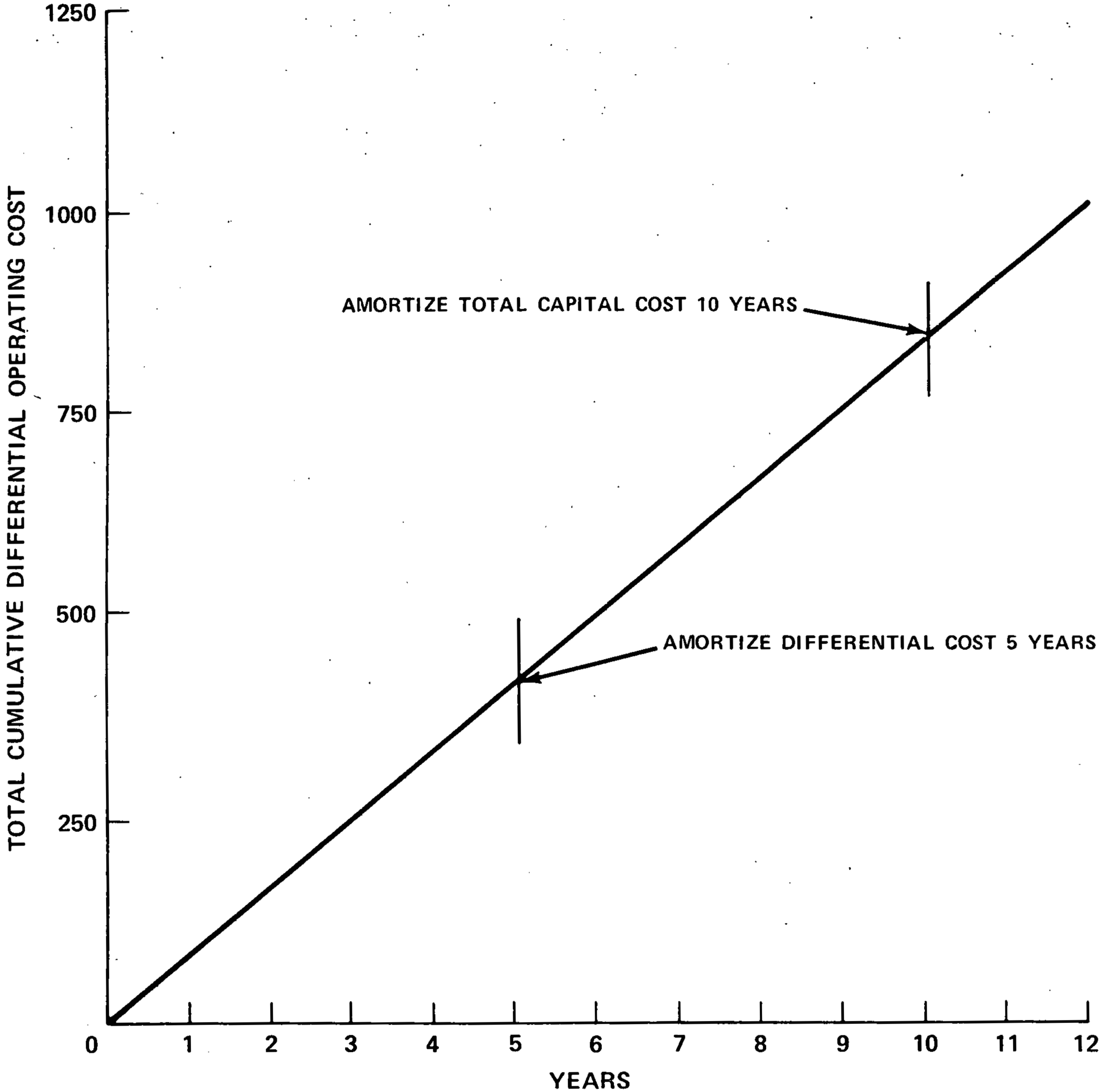

FIGURE 1. CUMULATIVE DIFFERENTIAL FUEL COST SAVINGS NUCLEAR FUEL VERSUS OIL

NUCLEAR-EGYPT-10

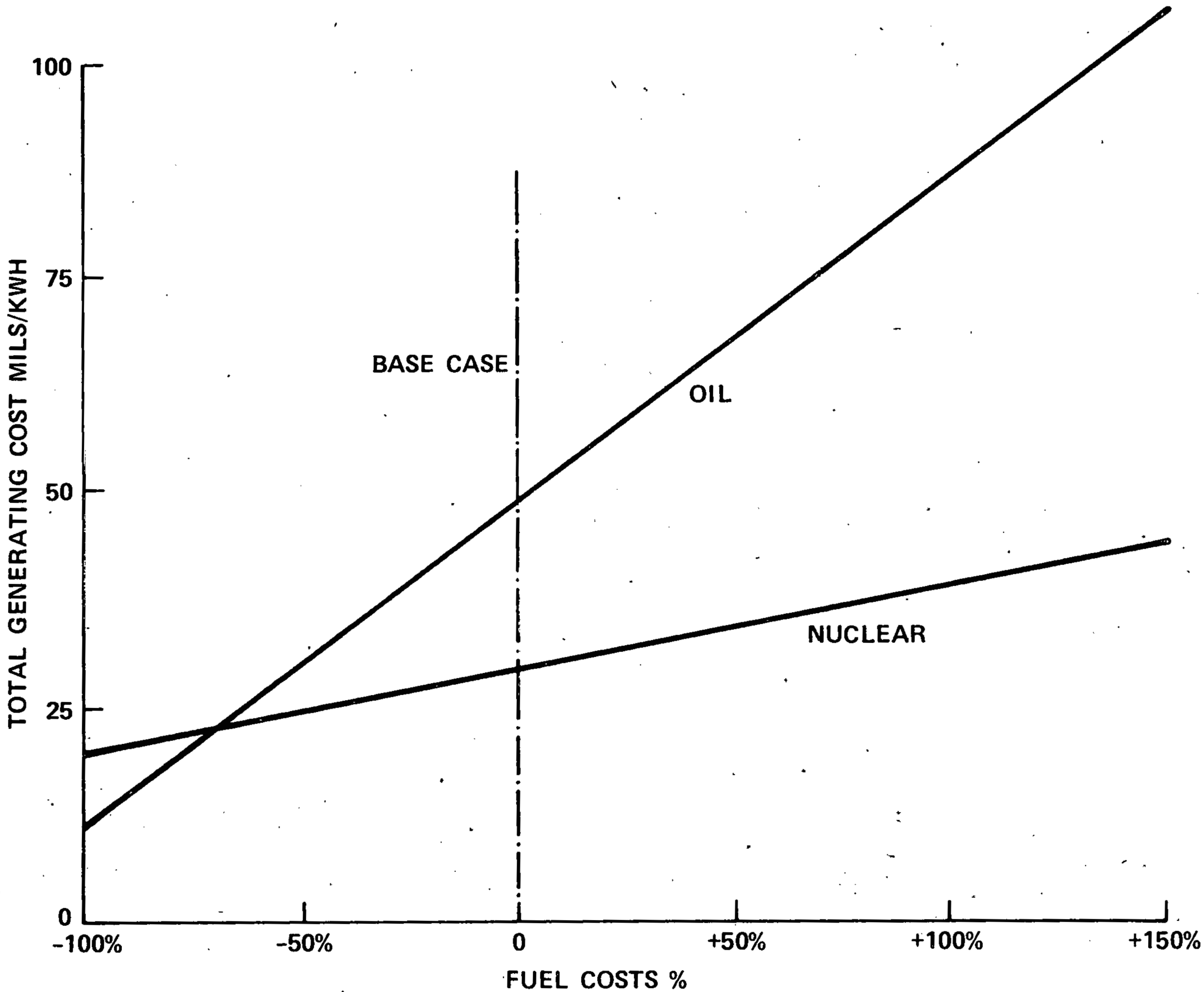

FIGURE 2. SENSITIVITY OF POWER GENERATING COSTS TO FUEL PRICE VARIATION NUCLEAR FUEL VERSUS OIL

Cost estimates presented in this report are for January 1977 as the nominal month of contact execution and January 1983 for commercial operation with escalation and interest during construction included."

"The total estimated capital is $815 million for the nuclear power plant and the cost of the desalination plant is not included. These estimates include interest during construction at an average rate of 5 percent per year and cost escalation to January 1983 at approximately 6.4 percent per year.

3.4 Immediate Focus of Egyptian Nuclear Effort

The primary focus of the Egyptian nuclear power plant effort during the past several years has been to initiate construction of Egypt's first nuclear power plant at Sidi Krier, 34 kilometers west of Alexandria on the Mediterranean coast. This site was selected in 1962. It is still the selected site because of the availability of the large amounts of cooling water required, the ability to link up with the national grid which extends to Sidi Krier, the relative nearness of a major load center in the Alexandria region, the availability of sufficient empty land within which to site the plant and its exclusion area, and the proximity of facilities to support the large construction labor force.

A letter of intent was issued in 1976 by the Government of Egypt to the Westinghouse Corporation for supply of a two loop, 626 MWe (net) pressurized water reactor (PWR) nuclear power plant under a modified turn-key arrangement. Completion of negotiations of this contract await the negotiation and ratification of a bilateral agreement between the Governments of Egypt and the U.S. This bilateral agreement will establish a framework for nuclear cooperation between Egypt and the U.S. including provision for fuels safeguards and provision for non-proliferation of nuclear weapons.

Based on the status of these negotiations, it now appears that the earliest optimistic operational start-up date for the Sidi Krier plant is 1986*. In light of the delays in the projected operational date of the Sidi Krier plants and projected peak demand increase, Egypt is projecting the need for construction of shorter lead-time, oil-fired power plants to begin operation in the 1984-1985 time frame.

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*This was the conclusion at the completion of the in-country data collection phase and initial preparation of this report in May 1978. Due to delays in the intervening period, the earliest optimistic date is now 1987.

Egypt initialed but did not ratify the Nuclear Non-Proliferation Treaty (NPT) in 1968 and had indicated its willingness to accept safeguards on its nuclear power plants. Egypt has also entered into a fixed commitment contract with the U.S. Government for the supply of enriched uranium for the initial core loading of the Sidi Krier plant.

Egypt ratified the Vienna Convention in 1965 which, among other things, stipulates that Egypt will make provision for treatment of third party liability in the event of nuclear accidents. Extensive discussions have been held with the IAEA, and it is understood that draft legislation regarding third party liability has been prepared and is currently being reviewed.

4.0 EGYPT'S RESOURCES TO IMPLEMENT A NUCLEAR ENERGY PROGRAM

Effective implementation of an extensive use of nuclear power systems over the period to 2000 will require a large commitment of resources by the Government of Egypt. This section reviews some of those resource requirements and Egypt's potential capability to meet them.

4.1 Management

There are four organizations in the Government of Egypt which have authority within the broad range of nuclear activities. The Atomic Energy Establishment (AEE) was formed by a decree in 1957 specifying it as the sole responsible body for all nuclear activities. A 1960 decree reemphasized the authority of the AEE but delegated to the Ministry of Public Health the authority for sealed radioactive sources, X-ray machines and particle accelerators. The Nuclear Power Plants Authority (NPPA) was established by law in 1976 within the Ministry of Electricity and Energy as the organization responsible for the planning, siting, construction and operation of nuclear power plants. The Nuclear Materials Authority was established by law in 1977, with responsibility for uranium and thorium exploration and the development of reserves.

In these organizations a cadre of technically-trained personnel exist that can form the nucleus of a management capability for a nuclear power application program. However, as expected, the experience of these organizations has been focused primarily on theoretical or laboratory research work and the requirements to legislatively and contractually authorize the procurement, siting, and construction of Egypt's first nuclear power plant. There is not a broad base of management experience in the actual siting, licensing, construction, start-up, and operation and maintenance of nuclear power plants.

Effective achievement of an accelerated use of nuclear power systems will require both an enlarged management capability with appropriate delegations of authority and a disciplined management approach at the senior, middle, and craft-work supervision levels. A heightened awareness of quality assurance (the "quality concept") and the extensive measures required to assure a high-quality product is crucial to the required management concept. Greater delegation of authority and dedicated responsive exercise of that delegated authority must be achieved. Effective use of management reporting systems, project scheduling tools, project control, and management decision-making techniques will factor importantly in the achievement of project design specifications, safety requirements, schedule targets and cost limits.

The NPPA has overall responsibility for the Sidi Krier project. Through use of a modified turn-key contract arrangement, these responsibilities will provide an excellent opportunity to observe and learn from the contractor's management staff. By so doing, an improved management capability will start to be built by NPPA for application to subsequent plants, thus reducing the need to use expatriates. This approach has been effectively used in other countries and could be effective in Egypt. Nevertheless, priority attention needs to be applied to these and various other measures, including on-the-job training in other countries of experienced engineering or technical managers, middle-level administrators and craft supervisors.

Effective motivation of these people must also be achieved through improved salaries, job challenge and other measures as discussed in Annex 12-Manpower.

4.2 Plant Sites

Evaluation of potential sites for nuclear power plants was begun by Egypt in 1960 using the "Farmer's Criteria." Fourteen sites were examined with assistance by the English firm, Kennedy and Duncan. Sidi Krier was selected as the site for the first nuclear plant. The U.S. Nuclear Regulatory Commission's (NRC) Regulatory Guide Format and U.S. regulation standards, 10CFR50 Appendix A and 10CFR100, are being applied in the more specific evaluations of the sites.

Current policy, to insure zero risk of contamination of the Nile River, prevents siting of plants in the Nile Valley. Also, it has been decided that nuclear plants will not be sited along the Suez Canal. Potential sites exist in three areas; (1) the Mediterranean Coast west of Alexandria; (2) the Mediterranean Coast east of the delta near Port Said; and (3) along the coast of the Gulf of Suez and the Red Sea. A French firm, SOFRATOME, is currently identifying, evaluating, and ranking potential nuclear plant sites in each of these three areas considering site seismicity, geology and soils, hydrology, access to transport, weather conditions, population proximity, access to sources of aggregate, etc.

Two local seismically active belts exist in Egypt: (1) the Abu Roash - North Sinai belt which passes through Heliopolis toward Ismailia; and (2) the Red Sea - South Greece belt extending from the west coast of the Red Sea (near the Gulf of Suez) through the Nile Delta and the Mediterranean to South Greece. The maximum intensity earthquake reported in either of these zones in Egypt is about 5 on the modified Marcali scale. It does not appear that seismicity should limit the availability of sites.

Location of plants on sea coasts allows access to adequate cooling water either by once-through sea water cooling, or possible salt water cooling towers. Similarly, weather conditions along the coasts do not appear to be a major limitation on plant siting. Finally, sites would appear to be available in the three noted areas which are sufficiently remote from large population centers.

In summary, the availability of suitable nuclear plant sites would not appear to be a limiting resource on the application of nuclear power plants through the year 2000.

4.3 Siting and Safety Regulations

4.3.1 Codes and Standards: Egypt has a limited number of standards, none of which were indicated as mandatory. Implementation of siting, safety, and quality assurance requirements will involve extensive use of codes and standards in a number of areas, which in turn, will require experienced and qualified manpower and a regulatory authority to insure their proper application.

Well founded codes and standards can be obtained by either of two alternative means: (1) Egypt can prepare its own, drawing upon those used by other countries; or, (2) Egypt can adopt and apply codes and standards developed and proven to be adequate in other countries, the IAEA, or other international bodies.

Egypt has opted for the approach of adopting readily available codes and standards developed by others for its specific nuclear power plant project needs, at least until it is able to modify those codes and standards to its local conditions and requirements. In this light, Egypt plans to use U.S. codes and standards for the Sidi Krier plant. If, in the future, nuclear power plants are procured from other nuclear-export countries, Egypt expects to use the codes and standards of that exporting country, at least for its initial procurements from that country.

A challenge evolving from this approach will be to maintain an effective quality assurance and inspection program using several different sets of codes and standards. Fortunately, the codes and standards of most nuclear exporting countries have a fair degree of technical consistency. However, it will be necessary to train an experienced cadre of Egyptian QA personnel and inspectors capable of using and distinguishing between several sets of codes and standards.

The potential use of several sets of codes and standards could also pose a problem in the development of Egyptian manufacturing and engineering service industries. At that time, Egypt may find it desirable to develop its own codes and standards through modification of those of other countries.

An associated need will be the integration of nuclear codes and standards, inspection, and quality assurance into Egypt's infrastructure supporting nuclear energy, which must have viable QA programs for nuclear work and qualified personnel. The enforcement of these QA programs must be a function of the nuclear regulatory body, with the NPPA taking the lead in implementation.

<u>4.3.2 Regulatory Evaluation Process, Organization, and Staffing</u>: The IAEA, in its "Code of Practice for Safe Operation of Nuclear Power Plants" states that "In discharging its responsibilities for public health and safety, the government should insure that the operational safety of a nuclear reactor is subject to surveillance by a regulatory body independent of the operating organization." The following primary responsibilities must be assigned:

1. Establishing or adopting safety criteria and safety requirements for the nuclear installation.

2. Establishing criteria for selecting operators and setting methods to verify their qualifications for an assigned job.

3. Safety assessment of the design of any nuclear installation in all its stages including design development after operation.

4. Issuing permits for construction and operation of the installation.

5. Inspection during all phases of construction and operation of the installation to check conformity with the approved design and operating limits.

6. Issuing licenses for operators and periodic testing of their qualifications for their responsibilities.

It is further specified that "In performing its function, the regulatory body should act independently of applicants, vendors and operating organizations, and should also not be directly responsible for promotion of nuclear energy. However, full use of available expertise is essential and should be made under the control of the regulatory body."

This leads to a choice between (1) forming a nuclear regulatory body before the initiation of a nuclear plant program, (2) taking this step shortly after the nuclear program is underway, or (3) depending, at least initially, upon the nuclear regulatory body of another country under some service arrangement. The current thinking in Egypt appears to be that the late establishment of its own nuclear regulatory body is not advisable, and, therefore, a nuclear regulatory body must be established before implementing its first nuclear power plant project. The possibility of remaining dependent upon an external regulatory body does not appear to have been seriously considered.

This makes establishment of an Egyptian Nuclear Regulatory Board (ENRB) an urgent matter. Decisions are needed now as to its organization, its review and evaluation procedures and criteria, and staffing. Identification of qualified people for the ENRB staff should be started immediately.

The AEE has a staff of about 2200, approximately 200 holding Ph.D's and over 600 with advanced degrees. This is a potential source of qualified people. Training and experience in the regulatory review process and appropriate application of codes, standards and evaluation criteria will be urgently needed. Egypt is considering an offer by the U.S. Nuclear Regulatory Commission (NRC) to host limited numbers of Egyptian specialists for training in performing typical NRC tasks. In view of the extensive training requirements of the ENRB, this offer by the U.S. NRC might be helpful but is insufficient.

Since the initial work of the ENRB might only be part-time, there may be problems in assuring complete independence of its staff. Consideration could be given to preparing and implementing conflict of interest regulations for the ENRB staff.

A related difficulty will be the potential need to modify or amend U.S. NRC Regulatory Guides as applied in Egypt based on Egypt's local conditions and problems. Other software-related problems involve the selection and availability of computer programs, analytic methods and experimental data in a number of diverse technical areas for use in the design review process. This will undoubtedly entail a need for reliance on outside assistance initially.

The ENRB will require certain facilities, including computational facilities for design reviews and safety assessments. Information storage and retrieval facilities and systems will be required. Access to foreign information centers should be arranged.

Establishing and maintaining an ENRB will be costly. Large numbers of people and many detailed organizational and staffing choices are involved. It was not practical to estimate the total cost of establishing and maintaining an ENRB. A detailed plan of action, specific to Egyptian conditions, needs to be prepared to establish the ENRB.

It is also noted that, should there be a major reduction in Egypt's projected nuclear generating capacity, then current thinking may need to be altered in the direction of increased reliance on consultants and support by the regulatory bodies of other countries.

4.4 Equipment Manufacture and Plant Construction

The first Egyptian nuclear power plant will be provided and constructed on a modified turn-key arrangment with essentially all professional and skilled crafts manpower, equipment and construction materials being imported. However, Egypt's policy is that some local manufacture be included in material or equipment supply contracts, with a minimum objective being 25 percent.

Egypt has the basic material capability to develop a capacity for local manufacture of some items to support nuclear construction. A demonstration of this capability is in the latest expansion of the Helwan Steel Works where about 80 percent of the equipment for an additional blast furnace complex was manufactured in Egypt. Egypt has several organizations with carbon steel machining and manufacturing capability. One apparent limit is a 60-ton crane capacity limit. Additionally, there is only a limited stainless steel welding capability in Egypt. This will have to be increased to support the projected construction of power plants (nuclear or thermal). The facility needs for this are small; the main problem will be manpower training. The development of the qualified manpower and QA methods, procedures, and standards are essential prerequisites for local manufacture and must be given high priority.

Certain items of nuclear power plants could not reasonably be expected, even under optimum conditions, to be suitable for local manufacture or supply during the period to 2000. Those nuclear plant equipment items judged as not suitable for Egyptian local manufacture include:

1. Nuclear grade forgings and castings

2. Stainless steel piping

3. Heavy section, nuclear grade piping and fittings

4. Reactor vessels

5. Steam generators

6. Pressurizers

7. Turbine-generators

8. Main coolant pumps and drives

Items which might be locally provided, if a manufacturer locates and operates a production facility in Egypt for export, as well as domestic consumption include:

1. Instrumentation and a control equipment

2. Small and moderate size electric motors and drives

3. Switch gear

4. Control rod drives

Items which appear to be favorable for local manufacture or supply include:

1. Structural steel

2. Cement

3. Reinforcing steel (Rebar)

4. Non-nuclear piping

5. Non-nuclear valves

6. Radioactive waste processing equipment

7. Small pumps

8. Machining of components up to 60 tons, where forming and welding was done prior to shipment

9. Piping spool pieces

10. Containment vessel materials and on-site assembly

Egypt provides a significant portion of construction crafts labor in the Middle East. This is a benefit on Egypt's balance of trade due to foreign exchange returns. The problem is that this export of skilled craft labor constitutes a continual drain on Egypt's resources of trained manpower. Therefore, for Egypt to maintain a significant pool of trained Egyptian construction personnel, it must provide sufficient incentive to attract and keep top capability levels of these experienced Egyptian people to work on projects in Egypt. This subject is discussed in more depth in Annex 12-Manpower.

Egypt's Ministry of Electricity has three construction companies. Arrangments are now underway to make these construction companies joint ventures with major worldwide construction companies. One would be a joint venture with a U.S. company, Brown and Root. The other two would become joint ventures with designated construction companies in Italy and Austria.

There are also private sector construction companies (not owned by the government) which are rapidly growing and undertaking an increasing share of Egyptian construction. Construction on the first nuclear plant (Sidi Krier) is currently envisioned to be accomplished by J. A. Jones, a U.S. construction company operating in Egypt. If experience from this project can be successfully transferred, Egypt's construction companies should be able to play a greater role in subsequent nuclear power plant construction activities.

4.4.1 Multiple Supply Sources: Assuming arrangments for the Sidi Krier project proceed successfully, the first Egyptian nuclear plant will be a U.S. designed and manufactured pressurized water reactor (PWR) type nuclear power plant. There is a significant incentive for countries during the early stage of the use of nuclear power systems to standardize on a single type of plant design. This offers saving in spare parts, training programs, safety design reviews, operations and maintenance service needs, fuel procurement, etc.

At the same time, it must be recognized that multiple supply sources possibly with different reactor types will compete for subsequent Egyptian nuclear power plant projects and there could be substantive advantages to Egypt to utilize different supply sources for those subsequent projects, (e.g., assured international financing). Use of alternative supply sources involves not only different countries, but significant differences in reactor design both within the same type as well as in different types, i.e., PWR, boiling water reactor (BWR), and heavy water reactor (HWR). Existing supply sources and reactor types include: U.S.--both PWR's and BWR's; France--PWR's under U.S. license arrangements; West Germany--PWR's; Russia--PWR's; and Canada--HWR's. Potential suppliers and reactor types include: Japan--PWR's and BWR's, and India--HWR's.

Both PWR's and BWR's require enrichment of the uranium 235 isotope in the fuel to be used. A major advantage of HWR's is that they can use natural uranium, thus avoiding the need for fuel enrichment services; however, HWR's may use some enrichment of fuel (less than for PWR's and BWR's) on the basis of least cost electric generation. The following discussion in this annex addresses PWR's. The following key differences exist between PWR's and HWR's:

- Capital cost of HWR's are higher by about 25 percent.

- Operating cost is increased due to the need for replacing losses of expensive heavy water.

- o The use of natural uranium and a throw-away fuel cycle removes the necessity for fuel enrichment and fuel processing facilities.

- o More fuel must be fabricated due to lower burnup resulting from use of natural (or only slightly enriched) uranium.

4.4.2 Speciality Services: Operation and maintenance of nuclear power plants involves a need for many specialty services such as instrument maintenance, radiation monitoring, health physics, fuel management, water chemistry services, etc. These specialty services can be costly if done on a single plant basis and significantly lower costs can be achieved through purchase from a service source geared to handle a large number of plants. Such service sources can provide highly technical and expensive personnel and sophisticated systems that have benefited from many years of experience on other plants. Recognizing that the NPPA has the authority to obtain qualified expatriate labor as needed, Egypt should carefully review how these specialty services will be provided for the first plant and how it wishes to proceed regarding such service requirements as subsequent nuclear power plant projects are considered.

By the mid-1980's, plants of the same type and design as that at Sidi Krier will have been operating in Korea, Yugoslavia, Brazil, and the Philippines. The plant in Korea is now operating, and there will be at least nine years operational experience by 1986. This provides a source for operating, maintenance, and testing procedures, as well as opportunities for training people. Egypt should consider means to exercise this opportunity in its preparations for the Sidi Krier plant.

4.5 Fuel Supply

Egypt currently has limited proven economically recoverable reserves of uranium and thorium. Therefore, although nuclear energy appears to offer lower cost electric energy than use of oil-fired electric generation, it could involve greater dependence by Egypt upon foreign fuel supply capabilities unless proven, economically recoverable, indigenous fuel resources can be found and developed. In addition, dependence upon other foreign uranium enrichment and fuel fabrication capabilities will probably be the lowest cost means of acquiring these services for a number of years. In this context, a matter of great importance to Egypt's planned use of nuclear energy will be to establish an indigenous uranium supply capability and to obtain an assured supply of other nuclear fuel services. This section reviews the nuclear fuel requirements and the prospect of an indigenous fuel supply capability in the various areas of the nuclear fuel cycle operations.

4.5.1 Uranium and Thorium Reserves: A small effort on systematic prospecting for nuclear materials was begun in Egypt in 1961. Small concentrations of thorium and uranium were found to exist in uranium bearing monazite, heavy mineral beach sands and phosphate rock. However, the concentrations are sufficiently low that economic recovery would be possible only if the sands or phosphate rock were being used for other purposes and the extraction of uranium and thorium could be done as a by-product operation of these other economical uses. To illustrate, a phosphate plant handling 500,000 tonnes of raw phosphate ores per year could theoretically produce about 25 tonnes of U_3O_8 per year. Large-scale processing of phosphate ores is not currently contemplated.

As reported in more detail in Annex 1-Energy Resources of Egypt, recent exploration activities have focused upon aerial radiometric surveys. A large number of radiological anomalies have been identified. Ground survey work has not proceeded to the point that prospective uranium deposits have been confirmed as proven reserves. However, several promising potential deposits have been identified and it is possible that Egypt could, within a number of years, have significant proven reserves of economically recoverable uranium. Egypt has recently initiated discussions with private corporations to explore possible arrangements to more thoroughly determine potential uranium reserves through joint efforts similar to those used with regard to oil reserves in Egypt.

4.5.2 Uranium Ore Requirements: Taking into account fuel processing losses (e.g., enrichment tails) and fuel remaining in the fuel elements upon discharge from the reactor, a PWR type nuclear power plant requires about 15 metric tonnes of U_3O_8 per year for each 100 MWe of generating capacity. On this basis a 600 MWe nuclear power plant needs about 90 metric tonnes of uranium as fuel for each year of operation.

To illustrate potential mine and mill requirements, if one assumes a typical surface mine of 6800 tonnes per day of ore of 0.02 percent (200 ppm) concentration of U_3O_8 operating 70 percent of the time and with an 80 percent recovery of U_3O_8, it would produce about 275 tonnes per year of U_3O_8. The cost of such a surface mine would be on the order of eight million Egyptian pounds. Such a mine would also require a self-standing uranium milling plant unless a number of mines were sufficiently close in proximity that a single large mill could serve a number of mines. A milling plant to process the ore output of this hypothesized mine and extract the U_3O_8 from it would cost on the order of 4.5 million Egyptian pounds. Such a mine and mill complex could support about 1800 MWe of nuclear generating capacity.

A minimum of four years would be required to bring into operation a uranium mine and mill complex once a proven reserve of ore sufficient to warrant the investment has been determined to exist. Therefore, if Egypt wishes to establish its own means of supplying uranium for the operation of its nuclear power plant program, uranium exploration and development activities are of the highest priority.

<u>4.5.3 Conversion of U_3O_8, to UF_6</u>: Conversion of the product or uranium mills, U_3O_8, to UF_6 is required as a prerequisite to increasing the concentration of the U-235 isotope in a fuel enrichment plant. An economically competitive conversion plant would have a capacity of about 10,000 tons per year of UF_6. This is about 5 to 10 times the amount of uranium conversion that Egypt would need in the year 2000. Therefore, construction of a uranium conversion plant by Egypt would appear to be economically inadvisable and Egypt will probably remain dependent upon other countries for this service throughout the period of this assessment.

<u>4.5.4 Uranium Enrichment</u>: An economically competitive size commercial gaseous diffusion plant (8.75 million separative work units a year) would cost about 3.4 billion Egyptian pounds. This plant is many times larger than would be required to handle Egypt's maximum projected nuclear power plant capacity in the year 2000. The electric supply for such a plant would increase Egypt's need for energy. Hence, an attempt by Egypt to bring into being its own uranium enrichment capacity would appear to be economically inadvisable.

There are development activities underway in several countries on other uranium enrichment concepts which offer the prospect of lower unit cost of enrichment, along with the prospect that smaller capacity plants could provide economically competitive enrichment services. Egypt plans to continue following developments on these activities. If a system is developed which is economic on a scale consistent with Egypt's needs, then Egypt might reexamine uranium enrichment options.

Egypt recognizes numerous difficulties with uranium separation services:

1. Long lead contracts, requiring advanced payments approximately ten years prior to delivery are available. There are penalty clauses in case of delays by the purchaser.

2. The future cost of enrichment represents a major uncertainty in nuclear fuel cycle cost.

3. A reliable long-term source of supply is needed.

Possible advantages exist with respect to regional or multilateral arrangements, but a more attractive option appears to be the establishment of a reliable source of supply for provision of the entire fuel cycle. Any such arrangements should address availability of materials and services, timely delivery, price guarantees, and assurance of application of safeguards to achieve nonproliferation objectives.

4.5.5 Fuel Fabrication: A typical economically sized fuel fabrication facility for light water reactor (LWR) type fuels would cost in excess of 50 million Egyptian pounds and could fabricate about 600 tonnes of uranium per year as enriched UO_2 pellets mounted in fuel assemblies. A single such plant could support a LWR type nuclear generating capacity of about 20,000 MWe. The plant would convert UF_6 to UO_2, pelletize the UO_2 and load the pellets into fuel assemblies ready for insertion into the reactor core. As such, the fabrication process involves many technically complex steps with a very high requirement for technical accuracy and quality assurance.

Due to the large capacity of such a facility, construction of a fuel fabrication plant by Egypt prior to 2000 would mean it would initially need to operate on a partial basis or would also be supplying fuel fabrication services to other countries to fully occupy its capacity. Additionally, in some evaluations, it has been assumed that competition in the 1990's in the world nuclear fuel fabrication industry will bring about even larger sized fabrication plants with reduced unit fuel fabrication prices.

In this light, entrance by Egypt into the nuclear fuel fabrication business will probably not be economically attractive prior to 2000, and should be considered only if the resources requirements of other higher priority needs of Egypt's energy programs are fully satisfied.

4.5.6 Spent Fuel Processing: A throwaway fuel cycle was assumed for this assessment. Therefore, no spent fuel reprocessing was needed. In any event, with the current state of technology and the significant cost versus size scaling factors involved in spent fuel reprocessing facilities, it was judged that spent fuel reprocessing would not be an economically attractive option for Egypt until well beyond the year 2000.

4.5.7 Radioactive Waste Disposal: It is assumed that spent fuel will be returned to the fuel supplier pending decisions on fuel reprocessing and plutonium recovery for possible use. It was also assumed that Egypt has ample opportunities to develop sites for safe disposal of low-level radioactive wastes that would be generated by reactor operations.

Egypt has large areas potentially suitable for safe disposal of high-level radioactive wastes. It is understood that Egypt is evaluating radioactive waste storage prospects as a possible service to be made available on a commercial basis to other countries. No details on this possibility were available at the time of this assessment.

4.6 Financing

The overall aspects of Egypt's ability to finance its planned expansions of energy supply capability including the prospective use of nuclear power systems are addressed in Appendix G. This section of the Nuclear Annex provides comments only on selected nuclear specific aspects of the overall financing requirements discussed in that appendix.

Throughout the period examined in this assessment, nuclear financing requirements for the construction of power plants are the dominant factor in total energy financing needs if the high projected nuclear power plant capacity is to be pursued. Nuclear power plant financing needs could be of the order of 9 billion Egyptian pounds (not including interest during construction and fuel supply cost) depending, of course, upon the rate at which nuclear power plants are constructed. As is evident from the discussions of the prior section, there is great uncertainty in the degree to which Egypt will find it economically attractive to invest in nuclear fuel cycle facilities, but investing in these facilities would further increase Egypt's financing needs. If large-scale proven reserves of uranium are confirmed, the financing of uranium mines and mills will introduce financing needs consistent with the discussion in Section 4.5.2., which should not constitute a problem. Also, in that case, foreign participation in the financing of mine and mill development should be easily arranged.

Nuclear power plant procurement and construction in Egypt will be characterized, at least initially, by a heavy dependence on imported labor, materials and equipment. Clearly, it is in Egypt's best interest to reduce this dependence upon imported resources. This matter was discussed in some detail in Section 4.4 of this Annex. However, it should be recognized that significant changes in this respect would probably not take place until the 1990 time period. As such, progress in this direction would not change significantly the foreign financing needs of the nuclear energy program over the period of this assessment.

Siting and construction of nuclear power plants involve long lead-times on the order of 7-10 years. Yet, financing of the total construction cost of the project must be arranged at the time of commitment to its construction. As discussed in Appendix G, normal practice in financing of large construction projects is to allow a grace period on debt repayment until the facility becomes operational and, thereby, income producing. Interest owed during this construction grace period is accumulated and added to the debt to be repaid from operating revenues. It should be recognized that the extensive plant construction activities conducted during this grace period will create a significant input to the economic activity of Egypt prior to the obligation to make repayments on the debt. This effect is greater in the case of facilities such as nuclear power plants which involve high capital costs and long construction lead-times.

The nuclear fuel cycle involves a number of activities which spread in time from a few years prior to insertion of the fuel into the reactor core through a 3-5 year core residence time, to a few years after removal of the fuel from the core when final disposition of the spent fuel is accomplished. Because of this extensive time period, its overlapping with other fuel provision arrangements, and the number of activities involved, financing of nuclear fuel is a complex undertaking with many cash-flow intricacies. Specialty services are available from fuel suppliers and consultants to assist in this complex undertaking.

However, if Egypt wishes to consider optional courses regarding fuel supply and the assurance of needed nuclear fuel services, it will be important that Egypt develop an independent expertise in the procurement and financing of nuclear fuels and fuel services.

As noted in Sections 4.2, 4.3, and 4.4, the siting, construction and operation of nuclear power plants involves a considerable supporting infrastructure. Nuclear generation costs cannot be viewed independent of the costs of these infrastructure needs. Creation of these infrastructure capabilities can involve a significant expense for training, staffing, facilities, etc. This required "investment for the future" is considerably greater for nuclear power systems than it is for more conventional power generation systems.

During the early stages of an expanding nuclear energy program when only a few plants are operating, these expenses could be significant when measured in terms of the unit cost of the electricity generated by those few plants. However, as more plants become operational, the contribution of the cost of this infrastructure becomes a minor element in the total cost of electricity generation by nuclear power plants.

5.0 POTENTIAL EFFECTS OF THE EXPANDED USE OF NUCLEAR ENERGY

The potential effects of an expanded use of nuclear power systems are addressed in the context of the following topics: (a) public reaction, (b) environmental effects, (c) regional development, (d) transmission system needs, and, (e) social/cultural effects.

5.1 Public Reaction

There has been no public reaction to Egypt's planned utilization of nuclear power systems as has been experienced in many other countries. This is not unexpected considering the early stage of the Egyptian activities and the lack in Egypt of any organized group concerned with so-called environmental and public safety issues.

In this light, Egypt has devoted little attention to public education relative to nuclear energy. Egypt does plan to conduct such a program when the need arises. However, it does not view it as a priority matter at this early stage of its planned nuclear energy program. Egypt might re-examine the need for enlarged public education activities in light of the experience of other countries.

5.2 Environmental Effects

The impact of the use of nuclear power systems upon the environment will stem primarily from: site preparation and plant construction activities, cooling water requirements of the plant and other plant effluents. Other generic environmental effects of energy facilities are addressed in Annex 11-Environmental Issues Associated with Egypts' Energy Options.

Site preparation and plant construction activities for a nuclear power plant are basically the same as those for an oil- or coal-fired power plant. Although a larger site is required for a nuclear power plant to insure an exclusion area around the plant for safety evaluation purposes, actual site occupancy of a nuclear plant is generally less than that of coal- or oil-fired power plants particularly when on-site fuel storage requirements of the coal- and oil-power plants is taken into account. Therefore, the environmental effect of site preparation and plant construction activities of nuclear power plants are no greater than those of a comparably sized coal- or oil-fired power plant.

Cooling water requirements of nuclear power plants are greater than those of comparably sized coal- or oil-fired power plants. This is due to the somewhat higher plant efficiency of new large-sized fossil-fired units. If the fossil-fired units require flue gas desulphurization to meet air pollution requirements, this difference in cooling water needs is considerably less. If the nuclear plants are located on the Mediterranean and Red Sea coasts, as is currently planned, this difference in cooling water needs should not introduce a significantly different environmental effect.

Nuclear power plants enjoy a considerable advantage in comparison with fossil-fired power plants in terms of their other effluents. Nuclear plant effluents would consist primarily of: (a) low-level radioactive gas releases at levels considerably below U.S. regulatory standards, (b) some contaminated water discharges stemming from water treatment operations, and (c) solid low-level radioactive waste materials from plant operations and maintenance activities. In addition, spent fuel and high-level radioactive wastes would be periodically removed from the plant and transported to approved spent fuel management facilities or high-level waste depositories.

In comparison, fossil-fired power plants release large quantities of carbon dioxide, sulphur dioxide, nitrous oxides and fine particulate matter to the atmosphere through their stacks. Contaminated water discharges from water treatment operations can be similar in magnitude to those of nuclear plants. If air pollution standards make flue gas desulphurization necessary, significant quantities of limestone sludge or other chemical interactants would need to be disposed of.

5.3 <u>Regional Development Plans</u>

Utilization of nuclear power plants and their prospective location along the coasts of the Mediterranean and Red Seas would appear to coincide nicely with Egypt's regional development goals of: (a) developing new communities in these areas to accommodate Egypt's growing population, (b) providing greater employment in non-agriculture economic activities, and (c) raising the economic well being of the citizens of Egypt. Construction of nuclear power plants will involve a construction labor force of a few thousand people over a period of about five years. In initial plants 30 percent or more of this labor force will be imported labor. As future plants are built, more of the construction labor force could be drawn from Egypt's labor market. In addition, there will be substantive demands for supporting community and commercial services that will derive from the presence of this sizeable well-paid labor force.

In Egypt, nuclear plant operations staffs are projected to be of the order of a few hundred people. Therefore, after plant construction is completed, the nuclear plant will make a relatively small direct contribution to the local employment situation. However, the very existence of the nuclear power plant could open opportunities for location of other high-employment industries due to the infrastructure development which was necessary to support the nuclear plant construction. Nuclear plants can also be the source of large quantities of low-temperature heat which could be applied to water desalting and low temperature industrial needs in co-generation operational modes.

5.4 Electric Transmission System Needs

Nuclear power plants, because of advantages of scale, tend to be large-sized units of 600 MWe or larger. Nuclear safety evaluations result in the requirement that nuclear plants be served by two separate, independent sources of off-site electricity of full-sized capacity. The existence of large-sized generating units on an electrical grid usually introduce unique system stability considerations. If current nuclear plant siting plans are followed, Egypt's nuclear plants, at least during the period of this assessment, will be located near the outer geographical limits of Egypt's transmission grid. All these factors combine such that the use of nuclear power plants could have a significant effect upon the planning and scheduled expansion of Egypt's electric transmission grid. This potential impact and its consequences warrant careful examination in the near future.

5.5 Social/Cultural Effects

Nuclear energy involves high technology and specialization at the scientific, engineering, administration, and craft levels. Therefore, the construction and operation of nuclear power plants can be expected to introduce a highly-trained and well-paid element into the local population. At least initially, many of these people might be foreigners. Accordingly, there is a real potential for social/cultural effects upon those communities in close proximity to nuclear power plants. The potential impact will be greatest during the plant construction stage when larger numbers of foreign employees could be involved. In those instances where the nuclear plant site is remote from large urban areas, this introduction of a large-sized contingent of highly skilled and possibly foreign workers could have major local impacts.

These potential social/cultural effects of the use of nuclear energy merit careful attention in Egypt's nuclear energy program planning and, more importantly, in the planning of specific nuclear plant projects.

6.0 NEXT STEPS

If Egypt intends to pursue a program for expanded use of nuclear power systems to meet its future demands for electric energy, the following "next steps" warrant early attention and commitment of resources. These "next steps" are in addition to those specifically required to initiate construction of a nuclear power plant at Sidi Krier.

6.1 Overall Nuclear Plan

Egypt needs to prepare an overall plan for the application of nuclear power systems to its electric energy needs which is based upon: (a) realistic projections of future demand for electric energy, (b) the role which nuclear energy should play in meeting that electricity demand, taking into account optimal electric system planning objectives and the role alternative electric generation systems can be expected to play, and (c) Egypt's resource capability to bring into being the required number of nuclear power plants.

The plan should clearly identify current resource inadequacies and set forth realistic programs for the correction of those resource inadequacies. Where realistic plans to provide needed resources are not feasible, the plan for nuclear capacity additions should be modified accordingly.

The plan should address not only the siting and construction of the power plants per se, but, also, the several supporting infrastructures identified in this annex which would need to be created and brought to an operational stage in the same time frame as the power plant project.

The plan should be closely coordinated, not only with Egypt's overall economic, energy supply and financial plans, but also with regional development plans and the planning of the industry and transport sectors of the economy.

Senior management officials of the Egyptian Government should be made aware of the resource needs of the proposed nuclear applications program. Commitments are needed at the highest levels to those efforts which would be needed to effectively implement a high quality and effective nuclear applications program.

6.2 Plan for Management Development

A direct corrollary of the overall nuclear plan is the need for a plan to bring into being in Egypt a management capability to implement the nuclear plan. The management requirements of an expanded use of nuclear systems was summarized in Section 4.1 of this annex. Measures to achieve the management approaches and capabilities identified in that section must be defined, and commitments to those measures made so that an adequate management capability is available when needed. Without such planning and commitments, Egypt's implementation of its overall nuclear energy plan could be ineffective; its schedule targets may not be met; and undue costs may occur. The existance of a strong Egyptian management capability should materially enhance Egypt's ability to manage international financing for its nuclear power plant projects.

6.3 Regulatory Structure

Commitments are urgently needed for the establishment of a regulatory process and structure to assure the safe siting, construction, and operation of nuclear power plants in Egypt. The requirements for this regulatory process and structure were addressed in Section 4.3 of this annex. If those commitments cannot be made in the near future, Egypt should re-examine other measures for acquiring this capability on an interim basis from outside sources.

6.4 Nuclear Fuel Supply

Egypt should proceed expeditiously to initiate an agressive uranium exploration program to more assuredly determine the potential of sizable reserves of uranium-bearing ores in concentrations that could make them a commercially competitive source of uranium. The scope of such a program was set forth in some detail in Annex 1-Energy Resources of Egypt. If economically recoverable reserves of uranium ores are determined to exist, Egypt should consider early development of mines and mills necessary to exploit those reserves. This might not only provide sufficient uranium for Egypt's own needs, but could also have a significant impact upon Egypt's ability to arrange assured supply of other necessary nuclear fuel cycle services. Additionally, export of uranium could be a source of international financing of energy projects.

Egypt should continue to closely monitor world developments with respect to nuclear fuel cycle services and reexamine fuel service supply opportunities on a periodic basis.

6.5 Indigenous Equipment Supply and Construction Capability

Areas where Egypt could possibly provide more of the equipment and construction services required for nuclear power plants were discussed in section 4.4 of this Annex. Due to the long lead-time to bring about these manufacturing or services capabilities, this matter should be addressed in the preparation of the overall nuclear plan. Interaction with industry sector planners should be sought to identify and initiate actions to develop Egypt's ability to participate to a greater extent in nuclear equipment supply and construction activities.

POTENTIAL USE OF RENEWABLE ENERGY RESOURCES IN EGYPT

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SEPTEMBER, 1978

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1.0 INTRODUCTION AND SUMMARY

1.1 Advantages of Solar Utilization

The renewable resources addressed in this section include direct solar energy as well as those energy sources which ultimately derive from solar energy in the forms of wind power, biomass, and ocean thermal gradients. There are many approaches for using these renewable energy resources. As will be discussed in section 2.0, Egypt has excellent climatic conditions for direct solar energy applications such as water heating and power generation with over 3,400 hours per year of solar availability in the north* to 3,900 in the south. Furthermore, the Red Sea and Mediterranean coasts have sufficiently high annual average wind velocities to effectively operate wind turbine pumps and generators. The supply of biomass in the form of agricultural wastes is abundant and is now, in fact, a primary fuel form in rural areas for cooking and water heating applications.

Several factors, combined with this basic resource availability, could make the use of renewable resource energy systems particularly attractive in Egypt. These factors are discussed below.

Rural Development. Presently, only about 17 percent of rural homes have electricity. Development plans call for increasing electrification of rural areas to improve living standards in general. Furthermore, it is a cornerstone of government policy to develop new land in desert areas to help disperse the population. Both of these trends will call for bringing power to remote areas; this is conventionally done by extending the utility grid or using on-site engine driven generators. Solar power generation is ideally suited for use in relatively small increments in distributing power systems. The near term use of solar power, therefore, is considered within the context of a program of increasing rural electrification which could relieve pressure on fossil fuel-fired systems and on the need to extend the utility grid to service uneconomical loads.

In-country Manufacture. For the most part, both solar heating and solar power systems could be manufactured in Egypt using indigenous labor and material resources. Manufacture in Egypt has the obvious advantage of reducing the foreign exchange component of developing energy resources. Possibly of equal importance would be the positive social/economic benefits resulting from building up an in-country capability in an exciting and growing technological field which can help create a job producing industrial base for both internal and export markets.

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* By comparison, Albuquerque, New Mexico which has one of the highest solar availabilities in the United States, has 3,200 hours per year.

Technical Status/Modularity. Several of the solar technologies considered are already quite well developed. Combined with the incremental nature of most solar related systems, this would allow Egypt to initiate a solar development plan with a minimum time delay and modest front load capital requirements.

The above factors could provide an incentive for Egypt to consider strongly supporting the widespread use of solar energy in appropriate applications.

1.2 Economic Considerations

Presently, both electric and direct fuel energy forms in Egypt are heavily subsidized with the subsidy for both butane gas and kerosene used in households being over 50 percent. The economics of solar applications would not appear favorable based on competition with current subsidized consumer prices for conventional energy. Therefore, the economic analysis of solar systems and conventional energy sources assumes the opportunity or actual value of conventional energy sources based on world fuel prices and real costs for energy delivery. For this to be the case, either the pricing of conventional energy sources will have to reflect world prices (fossil fuels) or the solar related systems will have to be subsidized to the same extent as conventional fuels. Which course is actually employed must take into consideration the social impacts of allowing fuel costs to rise rapidly to world costs.

Several of the solar technologies are sufficiently well developed that selected near-term applications might have favorable economics in Egypt. Such applications include water heating (which comprises a large percentage of kerosene and butane gas usage) and power generation by wind turbines in rural areas (in competition with diesel generators). In the longer term, the number of economically attractive options will increase as the cost of solar heating and power systems is reduced as a result of active research and development programs in the United States, Europe and Japan combined with larger scale commercial manufacturing capabilities.

There is a great deal of activity in the solar field on a worldwide basis. The technologies resulting from these activities will, in large part, be available for use in Egypt, in some cases through joint venture arrangements with foreign firms.

In the United States, the government agency responsible for developing solar technology and demonstrating its commercial applications is the Department of Energy (DOE). Many of the technology options and cost projections used in subsequent sections reflect the output of the DOE programs. However, consideration has been given to emphasizing system arrangements which are adaptable to use and/or manufacture in Egypt, such as simple solar water heaters using natural convection circulation and photovoltaics combined with solar concentration.

Most of the solar options discussed herein are not manufactured presently in significant quantities and many are only in an advanced research and development stage. Therefore, the eventual cost and performance of such systems is still quite uncertain. DOE has cost goals for systems in each of the technology areas which, if achieved, would justify their large scale use in Egypt. There is no guarantee that all these cost goals will be achieved given the technological uncertainties; therefore, for this assignment these cost goals are assumed to be the lower limit of cost expectations. Due, in part, to the excellent solar and wind regimes in Egypt, the various solar options often can be economically viable in Egypt at costs significantly higher than those required in the industrialized countries. The economic performance of solar power and heat systems in Egypt, therefore, is assessed over a range of costs in order to identify the cost requirements for economically viable operation.

1.3 Solar Technologies Considered

The renewable energy resources considered in this assignment were:

- Solar Water Heating
- Solar Electric Power Generation
  - Solar Thermal
  - Photovoltaics
- Wind Electric Power Generation
- Biomass Utilization
  - Agricultural Residues
  - Urban Wastes
- Solar Desalination
- Air Conditioning and Refrigeration

Ocean thermal gradients and tidal power were also considered initially, but were not pursued due to lack of data indicating the availability of exploitable resources. Hydropower, another renewable resource, is treated elsewhere in this report. A brief summary of the status of the technology options and their applicability in Egypt is given below.

Solar Water Heating. Solar water heating is a well-demonstrated technology which already has widespread application on a worldwide basis. These systems could be installed on a large scale in residential, institutional, and commercial buildings in Egypt resulting in reductions in the use of butagas and kerosene, now commonly used for water heating applications.

Solar Power Generation. The operation of small-scale (1 to 50 kW) solar thermal power units* has been demonstrated with a number of units fabricated in France, the United States, and Germany.* These systems usually operate at modest temperature levels of 180 to 300°F and convert heat generated by flat plate or trough collectors into power by means of specially designed heat engines.** The most common application for these smaller power units has been for water pumping, which is of primary concern in Egypt.

There are extensive industrial and government sponsored programs to improve the technical/economic performance of these systems so they are more competitive with conventional power sources; particularly diesel engines which are often used in remote areas for power production.

The major effort in large-scale (i.e., hundreds of megawatts) solar power generation is directed toward the central receiver concept whereby an array of mirrors redirect solar energy to a boiler placed on a tower. Initial testing of major subsystems associated with this concept has been initiated; and a 10 MWe power plant is scheduled to begin operation in 1981 at Barstow, California. If successful, large power units based on this concept could be commercially available by the late 1980's.

Photovoltaic power units, which convert solar energy to electricity with no moving parts, presently are in widespread use throughout the world to supply small amounts of power to such applications as remotely located communications equipment. The performance of these systems is well demonstrated and present efforts are directed primarily toward lowering their cost so they are competitive with conventional power systems. The large developmental effort in this field by major companies increases the probability that substantial cost reductions in photovoltaic solar cell power units will occur so that their widespread use in the 1980's, particularly for use in remote areas not serviced by the utility grid, can be justified.

Wind Power Generation. The performance and reliability of small wind power units for electric power and water pumping has been demonstrated and over ten firms in the United States, Europe, and Australia manufacture systems in the 1 to 25 kW range.*** These systems are readily available for use in remote areas in Egypt.

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* Test units from these countries are now or will shortly be installed in Egypt by the Ministry of Electricity and the National Research Center.

** Organic Rankine cycle engines which use highly volatile refrigeration fluids.

*** Small wind-powered water pumps were, in fact, produced in Egypt during the 1950's, many of which are still operating in the region near Alexandria.

Large wind power systems with rated outputs of 100 kW to 4 MW are now under development and several systems with 100 to 200 kW capacity are undergoing performance testing in the United States. The technology of wind power systems is relatively straightforward; thus the goal of having large systems available by the early to mid 1980's should be attained.

The advanced state of development of both large and small wind power units and the favorable wind regimes along the Mediterranean and Red Sea coasts could lead to a significant role for wind power in Egypt.

Biomass Utilization. Biomass, in the form of agricultural residues, is presently the primary energy form used for cooking and water heating in rural areas of Egypt. However, with improving standards of living, there is a trend to replace open fire stoves with kerosene or butane stoves which are more convenient and cleaner to use.

There is a need, therefore, to consider alternative approaches for using agricultural residues as an energy source which is consistent with the desire to improve living standards. Both direct combustion of residue to generate electricity in a thermal system or the generation of gas in a digestion system for use in stoves, etc., at the village level have been demonstrated and could, in principle, be implemented in the near-term. There are, however, serious social/institutional problems associated with residue collection and conversion system operation which must be addressed before undertaking such a program.

The use of urban biomass resources in the form of solid wastes and sewage also could result in the generation of significant amounts of electric power as is now being done on a limited scale in the industrialized countries. The use of these resources has the advantage that they are collected as part of the normal functioning of society and their conversion to fuel or power assists in their environmentally acceptable disposal.

Solar Desalination. Desalination could be an important aspect of developing areas remote from the Nile Valley where supplies of potable water are often limited. Solar energy is well suited to performing desalination functions on both a small and large scale. The economics of solar desalination are favored by the fact that energy storage can be in the form of fresh water. The equipment required for desalination is, in many cases, quite well developed and ranges from simple solar stills* to the aforementioned power units which can be used to operate conventional reverse osmosis and vapor compression desalination systems.

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* Small solar stills have been the object of research and development programs at the National Research Center over the last 15 years.

Air Conditioning and Refrigeration. Air conditioning presently is not a big energy consumer in Egypt. The role of air conditioning is, however, expected to increase as living standards improve. There are several approaches for using solar energy to operate air conditioning systems including those using absorption cycles (which require heat) and conventional vapor compression cycles using electrical or mechanical energy.

The technical feasibility of solar air conditioning has been demonstrated so that the near term introduction of solar air conditioning is judged to be a realistic option for application in the 1985-2000 period.

Solar refrigeration often can use the same basic technologies as required by solar air conditioning. Refrigeration of agricultural produce could be an important consideration associated with improving agricultural productivity and developing new lands. The economics of solar refrigeration are favored by the fact that storage can be in the form of cold or frozen produce.

1.4 Impact Summary

Tables 1 and 2 summarize the potential energy impact of solar technologies in Egypt through the year 2000. The implementation rate of various solar technologies required to achieve the impacts of tables 1 and 2 are discussed in the individual technology section within section 3.0.

The Case A scenario is consistent with a relatively low key government program in the solar area. Even this scenario, however, would require that solar heating and power units are subsidized in some way (direct subsidy, low interest loans, etc.) to equalize subsidies provided to conventional energy forms.

The Case B scenario assumes that the beneficial social and foreign exchange factors associated with solar options induce the government to actively pursue a solar policy (via low cost financing, requirements for solar in new cities, etc.). In this scenario, solar energy would contribute 15 percent of electrical energy needs by the year 2000 and a substantial portion of the energy required in households and institutional and commercial buildings for water heating functions.

The effect of the accelerated renewable energy resource strategy is most pronounced during the earlier years when the lack of familiarity with the technologies involved inhibit their widespread use.

As the year 2000 approaches, the technical/economical performance characteristics of renewable energy resource systems are assumed to be sufficiently well established that their widespread use would follow even without an active government commitment.

TABLE 1

ELECTRIC POWER GENERATION IMPACTS OF RENEWABLE ENERGY RESOURCES

	1985 CASE A	1985 CASE B	1990 CASE A	1990 CASE B	2000 CASE A	2000 CASE B
(A) Direct Solar[1]						
Installed Capacity (MW)[2]	2.5	125.00	102.00	562.0	902.0	2,625.0
Annual Power Output (10^9 kWh)[4]	0.006	0.28	0.23	1.4	2.0	6.0
(B) Wind Power						
Installed Capacity (MW)[3]	0.65	32.00	48.00	272.0	364.0	1,048.0
Annual Power Output (10^9 kWh)[4]	0.002	0.12	0.18	1.0	1.4	4.0
(C) Biomass						
Installed Capacity (MW)	0.42	21.00	33.00	180.0	240.0	660.0
Annual Power Output (10^9 kWh)[4]	0.003	0.14	0.21	1.2	1.5	4.5

[1] Includes both photovoltaic and solar thermal.
[2] Peak power at solar noon.
[3] Rated capacity in 18 MPH wind.
[4] Capacity factors:
Direct Solar - 0.26
Wind Power - 0.42
Biomass - 0.75

TABLE 2

SOLAR WATER HEATING IMPACT (SUMMARY)

	1985[1]		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
Installed Area (10^6 m^2)	0.053	0.77	0.5	3.5	2.5	10.9
Annual Heat Delivered (10^{15} joules)	0.220	3.10	2.0	14.2	10.0	44.0

[1] Divided 80 percent residential and 20 percent institutional/commercial

The cost of solar heating and power units is expected to decrease as a result of continuing research and development efforts and larger production volumes. The rate and extent of cost reductions will depend, however, on the present development status of the technologies. For example, the unit cost of solar hot water systems was assumed to average about $\$10/ft^2$ (installed) and only limited further cost reductions were expected in the future since the technologies required are well-developed.

The average unit installed cost of the solar power generating options decreases from about $1,400 (L.E. 940) per kW in 1985 to $1,100 per kW (L.E. 730) in 2000. The average capacity factor for the generating mix of direct solar, wind, and biomass is about 0.4.

The relatively modest decrease in unit cost is due primarily to two factors: (1) the technologies considered will be quite well developed by 1985 (i.e., the major cost reductions will occur before that time), and (2) a large portion of system costs is associated with conventional equipment, such as light steel support structures, piping, systems, etc., for which the cost reduction opportunities are limited. The installed system costs are over 50 percent labor related and many of the materials required are produced in Egypt. Therefore, the foreign exchange value of system costs is considerably less than that indicated above.

It should be noted that the rationale for the implementation of solar technologies was economically based. For example, in the 1980's it was assumed that solar power units would be primarily used either to replace power normally produced by diesel engines or to provide power in remote areas where no power would otherwise be made available. As indicated in Section 4.0, several of the solar/wind power alternatives are expected to be economically competitive with diesel engines during this time frame. Preliminary estimates indicate that there is over 300 MWe of installed diesel engine capacity in pumping and electric power applications which is suggestive of the near-term potential for solar power generation.

Despite their relatively modest impact, the solar scenarios outlined would require the large-scale implementation of solar/wind equipment and represents a challenging undertaking. For example, the accelerated solar option requires that over 2500 wind turbines, 2500 solar wind power units, 400,000 solar water heating units, and 600 village size biogas digesters will be installed annually during the 1990's. This installation rate will require early commitments and thorough planning on the part of the government to achieve.

1.5 Resource Requirements

Each of the solar options can be accomplished with a variety of system options each of which have differing requirements for manpower, finances, and materials. The baseline options selected in the technology sections, however, were considered to be consistent with Egypt's resources in the above areas.

Resource requirements to implement the options leading to the energy savings of tables 1 and 2 are indicated in table 3. Solar related energy systems are fabricated primarily from basic construction materials such as steel, cement, glass, and aluminum, all of which are manufactured in Egypt. The requirement for these materials is substantial* since the use of solar and wind energy resources requires covering substantial areas with collecting surfaces capable of withstanding severe environmental conditions. In many cases, the material mix could be modified to take better advantage of in-country resources; for example, aluminum could be substituted for steel in many functions.

The financial requirements indicated in table 4 are broken down between materials/components and labor to indicate foreign exchange implications. Total outlays for manufacturing and installation corresponding to the accelerated case increase to L.E. 96 million in 1985 and L.E. 367 million by the year 2000 with roughly 50 percent of outlays being labor associated directly with the fabrication and installation of solar related systems. Additional labor inputs are associated indirectly with solar applications by virtue of in-country manufacture of some of the basic materials used in the fabrication of subsystems (steel, aluminum, etc.).

The annual O&M are also indicated in tables 4 and 5. During the earlier years, O&M costs and manpower requirements are relatively modest compared to the costs associated with manufacturing and installing the equipment. However, O&M resource requirements become significant after 1990 since the inventory of equipment already in the field (and requiring the attention of O&M personnel) starts to predominate over that installed on an annual basis. The costs associated with the O&M functions, however, are predominantly those required for semi-skilled labor which reduces the foreign exchange component of this cost factor.

The breakdown of table 4 to indicate potential foreign and domestic investments, requires making assumptions relative to which components are purchased abroad and which are manufactured in Egypt. Specific assumptions are outlined in the technology descriptions of section 3.0.

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* For example, the use of glass and aluminum indicated for the year 2000 in the accelerated solar case represents 30% and 10% respectively of projected internal production capacity. The use of steel and cement, however, are less than 2.5% of projected capacity.

TABLE 3

RESOURCE REQUIREMENTS

RENEWABLE ENERGY RESOURCE SCENARIOS

MATERIAL REQUIREMENTS (TONS)

	1985		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
Steel	800	21,000	18,500	58,500	44,000	99,500
Glass	300	8,500	7,500	27,500	20,000	45,000
Aluminum	80	4,000	3,000	11,000	9,000	18,000
Cement	450	18,000	16,500	49,000	41,000	76,000

TABLE 4

RESOURCE REQUIREMENTS

RENEWABLE ENERGY RESOURCE SCENARIOS

ANNUAL FINANCIAL REQUIREMENTS

(MILLIONS OF EGYPTIAN POUNDS, 1978)*

	1985		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
Materials/Components	1.6	55	45	135	103	207
Labor (Man. & Install.)	1.3	42	39	108	81	171
O&M	.2	6	6	26	34	87
TOTAL	3.1	103	90	269	218	465

* Does not include expenditures for production facilities

TABLE 5

RESOURCE REQUIREMENTS

RENEWABLE ENERGY RESOURCE SCENARIOS

LABOR REQUIREMENTS (PERSON-YEARS)

	1985		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
Technical/Management	20	470	400	1,200	960	2,200
Manufacturing and Installation	190	5,500	5,150	15,600	11,900	27,000
O&M	30	950	950	3,800	5,500	12,500

In general, it was assumed that components which do not require specialized technology and/or manufacturing capabilities are made in Egypt. These would include such components as the towers of wind turbine units, collector array support structures, and flat plate thermal collectors. More sophisticated subsystems, such as the blades of large wind turbines and photovoltaic solar cells were assumed to be purchased abroad. These judgments are somewhat arbitrary and will require careful scrutiny in the future as a solar program develops. Also, decisions as to purchase or in-country manufacture will change in time as Egypt's industrial capability improves.

The labor requirements of table 5 indicates that up to 6,000 people would be working in the solar energy sector (manufacturing plus installation) of the economy by 1985 and 27,000 people by 2000 if the accelerated solar option was pursued. The employment opportunities arising from a solar program are seen to be substantial and would be even more than indicated in table 5 if an export market is developed.

It should be emphasized that the level of specialized training required for most of the solar fabrication, installation, and operation of related systems is far less than that required for most advanced energy conversion facilities such as nuclear power plants or large oil refineries. As such, it should not be difficult to train people to take advantage of the employment opportunities resulting from the solar implementation scenarios.

1.6 Implementation Priorities

As indicated in section 3.0, there are many options available for utilizing renewable energy resources in Egypt. Several of these systems may be competitive with one another so that the simultaneous implementation of all system options may not be a realistic option. This was accounted for explicitly by assuming that the direct solar power option would consist of a combination of photovoltaics and solar thermal power units. For purposes of estimating material, financial, and manpower requirements the division between the two technologies was assumed to be 50-50. The actual division in future years will, of course, depend on the relative technical/economical performance of the two options based on experience.

Seemingly unrelated systems, such as wind turbines and solar thermal units, also could be used for the same function (water pumping, etc.). Future decisions on which system option is most economical will again depend on the relative improvements during the next five to ten years in the technical/economical performance of the systems involved.

There is the possibility that certain of the technologies discussed will not prove economically viable and therefore would not be a good justification for its widespread implementation. In such cases it was assumed that other technology options would see more widespread use so that the energy impacts and resource requirements of the overall renewable energy source system would not be greatly modified.

As previously discussed, the various technology options are not all in a similar state of development. The implementation scenarios indicated assume that those technologies which are best demonstrated and show greatest economic benefits are stressed during the initial solar implementation program. These technologies would include solar water heating and wind turbines. The widespread implementation of the more advanced technologies (photovoltaics and solar thermal) would be contingent upon a successful demonstration program in Egypt as well as further progress in improving performance and/or lowering costs as a result of ongoing research and development programs in the United States and other industrialized countries.

1.7 Implementation Planning

The implementation scenarios for specific technologies indicated in section 3.0 are divided into two phases, as follows:

Phase 1 -- Installation and operation of demonstration (or test) systems, and

Phase 2 -- Large scale manufacture and installation program.

The Phase 1 program would consist of a relatively limited number of installations which would have as its purpose to

- Acquaint Egyptian technical and energy planning personnel with the technology options available;
- Gain operating experience under Egyptian conditions;
- Indicate which system configurations are most appropriate for manufacture and use in Egypt; and
- Identify social and institutional issues which could significantly impact the design and use of system options (particularly appropriate for solar hot water units).

For solar water units, the demonstration phase could include several thousand installations located on individual dwellings and institutional buildings throughout Egypt.

For advanced technologies, such as photovoltaic power units, the test systems would probably be installed at a relatively small number of test sites under the careful control of trained personnel.

In all cases, the demonstration (or test) systems would be purchased primarily from the United States, Europe, and Japan, where most of the advanced developments in renewable energy resource utilization are occurring.* This phase of the program will require, therefore, little or no manufacturing capability in Egypt. However, the success of this phase of the program would be contingent on the direct participation of Egyptian personnel who would have eventual responsibility for future program phases leading to increased in-country participation in the manufacture, distribution, installation, and operation of system options. Therefore, for each technology option undergoing demonstration (or test), there should be a technology development team which could have the essential elements indicated in figure 1. As indicated, this team would maintain direct contact with those in government responsible for arranging for participation of foreign firms which have specialized technology and/or financial resources to contribute to the commercialization effort.

The formal participation of a technology development team will help ensure that a rational implementation plan for the Phase 2 program results from the Phase 1 effort. For those technologies which prove successful both as a result of the Phase 1 demonstration program and continued technological advancement, the Phase 2 plan could include provisions for complete or partial local manufacture, setting up of a local distribution network, arranging for appropriate government incentives, public education, and initiation of manpower training.

Technology options for which there are continued technology and/or cost questions resulting from the test program would continue to undergo demonstration until such time as the required improvements are made or the system option was dropped in favor of those showing more promise.

1.8 Manpower Training

The widespread implementation of any of the solar options will require training of manpower at all levels including those skilled in management, science/engineering, manufacturing and production, installation and maintenance, and system operation. One purpose of the Phase 1 program is to provide a nucleus of experienced personnel who can assist in initiating the substantial manpower training effort required for a significant implementation program.

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* The present solar "Tender" program being formulated by the Ministry of Electricity in solar water heaters and photovoltaics is consistent with the Phase 1 program.

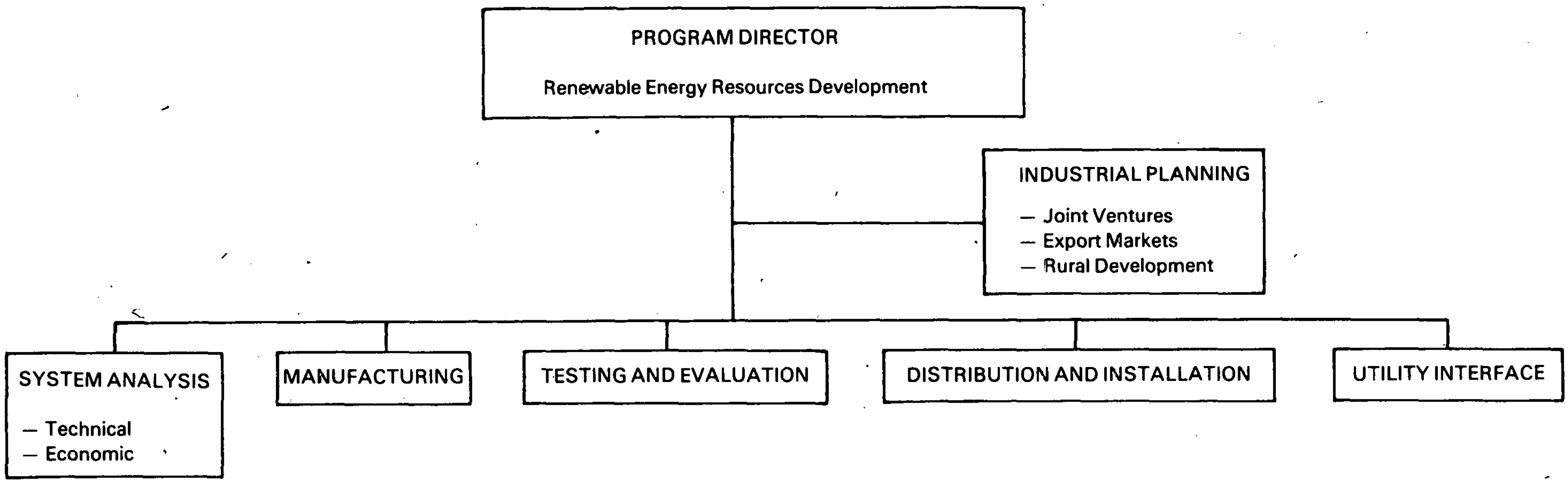

Fig. 1 Elements of phase 1 implementation organization

One aspect of most solar technologies is that many of the subsystems, such as support structures, towers, and storage tanks, are similar in construction to conventional equipment. These subsystems require various skill levels in metal forming, welding, plumbing, mechanical assembly, site preparation, concrete pouring, etc., common to a range of conventional power systems. Therefore, a significant portion of the manpower requirements will involve basic skills similar to those already being provided by the existing manpower training infrastructure.

There will be, however, special training required for many aspects of solar related equipment design, manufacture, and installation. This will range from training of engineers to design and size solar water units to personnel trained to maintain wind turbine units. It is critical that proper training of these personnel take place at an early stage of the program (including the demonstration phase) to minimize the possibilities of long and costly delays. There are several avenues which could be considered for the initial manpower training effort including cooperative United States - Egypt training courses and an extensive contract with firms making equipment which may be deployed in Egypt through joint venture agreements. The specifics of the training options would require a more detailed program plan in the renewable energy resource area.

1.9 Utility Interface Considerations

There is very little water heating done in Egypt by means of electricity. The widespread use of solar water heaters would, therefore, have little impact on electric utility operations.

The implementation strategies indicated for the solar power generation options assume that the early installations (< 1990) are primarily in remote regions where utility power is not readily available and that, in fact, the non-availability of utility power without costly line extensions was a strong incentive to use a renewable energy power unit. Since these systems would not be grid connected, their use would not impact the operation of the utility system.

Large scale implementation of solar power systems which result from either scenario after 1990 would require grid connecting significant capacities of direct solar, wind, or biomass power plants. This process is complicated by the unpredictable and periodic nature of solar and wind resource availability. Power units operating with biomass resources, however, have similar characteristics as conventional fossil fuel power systems.

If no storage is built into either the solar power units themselves (batteries, thermal storage, compressed air, etc.) or into the overall utility system (pumped hydro), the solar and wind power systems function primarily as fuel savers and the requirements for conventional generator capacity are not significantly modified. This results from the possibility that both wind and solar availability may be negligible during periods of high power demand. The optimal mix of conventional generating capacity, however, may be altered since its operational requirements would be affected by significant capacities of solar and wind power units.

The issue of how to optimize the design of solar/wind power systems to best interface with utility operations is a complex one which depends on many factors, including: electric power demand characteristics, cost of storage alternatives, mix of conventional generating facilities, and solar/wind resource dependability. Two important aspects of future activities in the solar power generating field will be analyzing the utility interface issues and how best to configure both solar and conventional generating units (including pumped hydro facilities) to optimize the overall power generating and distribution system.

2.0 AVAILABILITY OF RENEWABLE ENERGY RESOURCES

2.1 Solar Energy

Egypt has been recording solar radiation in many locations since 1956, according to Dr. S. E. D. Harb of the Meteorological Authority of Cairo. Most of the recording stations use 10-Junction Epply pyranometers for solar insolation measurement, G-type Speedomax Recorders for recording data, and Linke-Feussner actinometers for calibration of the pyranometer-recorder. Solar data from these stations indicate that Egypt has a good solar regime with sunshine over the whole country.

Global Solar Radiation. Egypt is located in the northern hemisphere between 22^{o} and 32^{o} latitude. It has a mean longitude of 30^{o}. The Mediterranean Sea borders on the north and the Red Sea on the east; consequently, the weather in Egypt is dependent to a large extent on continental oceanic conditions. Figure 2 illustrates sunshine duration in Egypt during the winter. In southern Egypt, average sunshine duration is 9.5 hours, which is 92 percent of the possible duration.[1] In northern Egypt, average sunshine duration is 7 hours, i.e., 68 percent of the maximum. In the summertime, the country has days averaging 14 hours in length, and sunshine duration over the entire country goes up to 12.2 hours, which is 87 percent of the possible duration. Figure 3 shows how the sunshine duration changes with season and latitude. It

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[1] Solar Energy Thermal Process. J. Diffie and W. B. Eckman, John Wiley and Sons (New York, N.Y.) C 1074.

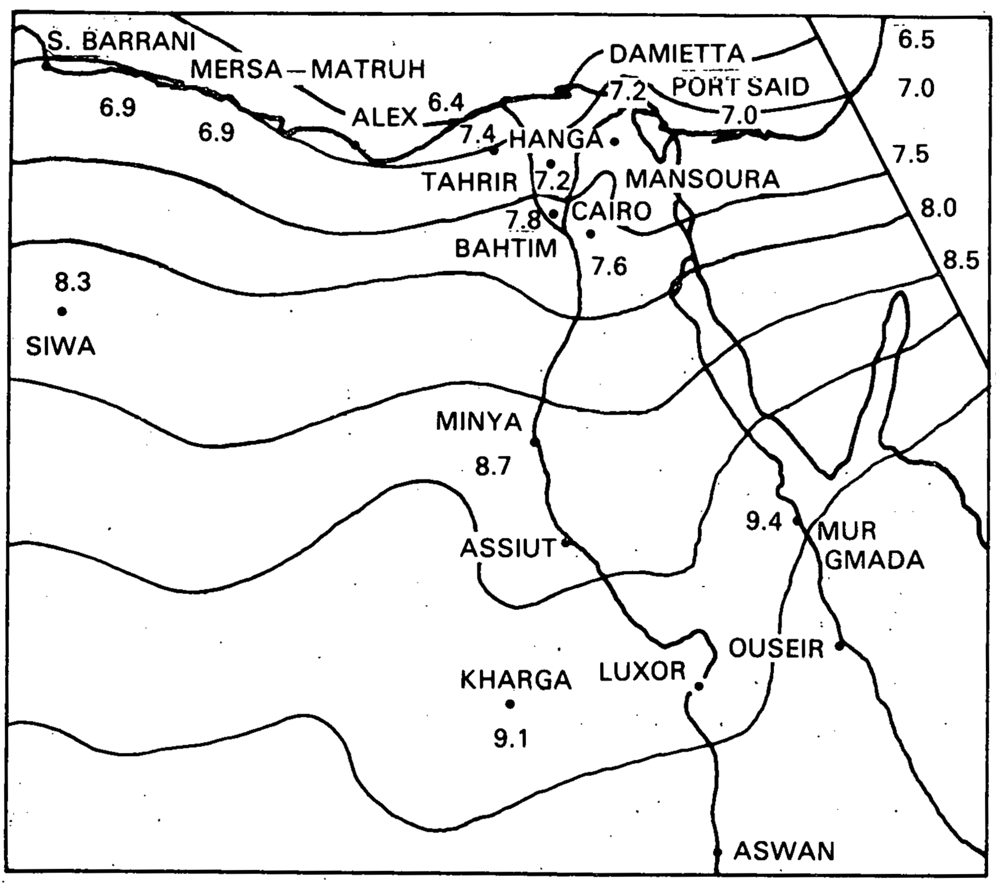

Fig. 2 Mean bright sunshine duration during winter (Jan) in Egypt

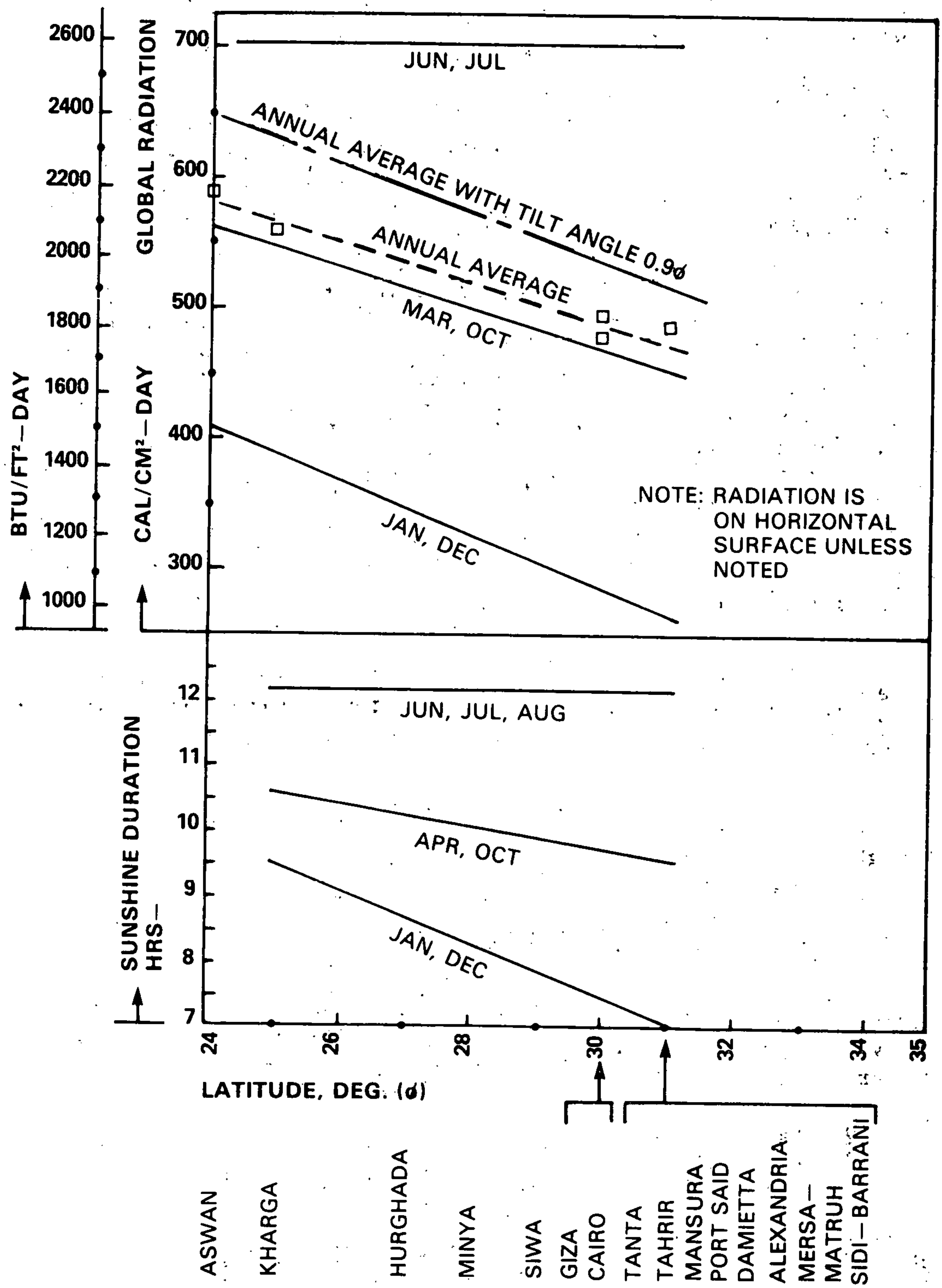

Fig. 3 Sunshine duration and solar insolation in Egypt

may be noted that, except in summer, sunshine duration is higher in southern Egypt than in northern Egypt. Sunshine duration is lowest in winter throughout the country.

Figure 3 illustrates the variation in solar insolation as a function of latitude and time of year. The solar insolation varies from 420 calories (cal)/cm^2-day (1,450 Btu/ft^2-day) in winter to 710 cal/cm^2-day (2,600 Btu/ft^2-day) in summer in southern Egypt and in northern Egypt it varies from 260 cal/cm^2-day (1,000 Btu/ft^2-day) to 710 cal/cm^2-day (2,600 Btu/ft^2-day).

It is known that solar energy incident on a surface titled by nine-tenths of the latitude and facing the equator receives the maximum energy annually.[2] The dotted line in figure 3 corresponds to this maximum average. This average is about 10 percent higher than the insolation on a flat horizontal surface. Its value ranges from 520 cal/cm^2-day (1,900 Btu/ft^2-day) in the north to 650 cal/cm^2-day (2,400 Btu/ft^2-day) in the south. While there is a climatic dependence on solar insolation from east to west of Egypt, this dependence is negligible compared to that of latitude. As far as hourly variation of solar insolation is concerned, in Cairo the typical peak insolations are 1.55 cal/cm^2-min (343 Btu/ft^2-hr) for summer, 1.30 cal/cm^2-min (288 Btu/ft^2-hr) for autumn, 1.0 cal/cm^2-min (221 Btu/ft^2-hr) for winter, and 1.5 cal/cm^2-min (332 Btu/ft^2-hr) for spring.

Cloudiness and Sandstorms. Cloudiness, sand rising, and sandstorms are main causes of scattering or diffusion of direct solar insolation. The mean frequency of dusty periods varies from 12 days/year in Cairo (north) to 6 days/year in Hurghada (south).

Besides cloudiness, fog and mist are two other meteorological factors. Numbers of occurrences in Cairo average 45 per year, and in Hurghada, 2. However, both phenomena occur late at night or early in the morning, and are dissipated by about two hours of morning sunshine. Therefore, these phenomena have little or no adverse effect on the annual average solar insolation.

It is worth mentioning here that although sand or dust has minimal effect on the annual average direct solar insolation, sandstorms create many difficulties in the operation and maintenance of solar devices, and solar equipment will require sandstorm-proof design.

Diffuse Solar Radiation. Statistical analysis and data[3] indicate that diffuse radiation ranges from 0.20 to 0.40 of global insolation for

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[2] Characteristic Features of Radiation Field in Egypt. S. Harb, Ministry of Electricity and Energy, Egyptian Solar Energy Commission, Egypt. 1978.

[3] Solar Energy Thermal Processes; J. Diffie, W. B. Eckman; John Wiley & Sons, New York, N.Y. c 1074.

all days of the year (clear, cloudy, sandy, daytime skies). This calculated factor is largest in spring, autumn, and winter, mainly due to dusty or sandy weather, in addition to cloudiness. In summer, this factor is at a minimum and diffuse radiation contributes about 0.25 of the global insolation.

For clear daytime skies, this factor ranges between 0.20 and 0.30 of the global radiation, and for cloudy daytime skies, this factor ranges between 0.25 and 0.40 of the global radiation. The variation is caused largely by sandy weather.

The effect of sand and dust in the atmosphere appears to result in Egypt having a relatively high percentage of diffuse radiation. Most of the concentrating collector options considered for solar thermal power generators, and several of the combined photovoltaic/concentrator systems can utilize only the highly directed portion of the solar radiation. Therefore, the effect of having a high diffuse component, within the total radiation availability is reduction in the output of these solar power options. Thus, it will be important in future programs to quantify the nature (direct, diffuse, and circumsolar) of solar availability in Egypt and how the ration of direct to diffuse radiation varies at different locations throughout the country.

2.2 Wind Resource Availability

In 1974, a study entitled "Characteristic Features of Wind Field in Windy Regions in Egypt" was performed by Dr. El Din Harb of the Institute for Research and Training Meteorological Authority, Cairo, Egypt. The purpose of this study was to analyze data records from a number of locations in Egypt to assess the potential for wind power generation in these areas.

The wind data recorded at each site consists of two basic parameters, wind speed and direction, both measured as a function of time. The data recorded at each location were not intended to be used to design a wind power system for that particular site, so much as to determine which sites have favorable winds worthy of more detailed analysis. Thus, the data can be used to assess, in a general way, an area's potential for wind power generation.

The data were taken at the locations (listed in table 6) at altitudes between 10 and 20 meters. Due to the extreme sensitivity of wind turbine output to wind speed (section 3.4), detailed system performance calculations require accurate data detailing, not only average wind characteristics, but diurnal and monthly variations as well. However, average data, such as that presented in this table are very useful in estimating the potential resource, and through the use of various correlations, representative estimates of unit power potential can be made. It is evident from this table that of the areas surveyed, the two most favorable are centered about Hurghada on the Red Sea coast and Mersa Matruh on the Mediterranean Sea coast.

TABLE 6

MONTHLY AND AVERAGE WINDS (KNOTS) AT SELECTED STATIONS FROM 1952-1970

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AVERAGE
Sallum	12.0	9.5	10.5	8.4	7.1	8.0	9.8	8.5	7.0	7.2	8.7	11.4	9.0
Sidi Barrani	11.0	10.8	11.5	10.6	9.1	8.6	9.9	8.5	7.2	7.8	8.8	11.0	9.6
Mersa Matruh	12.2	11.9	12.3	11.0	9.6	9.9	10.2	9.0	8.5	8.4	9.2	11.8	11.2
Dabaa	11.0	11.2	12.4	11.3	9.9	11.6	12.1	10.6	9.0	7.8	8.4	10.6	10.5
Alexandria	8.7	8.5	9.1	8.4	9.8	7.9	8.6	7.8	7.0	6.2	6.5	8.0	7.9
Rosetta	5.8	5.3	6.4	5.6	4.9	5.3	5.9	4.6	4.1	3.9	4.2	5.0	5.1
Damietta	6.2	6.1	8.4	7.5	6.8	6.4	5.6	4.9	4.1	5.0	4.6	5.4	5.9
Port Said	9.5	10.3	11.6	10.7	9.6	9.0	8.6	7.6	7.5	8.0	8.5	8.4	9.1
Duanhour	4.7	4.1	5.4	5.1	5.0	4.7	4.0	3.7	3.5	3.7	4.0	4.5	4.4
Tahrir	6.0	6.0	7.1	6.3	5.9	5.5	5.0	4.3	4.0	3.8	4.1	5.0	5.3
Tanta	3.8	4.1	5.0	4.8	4.6	4.4	3.2	3.2	3.2	3.2	3.0	3.6	3.8
Cairo	8.0	8.1	8.7	8.7	8.8	8.1	6.7	6.4	6.6	7.1	6.5	7.6	7.6
Abbassiya	4.0	4.3	4.9	4.9	4.5	4.1	3.5	3.5	4.0	3.9	3.5	3.7	4.1
Helwan	5.6	7.1	8.6	9.5	9.3	9.8	8.5	8.0	8.5	8.5	7.9	6.2	8.1
Fayoum	3.5	4.0	5.0	4.7	5.4	5.5	5.1	4.9	5.1	4.3	4.4	3.6	4.6
Minya	4.8	5.8	6.5	7.6	8.4	9.0	7.7	6.4	7.2	6.2	5.6	4.4	6.6
Asyout	6.6	7.1	8.2	8.0	7.9	7.5	7.0	6.4	8.2	7.2	6.6	6.0	7.2
Luxor	3.5	4.0	4.8	5.1	4.6	4.3	4.0	3.7	3.3	3.0	3.3	3.5	3.9
Aswan	7.5	8.0	8.8	9.2	8.6	9.0	8.1	8.0	8.3	8.1	8.0	7.5	8.3
Siwa	5.8	6.5	7.8	7.8	7.0	6.5	6.0	5.4	4.6	4.2	4.0	5.2	5.9
Dakhla	3.6	4.4	4.9	5.0	5.9	6.3	5.4	4.8	5.4	4.8	4.1	3.2	4.8
Kharga	6.2	7.7	8.4	8.6	9.6	11.5	9.1	8.3	9.4	92	7.4	6.0	8.4
Hurghada	11.4	12.5	12.3	12.7	13.6	14.5	13.3	13.2	13.6	11.3	9.9	10.5	12.4
Quseir	9.4	9.2	9.4	8.8	9.6	9.8	7.7	7.6	9.0	8.7	9.4	9.4	9.0

Among the conclusions reached by the study are:

- The highest values of wind speed for Mersa Matruh (Mediterranean Sea coast) occur in the winter; winds for most of the year are onshore (i.e., from the north-northwest) but in winter, winds prevail west-southwest. Strongest winds occur in summer for Hurghada (Red Sea coast) and are also onshore (east-southeast).

- Maximum wind speeds occur in the early afternoon in Mersa Matruh and in the early to mid morning in Hurghada during all seasons except winter, where winds occur in the mid to late morning for both locations.

Figure 4 shows the average monthly wind speeds for several locations. The wind speeds in Hurghada appear to complement those of Mersa Matruh. In the early part of the year, they are nearly equal. As the locations on the Red Sea experience a general lessening of the winds, Hurghada's winds are picking up. As the year approaches an end, the wind speeds again become more aligned.

Figure 5 indicates that wind speed for these four coastal locations is strongest during the daylight hours, as expected. The onshore winds are caused by the difference in heat given off between land and water masses. The relatively warm air over the land rises and the cooler air over the sea moves ashore to replace the rising warmer air. Thus, greatest wind activity is expected during the day while the sun is heating the land.

Figure 6 is a velocity duration curve for the two coastal locations with favorable wind schemes and two inland locations with lesser winds.

It should be noted that the wind speeds indicated here do not necessarily reflect the best that any one area has to offer. Judicious planning and careful site investigations may reveal local wind conditions even more attractive than those outlined here. For example, certain areas may contain gently rising slopes facing into the prevailing wind, which will significantly amplify wind power availability. Detailed studies of areas such as Hurghada and Mersa Matruh are needed to map wind regimes accurately and to aid in the development of such areas as power production locations.

3.0 TECHNOLOGY DESCRIPTIONS AND IMPACTS

The following section describes the types and economic performances of renewable energy resource systems that could be used in Egypt. This information is then used to develop implementation scenarios for each technology option. In each case, two scenarios are outlined.

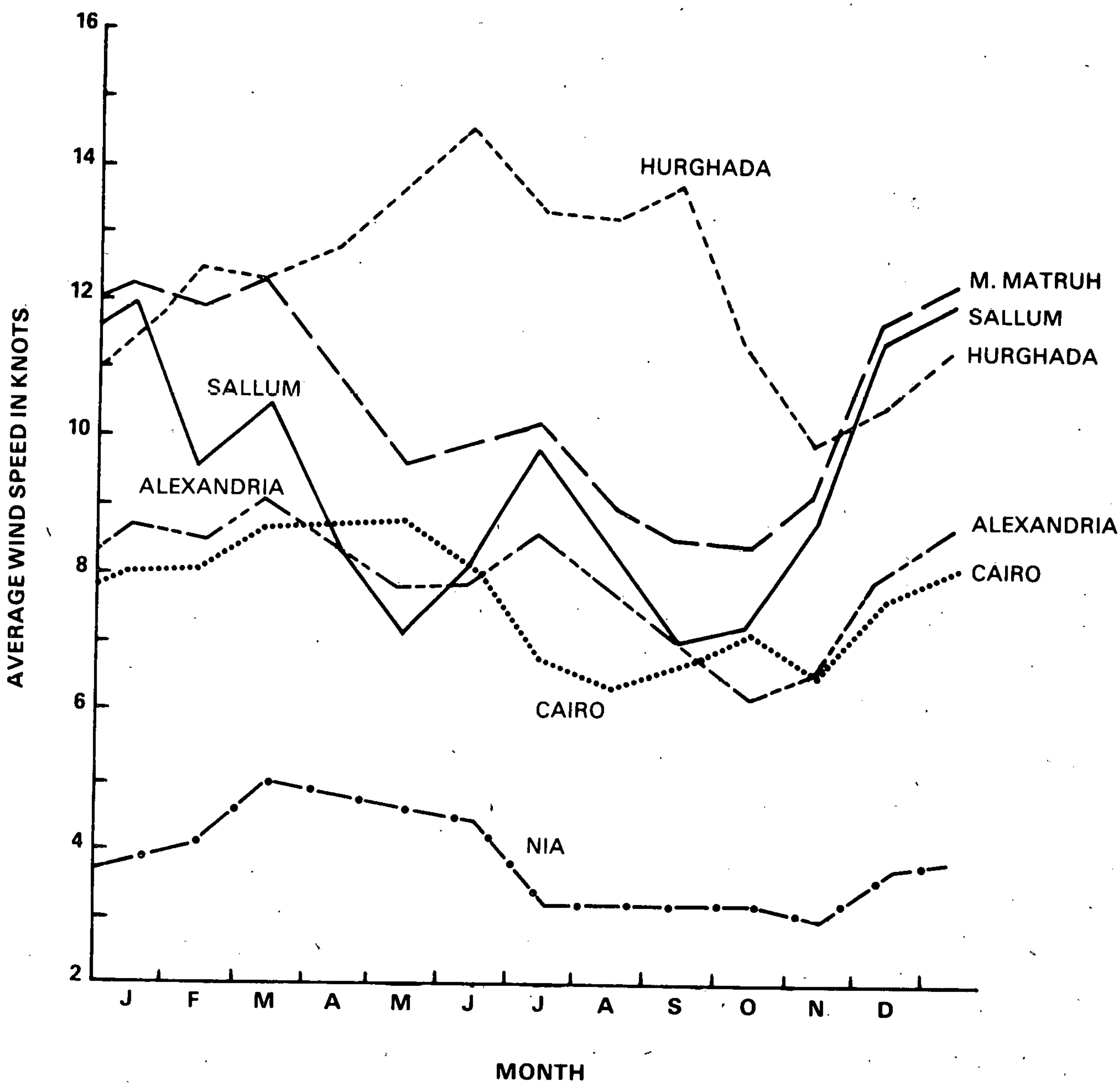

Fig. 4 Average monthly wind speeds for some localities

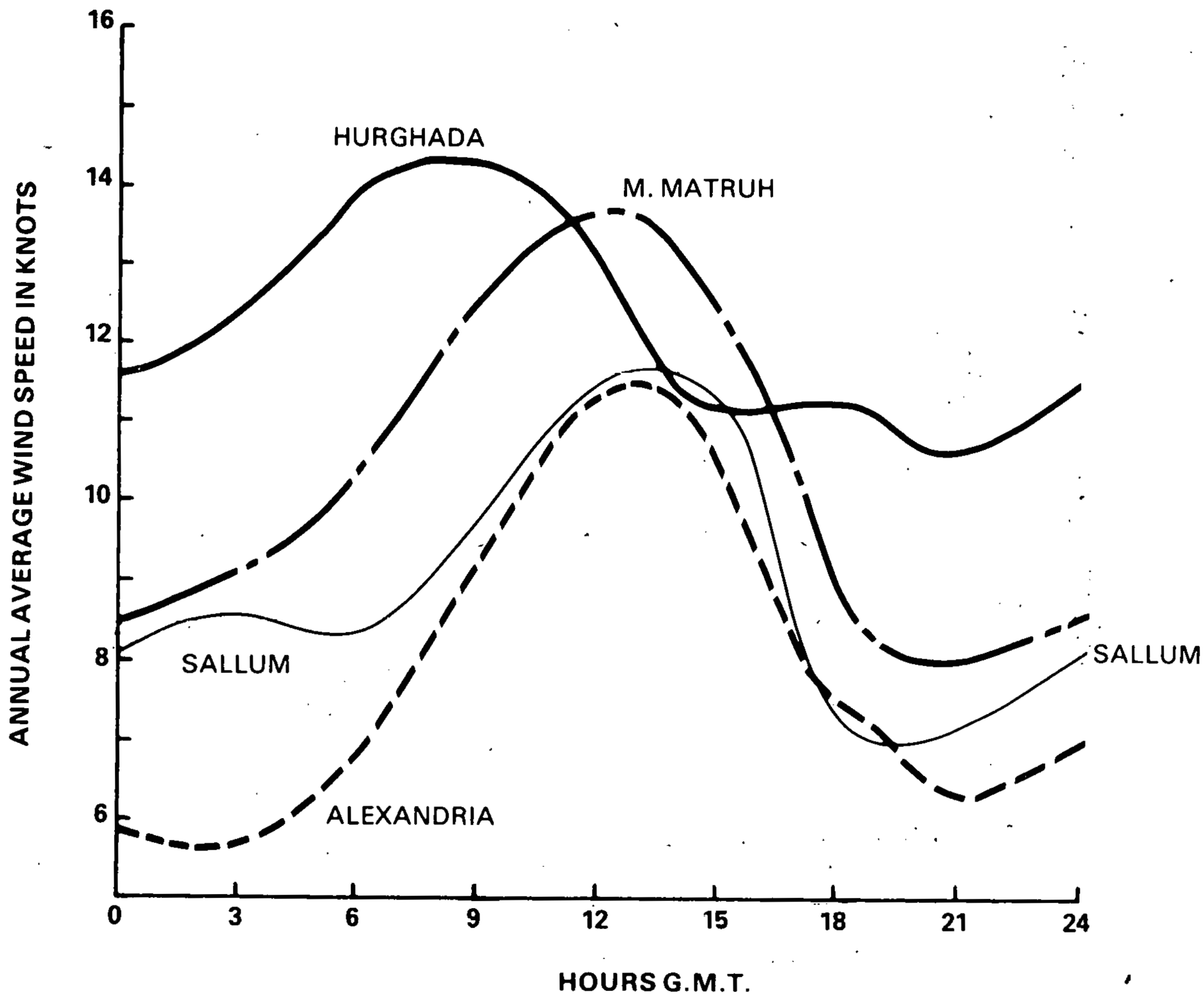

Fig. 5 Annual diurnal variation of wind speed in some localities

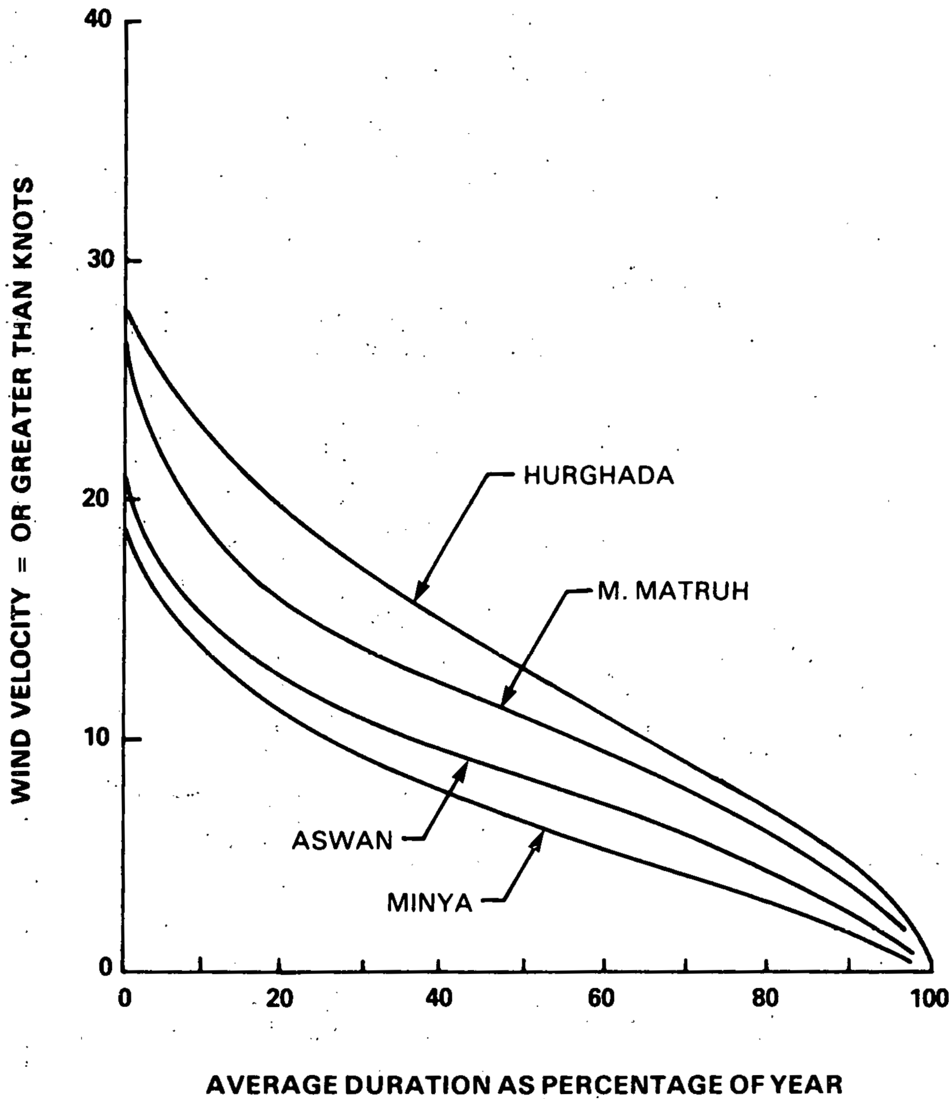

Fig. 6 Velocity duration curve

Comparison Case. This scenario is intended to be consistent with the situation where the renewable energy resource systems are not actively promoted by the government. It still assumes, however, that the solar systems are subsidized to the same extent as are the conventional energy resources so that the economic advantages of selected applications are apparent to the potential buyers (including the government).

Accelerated Solar Case. There are beneficial foreign exchange, industrial development, and employment considerations associated with many solar, wind, and biomass energy systems. These favorable social/institutional factors combined with good economic performance make it reasonable for the government to promote the rapid and widespread implementation of renewable energy resource systems. The accelerated solar scenario assumes that this is done via some combination of subsidies, low interest loans, and specific regulations.

The following sections emphasize the technology and economics of solar water heating and alternative approaches to power generation (photovoltaics, solar thermal, wind and biomass). Also, section 3.6 describes the advantages of using solar energy to operate desalination systems. Desalination, presently, is not a large energy user in Egypt; however, the need for desalination may increase significantly due to the program to disperse the population into areas where fresh water is not readily available.

Section 3.7 describes the options available for providing air conditioning and refrigeration by use of solar energy. Solar cooling is essentially a special application of one of the solar power alternatives. For example, the output of a wind generator can be used to operate the compression cycle of a vapor compression cooling system. Cooling applications may have advantages over more generalized electric power applications since any storage requirements can be in the form of chilled water rather than relatively expensive battery packs.

The early installation of demonstration systems would probably involve the purchase of most components from outside Egypt. However, one of the significant advantages of solar based energy systems is that they are amenable to manufacture in developing countries such as Egypt which have an existing industry and resource base. It has been assumed, therefore, that the substantial installation of solar related systems would emphasize the use of in-country fabrication and manpower resources. The resource requirements for all systems have been broken down between material and purchased components and manpower so that the potential foreign exchange implications can be readily identified. In this breakdown it has been assumed that all basic materials (steel, aluminum, etc.) produced in-country have a foreign exchange value equal to the world market price. This division of resources involves numerous judgments as to which components are likely to be purchased from abroad. For example, it was assumed that solar cells were purchased and then utilized within concentrating arrays produced in-country.

3.1 Solar Water Heating

3.1.1 Background: Egypt presently consumes approximately 1,288 metric tons of kerosene and 224,000 metric tons of butane for household use, and this consumption is expected to increase at annual rates of about 1 percent and 7.7 percent, respectively, as a result of population growth and increases in the standard of living, particularly in rural areas. The use of kerosene (in rural areas) and butane (in urban areas) has replaced the use of agricultural wastes (cow dung, corn stalks, etc.) for heating water used for clothes washing, cooking, and baking. (Home heating and cooling are unusual in Egypt).

The Egyptian government currently provides a substantial subsidy (over 50 percent) to reduce the cost of butagas and kerosene to households. The importation of these fuels, and the prospect for increasing imports in the future, have a significant effect on the country's balance of payments. The combination of the high cost of the subsidies, the foreign exchange losses, and the desire to improve the standard of living of the Egyptian people appears to create a favorable political climate for solar water heating. In addition, the relatively low temperature requirements of this particular application, the abundant sunshine in Egypt, and the comparatively high cost (if unsubsidized) of the fossil fuel alternatives combine to create favorable economics for solar water heating for both residential and non-residential buildings. This section explores the nature and extent of the opportunity for solar water heating in Egypt.

Solar water heating will displace the use of traditional fuels in households. Agricultural wastes are still an important fuel in much of rural Egypt although kerosene use is growing rapidly. (Agricultural wastes continue to be used for baking bread in traditional mud brick ovens.) Although butane is the primary fuel in urban areas, the use of electricity for water heating is growing in significance. Estimated fuel usage in urban and rural areas is shown in table 7. It should be noted that a large portion of the fuel use shown in Table 7 is used for cooking purposes. In-country discussions indicated that a significant portion of heat used in cooking is used to heat water (for example, tea is the major beverage in Egypt). Therefore, solar water heaters can be used to reduce fuel use in cooking as well as washing fuctions if solar heated hot water is used in place of cold tap water (i.e., solar energy can be used to preheat cooking water). The extent of such potential savings in cooking functions is difficult to estimate since doing so requires a detailed definition of cooking methods and how these vary by population type (urban, rural, economic strata, etc.). The following discussion assumes that roughly 20-30 percent of energy used in cooking (exclusive of that in ovens) could be saved by solar water heaters.

TABLE 7

FUEL USE IN EGYPT

ENERGY SOURCE	RURAL	URBAN	TOTAL
Kerosene (10^3 metric tons)	796	492	1,288
Butane (10^3 metric tons)	14	210	224
Electricity	268	1,429	1,697

In addition to heating water in households, there will be water heating in a range of institutional and commercial buildings, such as hospitals and hotels, and in industrial processes (textile and food processing industries, for example).

Although the following discussion does not explicitly consider the prospects for institutional applications or industrial process heat, these applications are accounted for in this preliminary analysis by adding 20 percent to the projected residential solar water heater collector areas. The extent of such applications in Egypt are projected to be quite modest due, in part, to two factors;

- A major portion of the industrial energy use in Egypt is associated with the production of fertilizer, aluminum, and iron and steel. These industrial sectors have little need for low temperature heat (80^{o}-$150^{o}C$) which can be supplied by low cost, reliable, collector systems, and

- In those industries (textile, food processing, etc.) which require some water at modest temperature levels, there is often an opportunity for heat recovery from higher temperature processes (as discussed in Annex 2-Industrial/Agricultural Sector Options) which reduces the incentive to use process heat.

The opportunities for solar process heat should, however, receive more attention so that the potential impacts of such applications can be better qualified.

Solar water heaters will have their primary energy impact in households by reducing the amount of energy required to heat water for bathing and laundering. In addition, the solar system will generate some incremental savings in cooking, since the hot water will require less heat for use in cooking. With the high amount of sunshine in Egypt, a solar water heating system can deliver the design quantity of hot water nearly every day without the need for large storage tanks. The typical delivery temperature of solar hot water will be 50 to 85^{o}C using collectors of simple reliable design. It is estimated that a solar water heater can reduce the use of kerosene or butane in households by 60 to 80 perent depending on details of water use patterns.

An important facet of the government's policy is to improve the standard of living of the Egyptian people. While running water is available in most urban homes, it is not common in rural areas where the people rely on central taps in the village for their water supply. While electrification is common in most urban households, it is estimated that only about 17 percent of villages now have electricity. The desire for modernization, particularly in rural areas, is reflected in the government's program to bring running water and electrification to a larger share of the populace.

These trends suggest both the modernization benefits obtainable from solar water heaters and the need to ensure that the solar systems are integrated into the social fabric with an understanding of the institutional/social/economic barriers and constraints which will affect their use.

3.1.2 System description: Effective and widespread implementation of solar water heating in Egypt will depend on the development of solar hot water systems which are both economical and appropriate for the market(s). It is expected that three alternative hot water systems may be suitable for different segments of the Egyptian market:

- o Active (Pumped) Systems
- o Thermosyphon Systems
- o Refillable Systems

Figure 7 shows the schematic for a solar hot water system which uses a pump to circulate water from a storage tank through the collector. Active systems will be most appropriate in commercial buildings (hospitals, hotels, and some apartments) where electricity and running water are available and storage is likely to be placed in lower stories of the building. It also may be used in residences where placing storage on the roof of the building is not appropriate.

In thermosyphon systems (figure 8), the water flows by natural convection from the hot collector to storage. This system has the considerable advantage of eliminating pumps and controls and thus the need for electricity. It is used throughout the world in non-freezing climates and is expected to be the primary hot water system for most dwellings in urban areas.

The third alternative (figure 9), a refillable system in which the collector and the storage are combined, is the simplest and most economical. This system, common in many rural areas of the world, requires no electricity but must be refilled by hand after the hot water in the system has been used. Although it may not be acceptable in markets where the refilling is considered an unacceptable inconvenience, the low cost of this system makes it a reasonable option for low income families in rural areas.

Solar collectors used in the active and thermosyphon systems are typically flat plate configurations as shown in figure 10. Although the cover plate is ordinary glass, the absorber can be made from a variety of materials, usually steel, copper, or aluminum. Copper is commonly used in the United States because of its excellent thermal conductivity and resistance to corrosion, but galvanized steel is the preferred material in most countries because of its lower cost and greater availability. Although aluminum is lightweight and relatively inexpensive, problems with corrosion are likely to limit its use. Plastic absorbers also may be used, but their poor stability under high temperatures may make them unacceptable in Egypt. This analysis assumes that the absorbers and frames are made from steel.

<u>3.1.3 System cost estimates</u>: The principal components of solar hot water systems (excluding the refillable system) include solar collector panels, structures for collector mounting, storage tanks, piping, and pumps and controllers (active systems only).

Estimates of the installed costs of solar hot water systems as a function of the size are shown in figure 11. Economics of scale are possible with active systems because of the relatively high cost of pumps and controls which are virtually the same for small and large systems. These cost estimates assume delivered collector costs of L.E. 50/m^2 and L.E. .1 to .2/liter, depending on size, for an insulated galvanized steel storage tank.

Installation costs are estimated to range from L.E. 21/m^2 of collector area for small systems to L.E. 14/m^2 for larger ones. However, it is likely that small prepackaged systems may be offered which could be installed by the homeowner to save on installation costs.

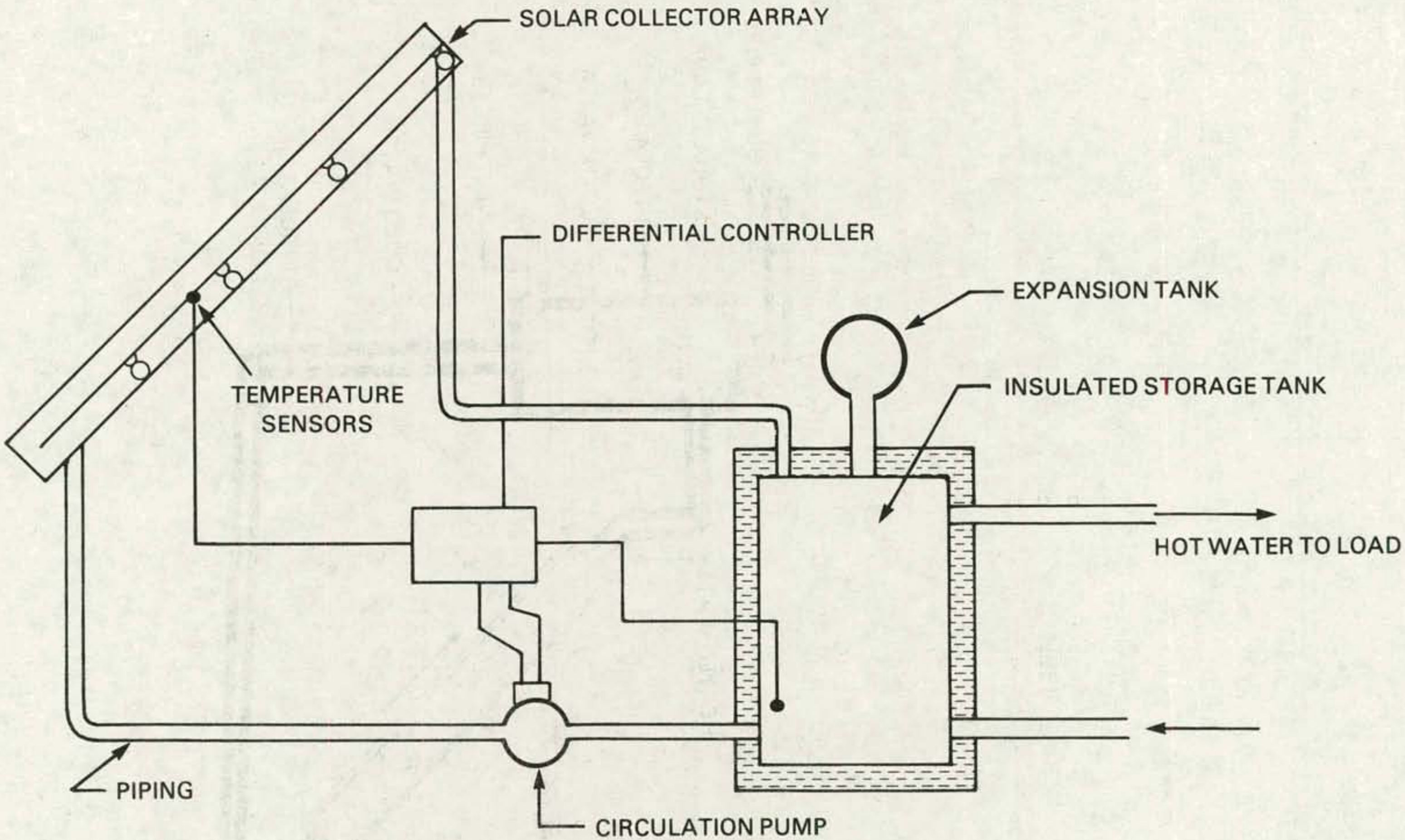

Fig. 7 Schematic of a pumped solar hot water system

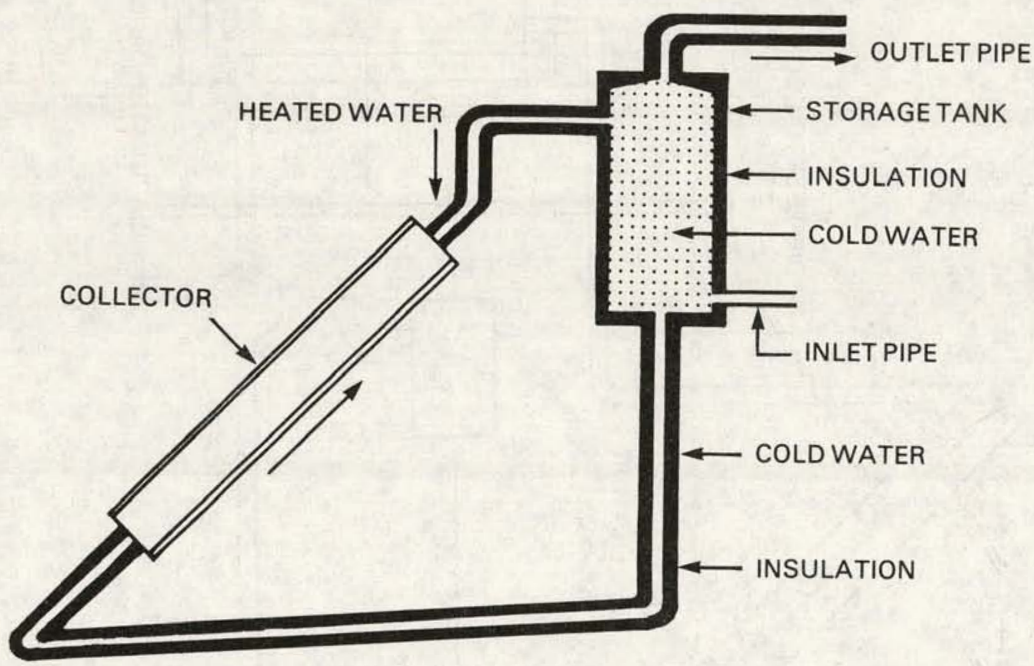

Fig. 8 Schematic of a thermosyphon solar water system

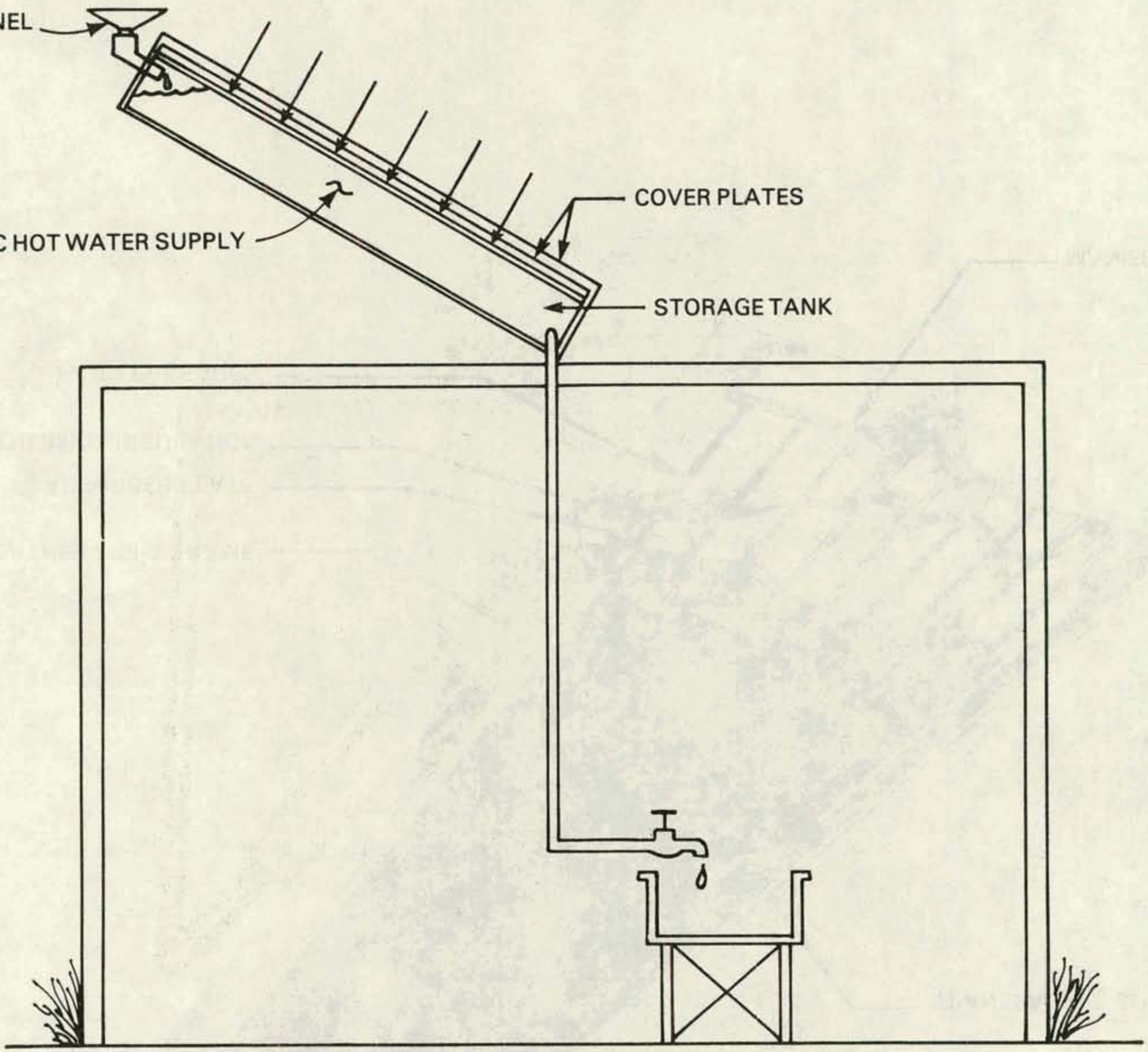

Fig. 9 Schematic of a "refill" solar water system

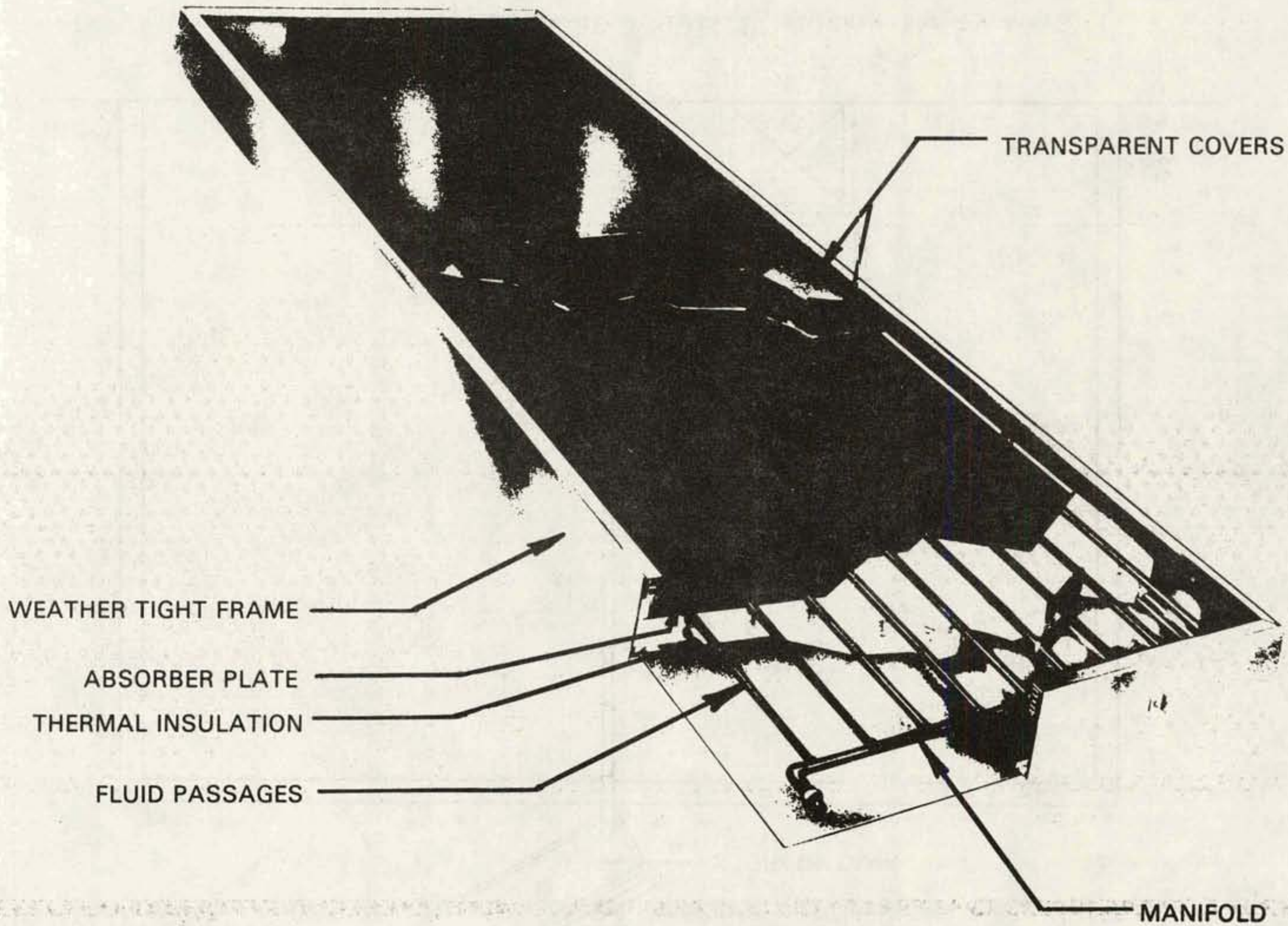

Fig. 10 View of a typical flat plate solar collector

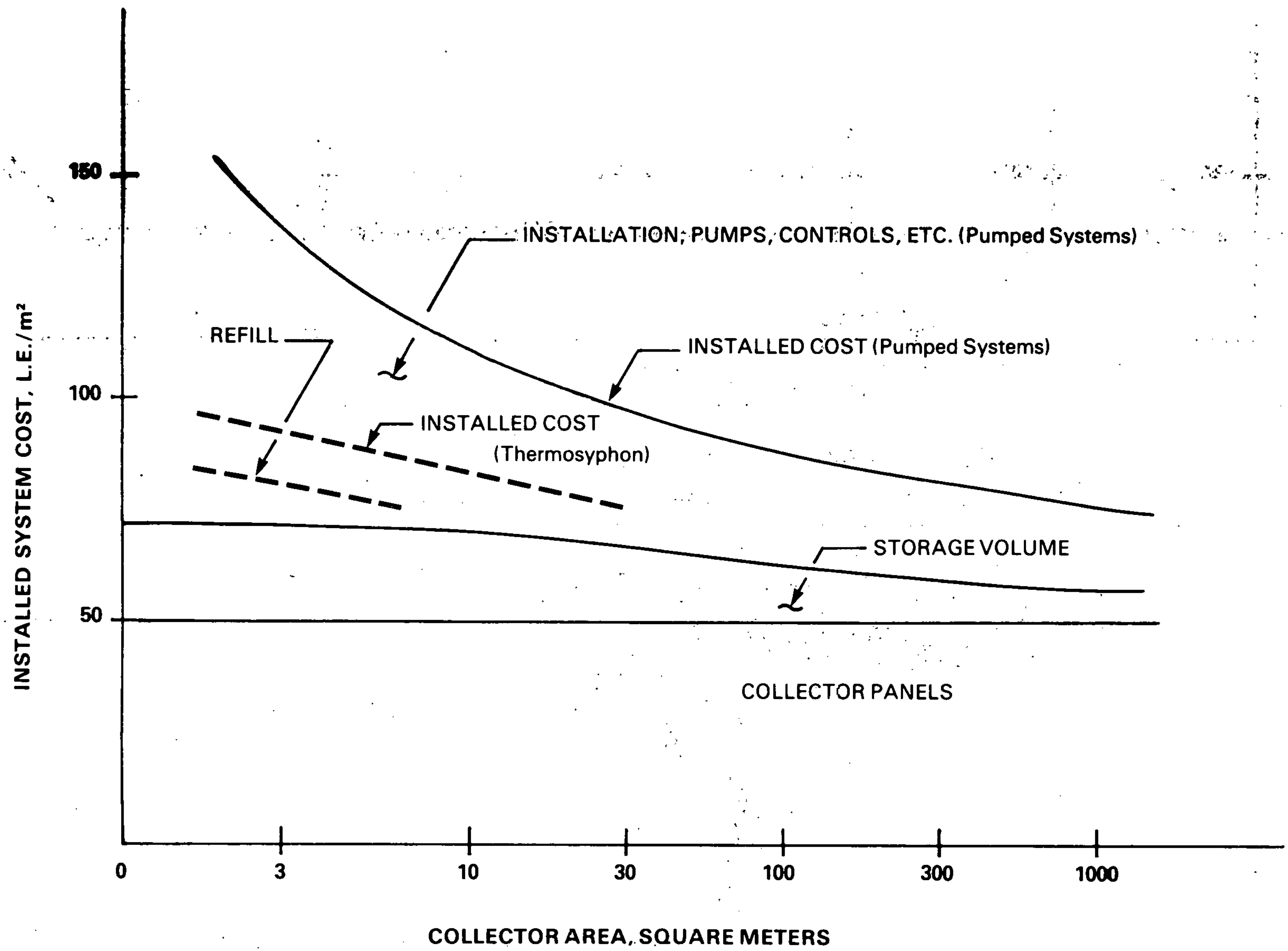

Fig. 11 Cost estimate for solar water heaters

The material requirements for a typical active solar water heater system (1.8 m^2) are indicated in table 8. Although other material options are available (for example, copper or aluminum for absorbers), the material usage shown in the table is expected to be representative and can be used to make preliminary judgments. The major discrepancy will occur for the refillable systems which typically rely on lesser amounts of materials and frequently use plastic rather than metal for the collector/tanks.

The economics of solar water heaters will be a primary determinant of their market acceptability. System economics will be influenced by:

- o Initial installed costs
- o Operating and maintenance costs
- o Financing costs (interest rates)
- o System life (depreciation)
- o Cost of conventional energy
- o System performance (efficiency)
- o Insolation levels

There are a number of different approaches for determining the economics of solar water heaters. The simplest approach involves a calculation of the payback period for the systems, i.e., the ratio of the initial cost of the systems to the annual cost of what would otherwise have been spent on conventional fuels. Because the payback period is easily understood by the market, it is useful in conducting market penetration analyses.

A more thorough analysis would be based on a consideration of the financing costs, depreciation, and operating and maintenance costs for the system. In this preliminary analysis, the cost of delivered heat for solar water heating is calculated so as to allow comparison to the cost of kerosene or butane. The cost figures that result provide a basis for determining whether solar water heaters should be supported by government policy.

Figure 12 shows the cost of delivered heat for solar water heaters operating ι ler the high solar flux of Egypt as a function of system cost. The upper curve assumes an interest rate of 8 percent, the lower curve a rate oi 5 percent; both assume government financial support. Both curves are based on a twenty-year life and an operating and maintenance charge of 2 percent of initial costs. With fully installed systems costs of L.E. 86 to 100/m^2, (typical of pumped systems) the cost of delivered heat would be from L.E. 2.60 to L.E. 4 per 10^9 joules.

TABLE 8

SOLAR WATER HEATING SYSTEM
MATERIAL REQUIREMENTS

SOLAR COLLECTORS	MATERIAL	WEIGHT[1] (kg/m^2)	MATERIAL COST[1] (LE/m^2)
Absorber Plate	Galvanized Steel	10	5.00
Cover Plate [2]	Glass	7.2	5.75
Insulation (2")	Fiberglass	2.4	3.50
Frame	Galvanized Steel	7.2	4.00
Miscellaneous Fittings		2.4	3.50
TOTAL			21.75
STORAGE VOLUME			
Tank	Galvanized Steel	2.4	1.45
Insulation (2")	Fiberglass	1.0	1.45
Frame & Outer Shell	Steel	2.4	1.45
TOTAL			4.35
MOUNTING FRAME	Steel	7.2	4.00
PLUMBING	Copper Tubing and Valves	14.4	2.15
TOTAL			LE 32.25

1 All weights and costs normalized to a square foot of collector.

2 Assuming double strength glass.

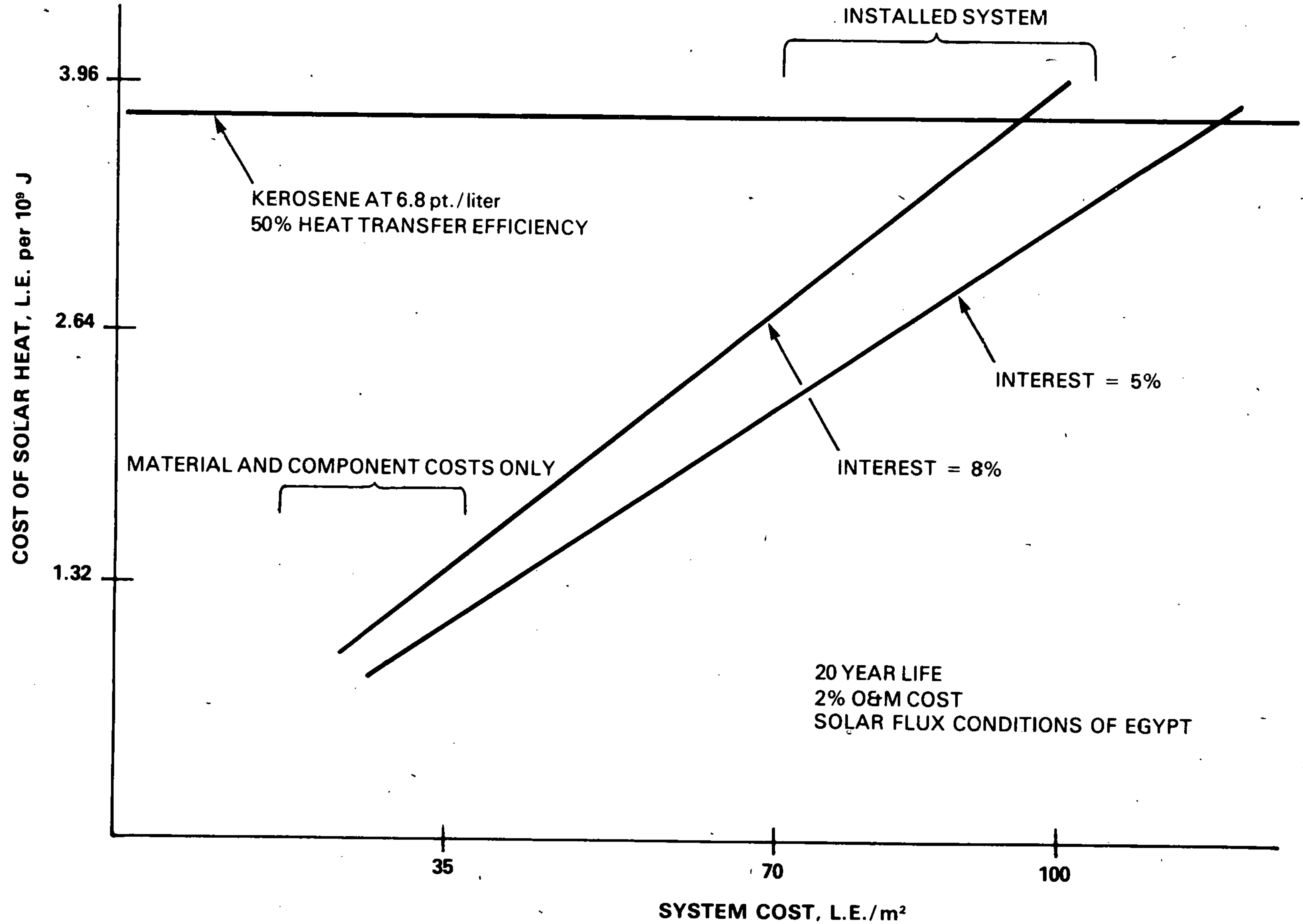

Fig. 12 Cost of heat from solar water heating systems

By comparison, the delivered cost of heat from a kerosene stove at 50 percent efficiency is approximately L.E. 3.80 per 10^9 joules assuming an unsubsidized fuel cost of 6.8 pt per liter. However, the cost of kerosene is subsidized by about 50 percent so that the consumer pays only about 3 pt per liter or L.E. 1.90 per 10^9 joules. It is clear that solar water heaters are economically competitive (under our assumptions) if the full cost of kerosene is considered.

One of the compelling arguments for the widespread implementation of solar water heaters is the saving of foreign exchange. The installed system costs have a high labor contribution, roughly 65 percent if all subsystems are considered. The total cost of materials is approximately L.E. 32/m^2 including all system components (per table 8). These systems could be fully manufactured in Egypt using materials made by Egyptian industry. One measure of the societal cost of solar heating is that which takes into account only the foreign exchange value of materials.* On this basis, solar water heaters deliver heat at a cost of less than L.E. 1.32 per 10^9 joules, well below the cost of kerosene.

Before the Egyptian government adopts a policy which supports solar energy, there must be compelling economic reasons for such support. The analysis above indicates that the net economic return to Egypt through investments in solar water heaters is clearly favorable compared to kerosene, assuming an unsubsidized cost of kerosene. Therefore, government action will be required to equalize the economics of fossil fuels and solar heating, either by removing the subsidies on kerosene or by offering equivalent subsidies for solar water heating.

3.1.4 Implementation issues:

3.1.4.1 Government policies: The use of solar energy for hot water in Egypt will be dependent largely on government policy. It is important, therefore, to assess solar implementation in the context of general government objectives. Those objectives that might be positively affected by the development of solar water heating include:

- The desire to reduce imports of butagas and kerosene.
- The desire to reduce the cost to the government of the subsidy on butagas and kerosene.

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* All materials, including those produced internally, are assumed to have a foreign exchange value equal to the world market price.

- The longstanding government aim of improving living standards in the rural areas and integrating remote villages more fully into the national life; it is also hoped that better living standards in rural areas can stem or reverse the massive migration to urban centers.

On the other hand, government policies aimed at a rapid increase in housing stock, both in the urban and rural areas, stress the need for low-cost housing, which militates against the introduction of appliances with relatively high initial costs such as solar water heaters. Since the rapidly increasing cost of residential construction is already making home ownership -- and even rental -- difficult for larger and larger segments of the population, the addition of solar water heating may reduce the number of people who could afford housing. Positive government policies to promote the introduction of solar water heaters could do much to offset this difficulty.

Current policy on the strict control of rents on most apartments discourages private apartment builders from putting in any additional cost features, such as solar water heaters. In addition, the maintenance of such systems may be the responsibility of the landlord and in many cases the rents barely cover minimum maintenance of buildings. Therefore, incentives must be offered to either the builders, landlords, or tenants to encourage solar water heater installations.

Production of solar water heating units in Egypt involves no significant technical constraints or resource limitations. Virtually all the components of most domestic hot water systems are now manufactured in Egypt and this production could readily be increased, thus enhancing industrial development. The requirements for labor, particularly technical labor for assembly and installation, also are seen to be well within Egyptian capabilities. Although the benefits of solar water heating are significant, it is evident that a major contribution can be made by solar energy only with a government commitment to overcome the capital cost barrier. In a country where capital is in short supply and where institutional barriers discourage capital investment in new energy systems, only the government is in the position to overcome the capital cost barrier. A financing mechanism that is available as well as affordable in terms of interest rates must also be established.

3.1.4.2 Market structure: Table 9 shows the inventory of residential structures in Egypt in 1976 and in 2000. The table also provides projections for 1976-2000 of new construction derived from data from the Ministry of Housing and Reconstruction (MOHR). Including the upgrading or replacement of substandard or deteriorating housing units (2.1 million units), it is estimated that a total of almost 7.9 million housing units must be built by 2000, an annual net increase in inventory of approximately 2.3 percent, consistent with population trends. Approximately 56 percent of this construction is in urban areas, 38 percent in rural areas, and 6 percent (500,000 units) in new cities to be developed by the government. On this basis, the population shifts from 56 percent rural in 1976 to almost 50 percent urban and 50 percent rural by 2000.

TABLE 9

RESIDENTIAL BUILDING INVENTORIES & NEW BUILDING PROJECTIONS
Thousands of Units

	Inventory 1976	New Construction 1976-2000	Inventory* 2000
Urban	3,200	4,400	5,850
Rural	4,090	2,950	6,350
New Cities	____	500	500
TOTAL	7,290	7,850	12,600

* Net of upgrading or replacement of 2,100 units.

The primary reason for the population migration to the cities, to achieve an improved standard of living, would also support the early development of solar energy systems in urban areas. However, the government's commitment to improving life in the rural areas would suggest a similar commitment to supporting the installation of solar water heaters in rural areas. Therefore, the difference between urban and rural areas is likely to have less effect on the market penetration of solar water heaters than on the type of solar systems which are installed. We expect that the simpler systems, the thermosyphon and especially the refillable systems, will be preferred in rural areas where the lack of capital, electrification, and running water make the pumped system (and to a lesser extent the thermosyphon system) less applicable. In urban areas, the thermosyphon and pumped system are likely to be preferred.

The data from MOHR implies significant levels of new construction between now and 2000, considerably higher than past construction levels. New construction offers particular advantages for the installation of solar devices when compared to installations on existing buildings. Arrangements for collector mounting and system plumbing can be made during the planning stages and installations costs consequently should be lower in new than in existing buildings. However, because of the warm climate, the configuration of most Egyptian buildings (flat roofs, low rise, etc.) and the small size and simple nature of most solar water heaters, it is unlikely that the direct cost of an installed system should be more than 20 percent higher in a retrofit application. The major cost difference may be in the distribution and marketing costs because of the greater complexity of selling to and installing for the retrofit customers, and their lesser familiarity and bargaining power in the purchasing process compared to the builder or contractor who usually will be the purchaser of the solar water heater in new construction.

Another advantage in new construction is that the purchaser is faced with an immediate decision on the type of hot water system to be installed, or indeed whether to install any system. The potential retrofit customer has been managing without the solar water heater and is not faced with an immediate purchase decision. Conversely, the decision-makers in much of the new building market (builders, contractors, designers, investors, government, etc.) are not going to be the actual users of the hot water and often will have no particular incentives to install a device which increases the cost of the building.

There also will be differences in the opportunity for solar water heaters in the different segments of the new construction market. The approximately 6 percent of new construction in the 1976-2000 period which is associated with the new cities will be under government control during planning and construction and, therefore, will represent an excellent opportunity for extensive use of solar water heaters. Of the remaining 90 percent of the market, it has been estimated, based on the information from MOHR, that approximately 40 percent will be public supported and 60 percent will be private sector housing. Since public sector housing -- including both low- and middle-income housing built directly under the supervision of MOHR and "semi-public" housing built by the General Organization of Housing Cooperatives (under MOHR supervision) -- is subject to direct government control, it also will represent a good opportunity for solar water heaters. It is not likely to be as favorable a market as the new cities since the construction will be considerably more diffuse and widespread and somewhat less amenable to changes from the current standards of operation. Private sector housing, the major portion of the market in the past, and in this analysis considered to be that portion of the market not directly controlled by the government, is expected to be the least favorable market for solar systems. Since much of this market is not directly subject to government control, it is not as likely to respond to government directives; also, since its financing is usually from outside the government, it is less likely to have financial incentives (low interest rate loans, etc.) available to reduce the comparatively high initial cost of the solar water heaters.

In addition to the residential applications of solar water heating, there are expected to be many institutional, commercial, and industrial applications. The extent of these non-residential applications is difficult to estimate due to the sparsity of data. Most non-residential buildings do not use hot water as extensively as do residential buildings. However, certain classes of structures -- hospitals, hotels, restaurants, schools, etc. -- are highly appropriate for solar water heating. Building data and solar market experience in other areas of the world suggest that institutional and commercial applications will increase the use of solar water heaters (in terms of area of collector area and energy savings) by roughly 20 percent over residential figures.

3.4.1.3 Policy options: As discussed previously, the rate at which solar water heaters are installed, and therefore, the potential energy savings, will depend on the actions taken by the Egyptian government. To define the potential impact of solar water heaters in more detail, two implementation scenarios have been adopted.

The Comparison Case assumes that the government does not strongly support solar water heating but does subsidize its use to the same extent as fossil fuels. Thus the market penetration will be the result of the free market response to the economics of solar water heaters. The Accelerated Solar Case assumes that the foreign exchange, industrial, and social benefits of solar water heaters induce the government to encourage their widespread implementation. A broad range of actions are possible in this scenario from the establishment of standards which require solar water heaters in certain classes of structures to financial incentives (low-interest loans, tax credits, grants, etc.) to encourage their installation. The Accelerated Solar Case implies that the government will incorporate solar water heating into the overall government planning process and that the solar programs that result will balance the range of issues that are of concern to the Egyptian government: rural development, energy savings, foreign exchange, capital availability, resource utilization, industrial development, etc.

3.4.1.4 Market penetration: Analysis of the potential market penetration of solar water heaters in Egypt is a highly uncertain exercise. Market penetration ultimately is dependent on a number of uncertain variables -- fuel costs and supply, solar system costs, market response, government action, industry structure and commitment, interest rates, capital availability, income levels -- none of which can be defined with precision. However, a penetration analysis is not only useful but necessary, since some estimate of the possible impact of various government actions is needed in order to design appropriate government policies.

Despite the inherent uncertainty it is appropriate to define the assumptions that are used in the analysis and to indicate the types of actions that will be required to increase the market penetration.

Several assumptions are incorporated into the analytical approach.

a. It is assumed that the market response and government policy will be related to the economic performance of solar water heaters. As economics improve, the government will be more likely to encourage solar utilization and the market will respond more favorably. Thus, the government will not decide to support solar installation without consideration of their economic performance.

b. Economics of solar water heaters will improve over time as fuel costs rise and solar system costs decline or efficiency improves. We have assumed a 2 percent annual improvement in solar system performance (which can be considered simply the differential increase of fuel costs over solar system costs).

c. Market penetration will follow a normal distribution curve related to payback. While the economic analysis indicated that solar water heaters were a good investment, market response is expected to be related to a much more simple function such as payback (capital cost/annual energy savings). The payback of the solar system discussed in section 3.4.1.3 is estimated to be about 6 years in 1980.

d. Systems will be designed to be appropriate for the particular market. These types of systems will vary (pumped, thermosyphon, and refillable), their size will vary, efficiency will vary, etc. For simplicity we have assumed that the typical residential unit will use a 1.8 m^2 collector (steel frame and absorber) of a thermosyphon design. At present this area is more than adequate to satisfy the needs of an Egyptian family given the high solar flux conditions of Egypt and their relatively low water use patterns. However, as living standards increase and bathing and washing in hot water is no longer considered a luxury, the hot water delivered by the assumed system size will probably be about in balance with requirements. Also, this size system can supply some portion (probably 20-30 percent) of the hot water used in cooking functions (tea, rice, beans, etc.).

e. The shape of the penetration curve, payback vs. market penetration, will vary considerably depending on market characteristics. In this analysis we have assumed a highly capital cost-sensitive penetration curve which corresponds to the most capital-sensitive segments of the U.S. market. Because capital availability is even more restricted in Egypt, the curve was adjusted downward even further. This results in a curve (pre-adjustment) with the following points: 1 percent penetration with a 6-year payback, 10 percent penetration with a four-year payback, and 50 percent penetration with a two-year payback.

f. Different market sectors will respond to or be affected by government action to a different extent. The response, from most favorable to least favorable will be: new cities, new public construction, new private construction and retrofit.

g. Installation of solar water heaters will follow a "normal" industry growth curve; installations must start slowly and build up gradually. This occurs naturally because of limitations on industry production capacity as well as slowness of market response.

h. In the Accelerated Solar Scenario, the penetration curve remains at its pre-adjusted level and the economics of solar water heaters are assumed to have been improved by a government subsidy, averaging 10 to 30 percent in the various markets.

Under these assumptions, table 10 reflects the number of solar water heaters and square feet of collector area installed by 1985, 1990, and 2000 in the Comparison Case and the Accelerated Solar Case. Figure 13 shows the annual energy delivered by the solar water heaters. The curves of this figure assume that the total collector area installed is 20 percent more than that for residential units only to account for institutional and industrial water heating applications.

The results in the Comparison Case are relatively modest with 1.2 million residential units installed and approximately 10×10^{15} joules of energy delivered on an annual basis. Despite the favorable economics (compared to many other areas of the world), market resistance, capital availability problems, and the lack of government commitment inhibit significant penetration of solar water heaters. Without a strong initiative, the present water heating patterns are expected to continue. These results are consistent with the historical market development of solar systems and other heating/hot water techniques throughout the world. The transition to new fuels or systems ordinarily takes from 30 to 50 years in the absence of any strong events or options. In the

TABLE 10

SOLAR WATER HEATERS - RESIDENTIAL INSTALLATIONS

(000 Units)

	CUMULATIVE INSTALLATIONS			ANNUAL RATE OF INSTALLATION		
	1985	1990	2000	1980-1985	1985-1990	1990-2000
COMPARISON CASE						
New Construction	8	80	350	2	13	27
Retrofit	15	130	820	3	21	69
TOTAL	23	210	1,170	5	34	96
ACCELERATED SOLAR CASE						
New Construction	90	350	2,100	18	52	175
Retrofit	220	870	3,300	44	130	243
TOTAL	310	1,220	5,400	62	182	418

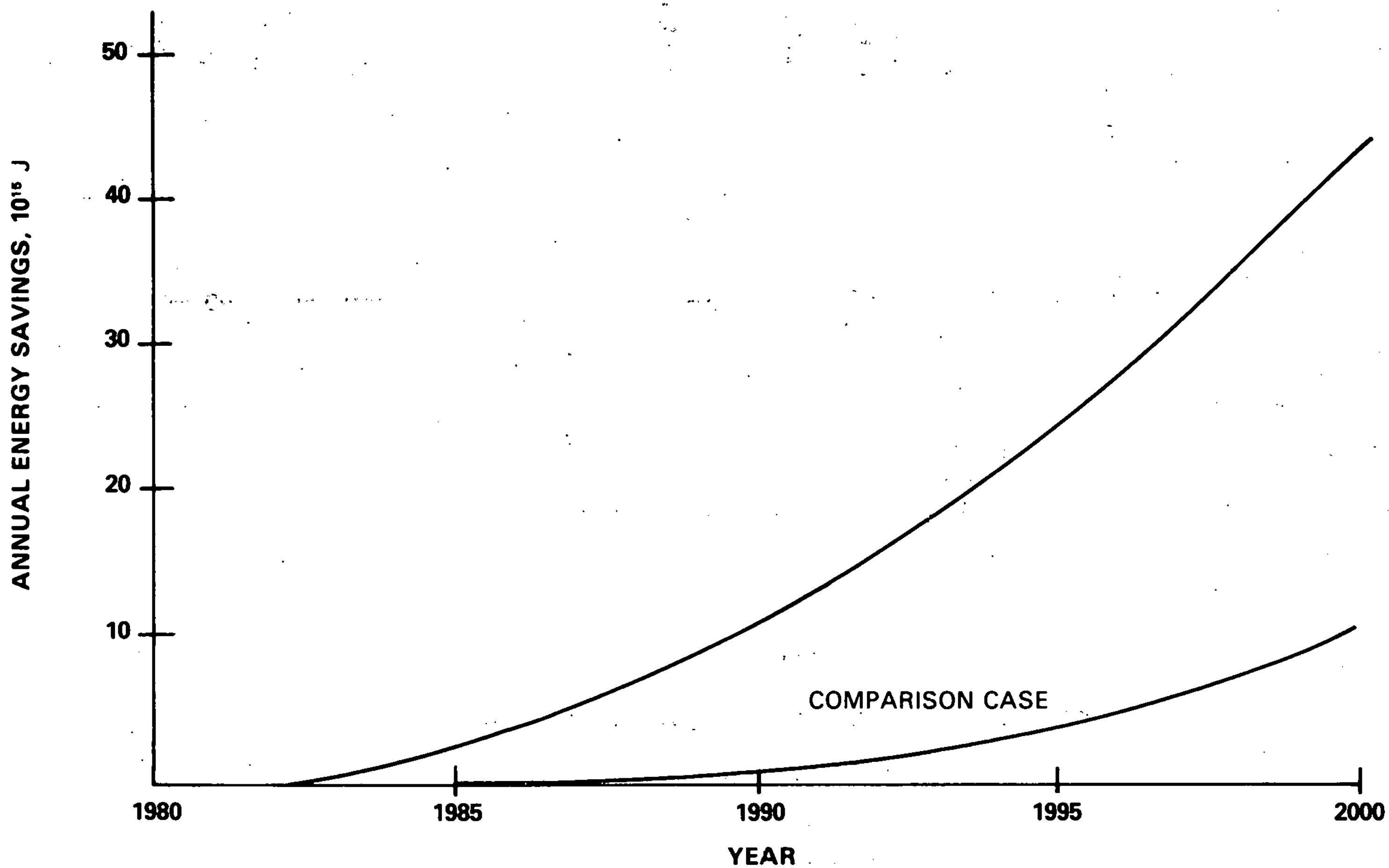

Fig. 13 Annual energy savings resulting from solar water heating scenarios

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Comparison Case, a viable solar industry will have begun to develop by 2000 and the penetration levels will have reached 10 to 15 percent of the new construction market by 2000. Approximately 9 percent of the existing residential units will have solar water heaters by 2000.

The Accelerated Solar Case dramatically increases solar penetration. Almost 5.4 million units are installed by 2000 (4.6 times the Comparison Case) and annual energy delivery increases to almost 45 X 10^{15} joules. Penetration levels reach 50 to 60 percent of the new construction market annually and by 2000, approximately 43 percent of the residential units will have solar water heaters.

Some portion of the heat delivered by solar water heaters will displace the use of kerosene and butagas. However, a significant portion will also be associated with an effective increase in demand, i.e., the ready availability of hot water at no additional cost will encourage its use over that which would occur if it had to be heated with expensive fuel forms. On the other hand, the heating of water on stoves is a very inefficient process (at best 50 percent) so that the savings in fuel are well in excess of the solar heat delivered in those cases where fuel is being displaced. If it is assumed that roughly 50 percent of the solar heat delivered is associated with a fossil fuel displacement, the total solar heat delivered by the scenarios is roughly equal to the overall fuel displacement.

3.1.5 Resource requirements: The total use of resources required to achieve the implementation scenarios outlined above is indicated in table 11. These figures are based on assignment of appropriate system types to uses in the urban and rural areas under each scenario. Preliminary judgments indicate that material use will be modest in relation to national output even if an Accelerated Solar Case is pursued.

The primary materials used in fabrication of the solar water heaters are steel, glass, and thermal insulation. Steel and glass are produced in Egypt which would facilitate local manufacture. Also, the manufacture and installation of solar water heaters is very labor intensive so that over 8,000 people would be employed in this activity in 2000, assuming the accelerated solar strategy is pursued.

The relative attractiveness of government policy options, i.e., an active solar policy in the context of rural development, industrialization, butane subsidies, etc., will be the ultimate determinant of the direction and extent of government participation in a solar water heating program.

TABLE 11

RESOURCE REQUIREMENTS FOR SOLAR HEATING SCENARIOS

	1985 CASE A	1985 CASE B	1990 CASE A	1990 CASE B	2000 CASE A	2000 CASE B
MATERIAL REQUIREMENTS (10^6 tons)						
Steel	350	4,400	2,500	13,100	6,900	30,000
Glass	140	1,800	880	5,200	2,700	12,000
Insulation	40	520	280	1,500	800	3,500
Copper	17	220	120	650	350	1,500
FINANCIAL REQUIREMENTS (L.E. X 10^6)						
Materials	.36	4.5	2.4	13.0	6.9	30
Labor	.52	6.5	3.5	19.0	9.9	43
TOTAL	0.88	11.0	5.9	32.0	16.8	73
LABOR REQUIREMENTS**						
Technical/Managerial	6	120	50	300	150	700
Manufacturing & Installation	65	1,050	400	3,200	1,100	7,400

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* In man-years assuming Egyptian labor practices.

<u>3.1.6 Institutional/social considerations</u>: Although economics may be considered favorable and the government may wish to promote solar installations actively, there is a broad range of institutional factors which will have a major impact on the use of solar water heaters in Egypt. New products or systems must be introduced in the context of established customs, social issues, political constituencies, established industries and infrastructures, etc.

Solar water heaters may require some modifications in living habits and this may indicate the appropriateness to a government of manufacturer-sponsored education program. The use of a solar hot water system, for example, may represent a significant departure from established habits in water collection, distribution, and use. If solar is to succeed, the consumer must understand and accept the life-style changes that are implied in its use. As another example, the roof areas of rural homes often are used for drying agricultural wastes and the roofs of many urban structures often are utilized for living space.

Solar water heater penetration also will depend on the rate of increase in the standard of living. In rural areas where hot water is a luxury and not a necessity, potential purchasers of solar water heaters may prefer other consumer items - radios and televisions, for example.

The nature and extent of the manufacturing/marketing/installation/maintenance infrastructure that develops to support the solar industry will be an important factor in achieving market acceptance. If the systems are appropriate, reliable and economical, marketed and financed effectively, and installed and maintained properly by reputable companies, the industry can be expected to develop rapidly and to address and overcome the constraints that exist. However, the opposite situation may prevail. Inexperienced companies which over-promote inappropriate (and expensive) systems which are not properly installed or maintained will seriously inhibit government efforts to promote the use of solar water heaters. It should be noted that a government program for the rapid development of solar energy is intended to shorten the period of time required for new product acceptance. The usual period of time required for new construction related products to be accepted in the market is 25 to 30 years, ample time for overcoming the inevitable constraints on new product acceptance. As this time is compressed, the need for careful planning and close monitoring is heightened.

The market introduction strategy for solar water heaters will influence the rate of acceptance. It has been suggested, for example, that the initial use of solar water heaters in many rural villages may be in conjunction with village bath houses. Such village baths could improve sanitary conditions, (since the people would be bathing in water that would be heated enough to kill bilharzia [65°C]) while providing educational inputs.

Environmental considerations should support strongly a policy to encourage solar water heaters. The technology assessment studies prepared in the United States indicated that solar water heating has net positive environmental impacts because it reduces the consumption of fossil fuels. In Egypt, solar water heating also will be beneficial because it will reduce the need to burn agricultural wastes or kerosene on open stoves.

3.2 Solar Thermal Power

3.2.1 Introduction: The technical feasibility of solar thermal power generation has been demonstrated from time to time over the last fifty years. One of the earliest demonstrations of solar thermal power was in Egypt in 1913. This system used parabolic trough concentrators to generate steam used to operate a 25 hp steam engine in an irrigation pumping unit.

There are active research and development programs in solar thermal power technology in the United States, Europe, and Japan. As a result of these programs several small scale (1 to 150 kW) units have been installed for irrigation pumping, air conditioning, and power generation applications. These installations include those developed by Sofretes* in France, Dornier* in Germany, and a number of firms in the United States. All these systems have used organic Rankine cycle engines to convert heat provided by the solar collectors into mechanical power. Sofretes uses non-tracking flat plate collectors in order to simplify system operation for use by unskilled personnel in remote areas. Most other systems installed to date use parabolic trough collectors in order to generate higher temperatures which lead to higher efficiency operation.

For large scale power generation, the primary focus in both the United States and Europe has been on the central receiver concept. In this system radiation incident on a multiplicity of individually controlled mirrors (called heliostats) is redirected to a single central receiver placed on a tower located in or adjacent to the mirror field. The heat generated in the receiver can be used to operate conventional steam power plants or, in advanced configurations, Brayton cycle engines. Many of the subsystems required to operate a central receiver power system are in the advanced design and testing stage and the first demonstration of a total system (10 MWe) is scheduled for 1981 in Barstow, California.

There are, therefore, a number of solar thermal power system options in various stages of development. It is expected that ongoing development and demonstration programs will lead to the commercial availability of systems over a wide power range by the early to mid 1980's.

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* Test units made by these firms are in the process of being installed in Egypt as a result of cooperative agreements.

Solar thermal power systems are comprised of a combination of thermal collectors, reflectors, heat exchangers, and thermal engines which utilize conventional manufacturing techniques in their assembly and are made of common construction materials (steel, aluminum, glass, concrete). These systems could be manufactured, for the most part, in Egypt thus providing an additional incentive to consider their widespread use.

<u>3.2.2 Description of system options</u>: As previously indicated, there are many approaches to solar thermal power being investigated. These include low to medium temperature systems (100 to 300°C) which can utilize low levels of solar concentration, and high temperature systems (300 to 1,000°C) which require high levels of solar concentration. Several of these system options include:

Low Levels of Solar Concentration (1X to 10X):

- o Flat plate collector with Rankine cycle engine
- o Compound parabolic concentrator (CPC) with Rankine cycle engine
- o Flat plate collector using planar reflector with Rankine cycle engine

Medium Levels of Solar Concentration (10X to 400X):

- o Parabolic trough with Rankine cycle engine
- o Linear slat concentrator with Rankine cycle engine
- o Linear Fresnel lens with Rankine cycle engine

High Levels of Solar Concentration (400X to 1500X):

- o Parabolic dish with open Brayton cycle engine
- o Parabolic dish with Stirling engine
- o Central receiver system with steam turbine
- o Central receiver system with open Brayton cycle engine

The economic performance of solar thermal power systems is influenced most by the cost and thermal performance of the solar collector subsystem used to convert solar energy into heat.

Several of these collector subsystems appropriate for solar thermal power generation applications are discussed in the following sections.

<u>Low Level Concentrator</u>. Flat plate collectors of advanced design have been used as heat sources for operating organic Rankine cycle engines at low temperature levels (90 to 120°C) for both water pumping and air conditioning applications. At these low operating temperatures, the efficiency of the engines is low, so that large areas

of collectors are required for a specified power output. It is, therefore, doubtful that solar power units using flat plate collectors will find widespread use except in very remote power applications where system simplicity is of paramount importance.

The efficient operation of organic Rankine cycle engines can be accomplished, however, with relatively moderate heat input temperatures of 120 to 300°C which can be achieved with low levels (2X to 10X) of solar concentration.

There are several options available for low level focusing which do not require any tracking and only periodic adjustments in tilt angle. An example of one such arrangement, shown in figure 14a, is the Compound Parabolic Concentrator (CPC). This collector arrangement is in an advanced development stage at the Argonne National Laboratory and several industrial firms have license agreements which probably will lead to its near-term commercial availability.

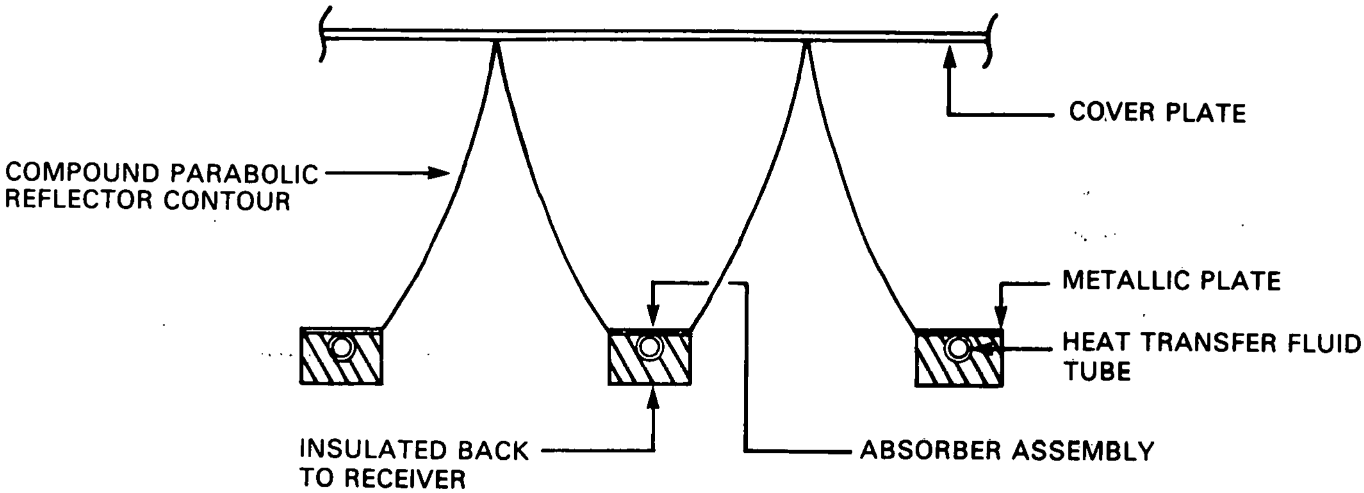
One advantage of this collector arrangement for use in Egypt is the outer glass or plastic plate which protects the reflective surfaces from dirt and sand and is easily cleaned. The CPC optics are such that it can utilize solar radiation over a wide acceptance angle (the magnitude depending on concentration ratio). Consequently, the collector need not track the sun on a daily basis and can accept a portion of the diffuse radiation.

Low level concentrators can achieve annual efficiency levels of 35 to 55 percent at temperatures of 120°C to 220°C which are consistent with the operation of Rankine cycle engine systems.

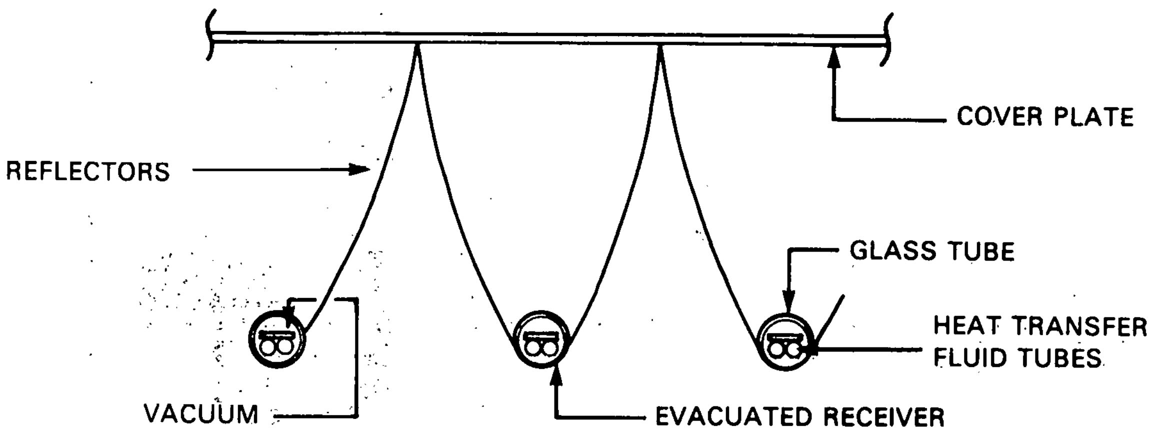
Linear Concentrators. Three types of medium level concentrators either in use or in an advanced stage of development are parabolic troughs, segmented mirrors, and Fresnel lenses.

In a parabolic trough collector, such as that shown in figure 15, the cross section of the reflector perpendicular to the major axis of the collector is a constant paraboloid which focusses the solar energy on a line. The linear receiver is rigidly located at the focus of this parabola.

Several types of receivers are being used depending on the operating temperature levels under consideration. Evacuated tube receivers, such as shown on figure 14b, are often considered for use in solar power applications, where there is an incentive to operate at elevated temperature levels.



a) Using conventional flat plate absorber



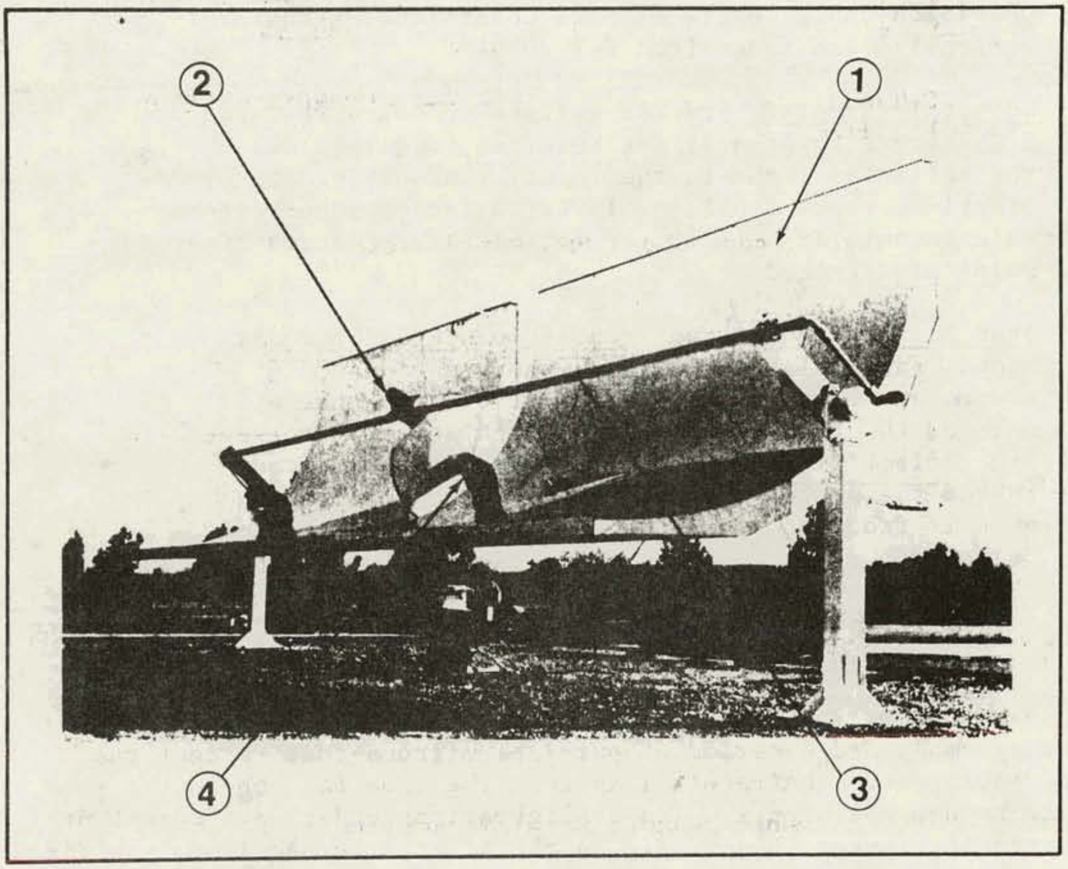
b) Using evacuated glass tube receivers

Characteristics:

- Accepts radiation over a wide half angles (13.6° for a 3X concentrator) which increases efficiency and minimizes number of tilt adjustments.
- Reflectors are protected by the cover plate which improves efficiency and reliability.
- No tracking required which simplifies installation and operation.

SOURCE: Arthur D. Little, Inc.

Fig. 14 CPC collector characteristics



1. REFLECTING LIGHTING SHEET
2. SHADOW BAND TRACKER
3. ABSORBING RECEIVER TUBE
4. MOTOR DRIVE

Fig. 15 Parabolic trough collector

The geometric concentration ratios for parabolic trough concentrators are typically in the 20X to 40X range. Higher concentration ratios require excessive contour and tracking accuracies to be practical in this or any linear concentrator configuration.

The major losses from the more sophisticated collector designs (in general, those using a special or evacuated receiver configuration) tend to be optical and not thermal in nature. Optical losses include the following:

- Surface Quality. For engineering surfaces capable of operation under severe climate conditions, specular reflectivities range from 0.7 to 0.9.

- Geometric Errors. Precise surface contours (0.1 to 0.25° error tolerance) are required to direct all the reflected light to the receiver assembly. In practice, there usually will be surface contour errors which result in 5 to 10 percent of the reflected light being misdirected.

- Dust Factor. Under many realistic operation conditions, particularly in Egypt, where sand and dust storms are common, thin layers of dirt or dust will form on the reflector surface which results in reducing reflectivity. Such layers of dust easily can reduce the amount of reflected light by 5 percent even if frequent reflector cleaning procedures are followed.

Parabolic trough collectors are generally considered for operation in the $150^{\circ}C$ to $300^{\circ}C$ temperature range.

A segmented mirror type concentrating collector is comprised of a receiver assembly and a series of parallel mirrors that reflect the incident energy onto the receiver in much the same fashion as the parabolic trough collectors. Two configurations under development are illustrated in figures 16 and 17. In the first, the receiver is affixed to the basic frame of the assembly and the mirrors are rotated about their major axes to direct the light into the stationary receiver. In the second concept, Fixed Mirror Solar Collector (FMSC), the mirrors are fixed in place and the receiver swings overhead to account for the daily apparent movement of the sun.

One motivation for such designs is to reduce the amount of equipment necessary to provide tracking, since it requires a smaller, simpler mechanism to move several small mirrors or one pipe, than it does to move a comparatively large, rigid trough and receiver assembly.

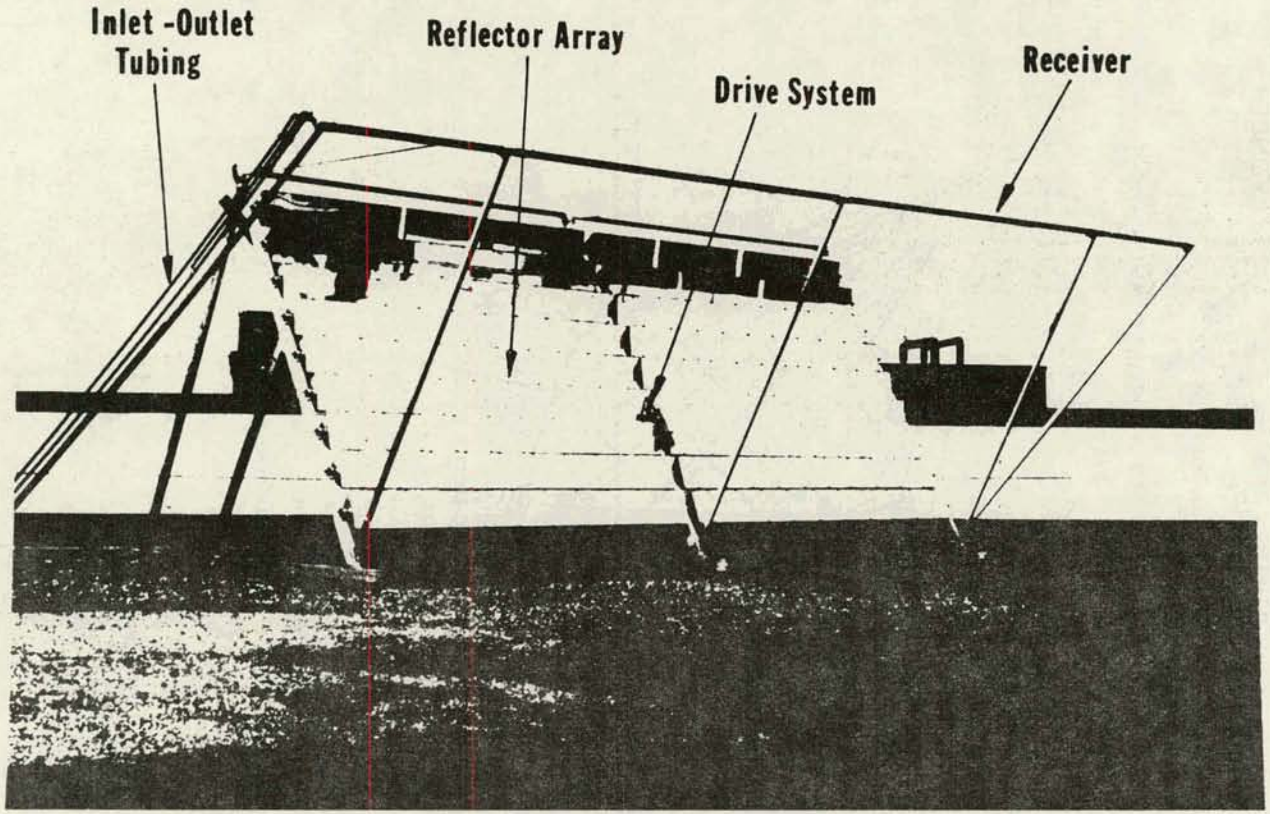


Fig. 16 Slats™ collector configuration

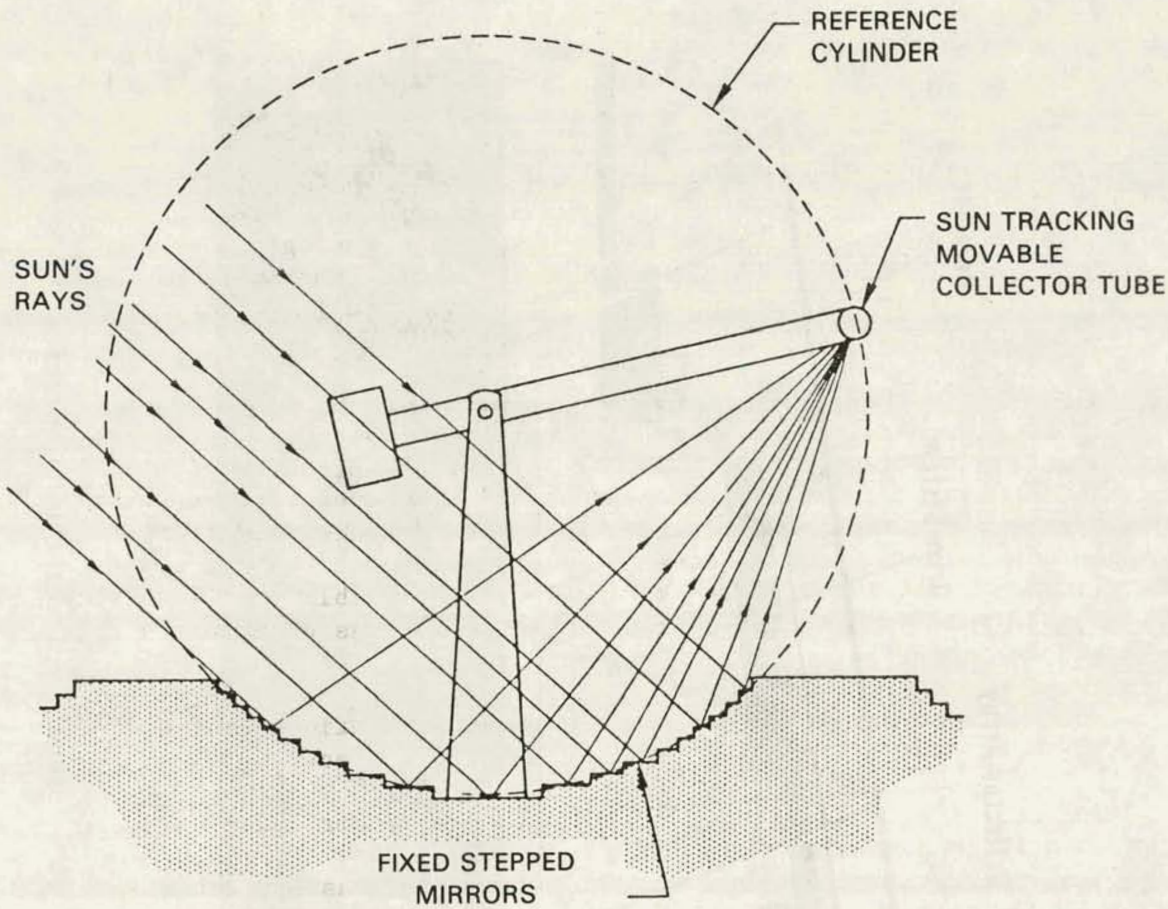


Fig. 17 Fixed mirror solar collector (FMSC) configuration

All segmented mirror type configurations are linear concentrators. Therefore, the comments on the optical and thermal losses associated with the parabolic trough designs apply here as well.

A Fresnel concentrator can be of either linear or point concentrator design. The distinguishing feature of these devices is that light is refracted and not reflected onto the receiver. As illustrated in figure 18, light energy is incident on the top surface of the Fresnel lens. This energy passes through the material (either glass or plastic) and is refracted by small ridges or grooves on the underside of the lens, which, though shown flat in the figure, can be either flat or curved. A curved Fresnel concentrator has a shorter focal length than a flat lens system, but is correspondingly more difficult to manufacture.

Tracking requirements are similar to those of reflector type concentrators for equal levels of solar concentration. Durability of plastic lenses and the difficulty in fabricating linear glass lenses are major challenges which have limited to use of these lens systems. In addition, maintaining clean surfaces under actual use (the grooves tend to become clogged with dust) is of real concern.

Point Concentrators. As previously mentioned, practical linear concentrators can achieve concentration ratios of about 20X to 40X and operating temperatures of 120 to 300°C. Point concentrators with similar tracking and geometrical accuracies can achieve concentration ratios of 400X to 1600X and thus the higher temperatures required of efficient thermal engines. However, this higher concentration ratio capability requires two axis tracking which considerably complicates the design and operation of point concentrating systems as compared to linear concentrators.

There are two basic approaches to high concentrations systems being investigated: central receiver and distributed collector.

A central receiver system (also know as the "power tower" concept) utilizes a large number of individually guided mirrors (heliostats) placed in an array at the base of a tall tower (such as indicated in figure 19). The incident solar energy is reflected from the mirrors to a receiver mounted on top of the tower, where it is absorbed by a heat transfer medium (usually steam). The steam so generated can be used to operate a conventional steam power plant.

The major cost component in such a system is expected to be the heliostats which require precise two axis tracking, highly reflective and geometrically precise surface contours, and structural rigidity to withstand high wind loads. Several of the heliostat concepts under development are indicated in figure 20.

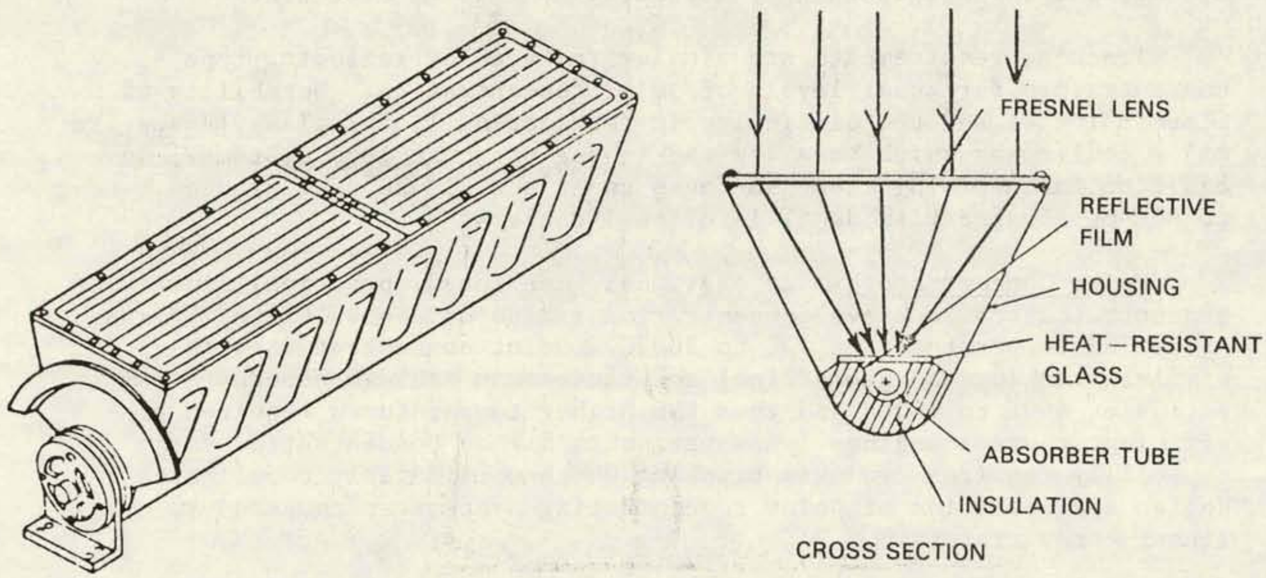


Fig. 18 Linear Fresnel lense concentrator

NAMEPLATE CAPACITY	215 MW(e)
AVG OVER 4000 HRS	147 MW (e)
TOWER HEIGHT	1500 FT
MIRROR FIELD SIZE	6200 FT OD
	1160 FT ID

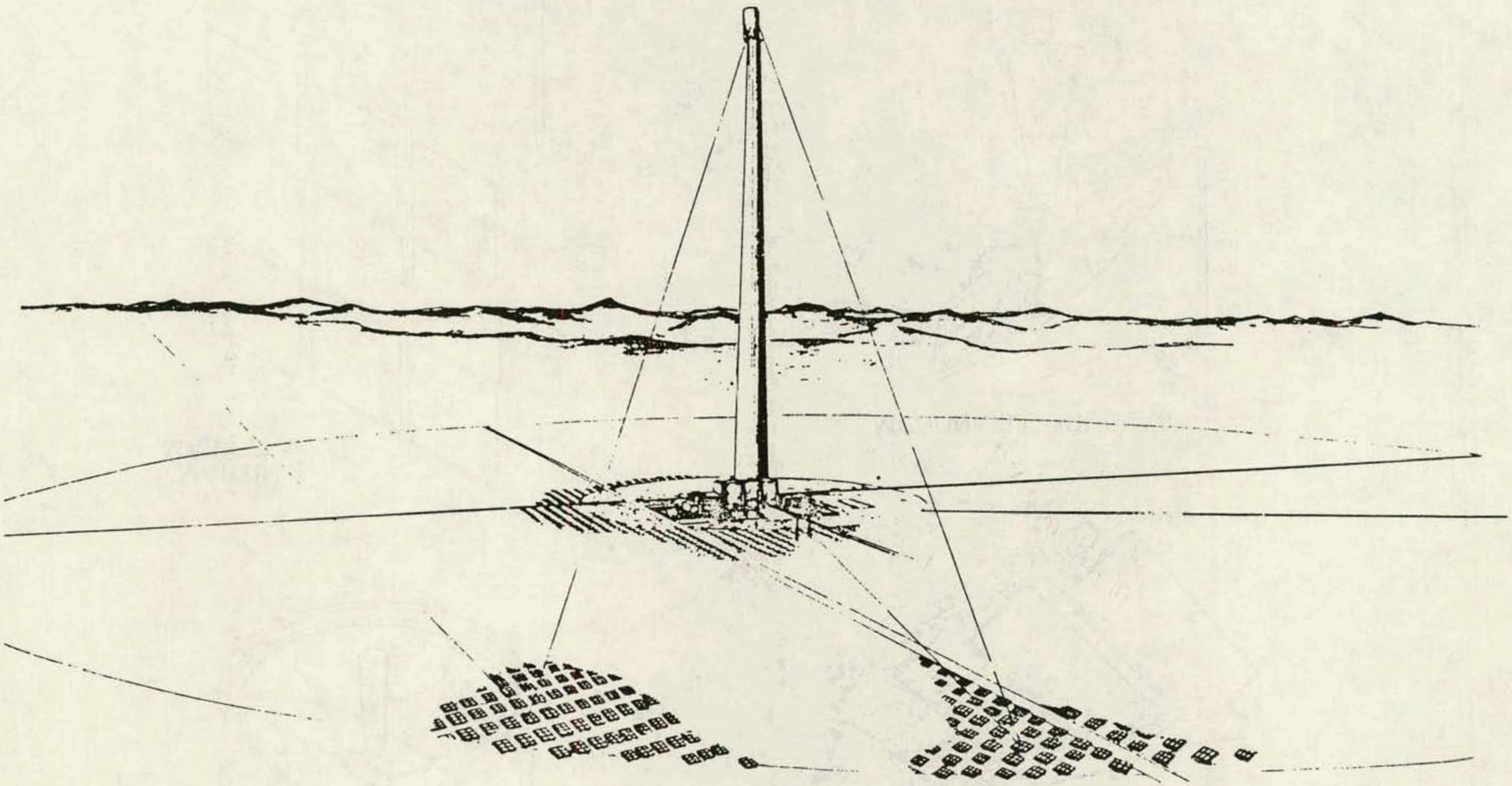


Fig. 19 Central receiver concept

SOLAR-EGYPT-63

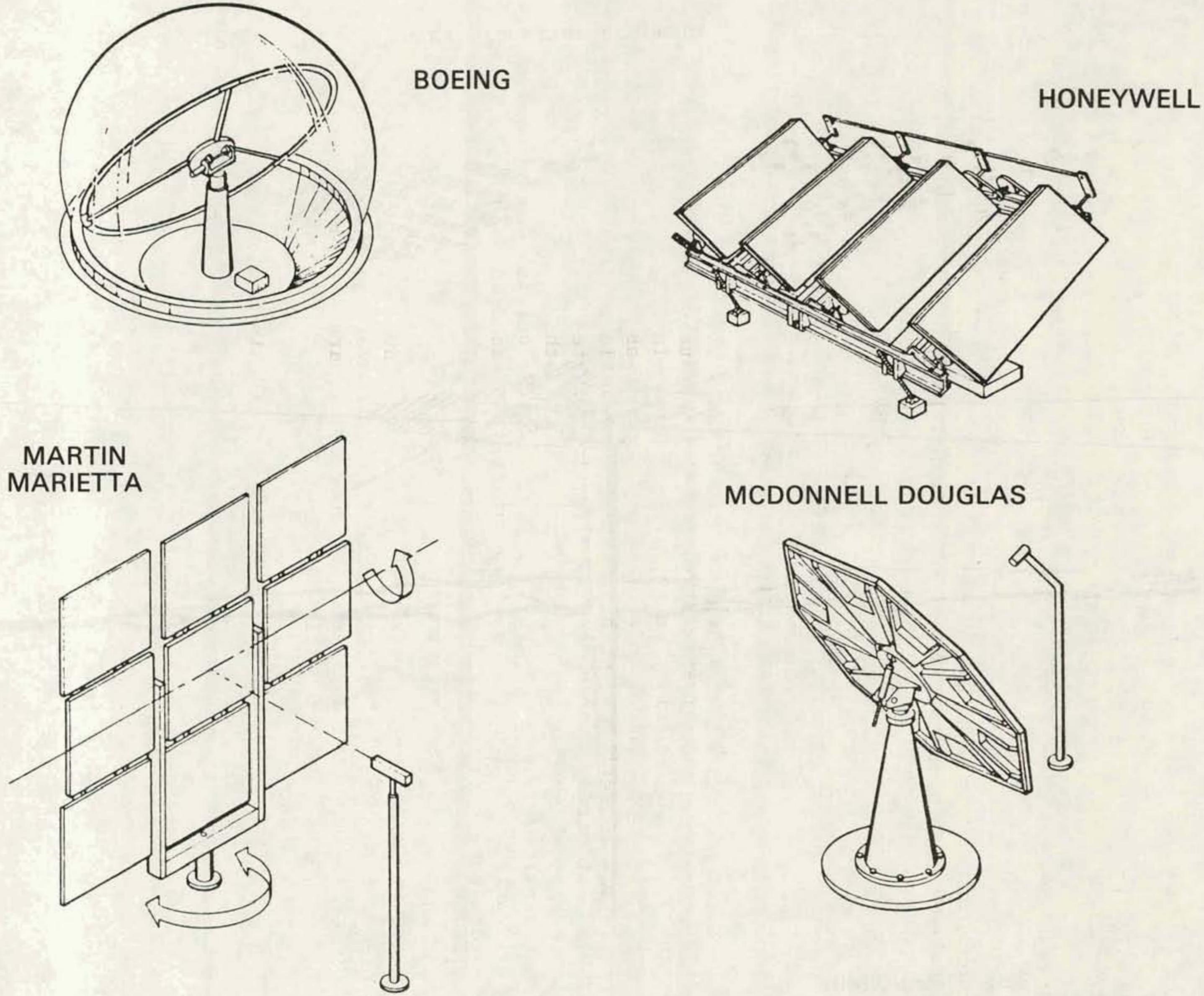


Fig. 20 Heliostat configurations

The primary advantage of the power tower concept, as compared to systems using a distributed collector array (troughs, etc), is that all the solar energy from a large area is collected in a central location, thus greatly reducing the requirement for piping of heat transfer fluids over long distances. Also, due to the high levels of solar concentration involved (1,000 to 2,000X) it is possible to efficiently attain temperatures consistent with the operation of conventional steam power systems (400 to 600°C).

The power tower system is most often considered for use at high power levels (50 MWe and higher) in regions where a particularly high percentage of the insolation is direct. However, the use of a mini-power tower for individual irrigation pumping systems at the 150 kW power level which might be applicable for use in remote areas, is also being investigated.

Another approach to high level concentration is the use of parabolic dish concentrators. A conceptual design of one such system is shown in figure 21. In this system the concentrated solar energy is used to operate an open Brayton cycle engine*, thereby eliminating the need for a heat rejection system as required by Rankine cycle engines. Brayton cycle engines (which require temperature levels in excess of 600°C for efficient operation) also are being considered for use in conjunction with the power tower point concentrator system previously described.

System Performance. There is a wide range in the projected thermal/economic performance levels of the various collector/heat engine solar power options being investigated. In general, the higher concentration systems (such as the power tower) are projected to have more favorable performance-characteristics than lower level concentrator systems, primarily due to their ability to operate at higher temperatures and thereby, higher efficiency levels. On the other hand, these high concentration systems may entail a higher degree of risk due to uncertainties in the nature of solar radiation (discussed in section 2.1) and the requirement to maintain precise two axis tracking under severe environmental conditions.

The type of systems which are in the most advanced development state at this time, by virtue of their use in several demonstration projects in the United States, are those using parabolic trough collectors and organic Rankine cycle engines.

The projected annual system efficiency of this system combination is presented in figure 22. As indicated, for this (and any other

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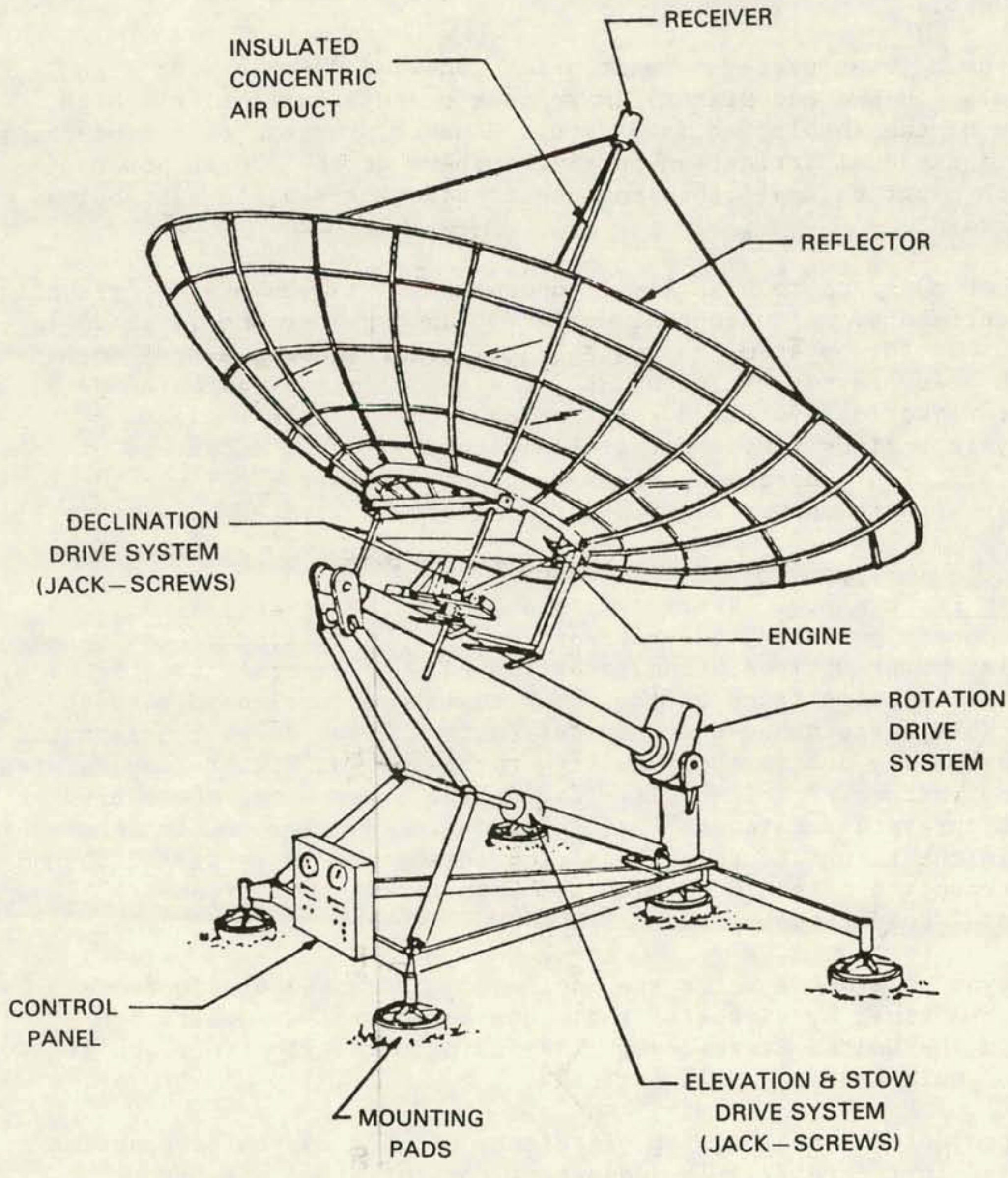
*One firm in the United States is currently producing a parabolic dish/steam power generation system.



SOURCE: ARTHUR D. LITTLE, INC.[14]

Fig. 21 Conceptual design for 10 kW solar concentrator system

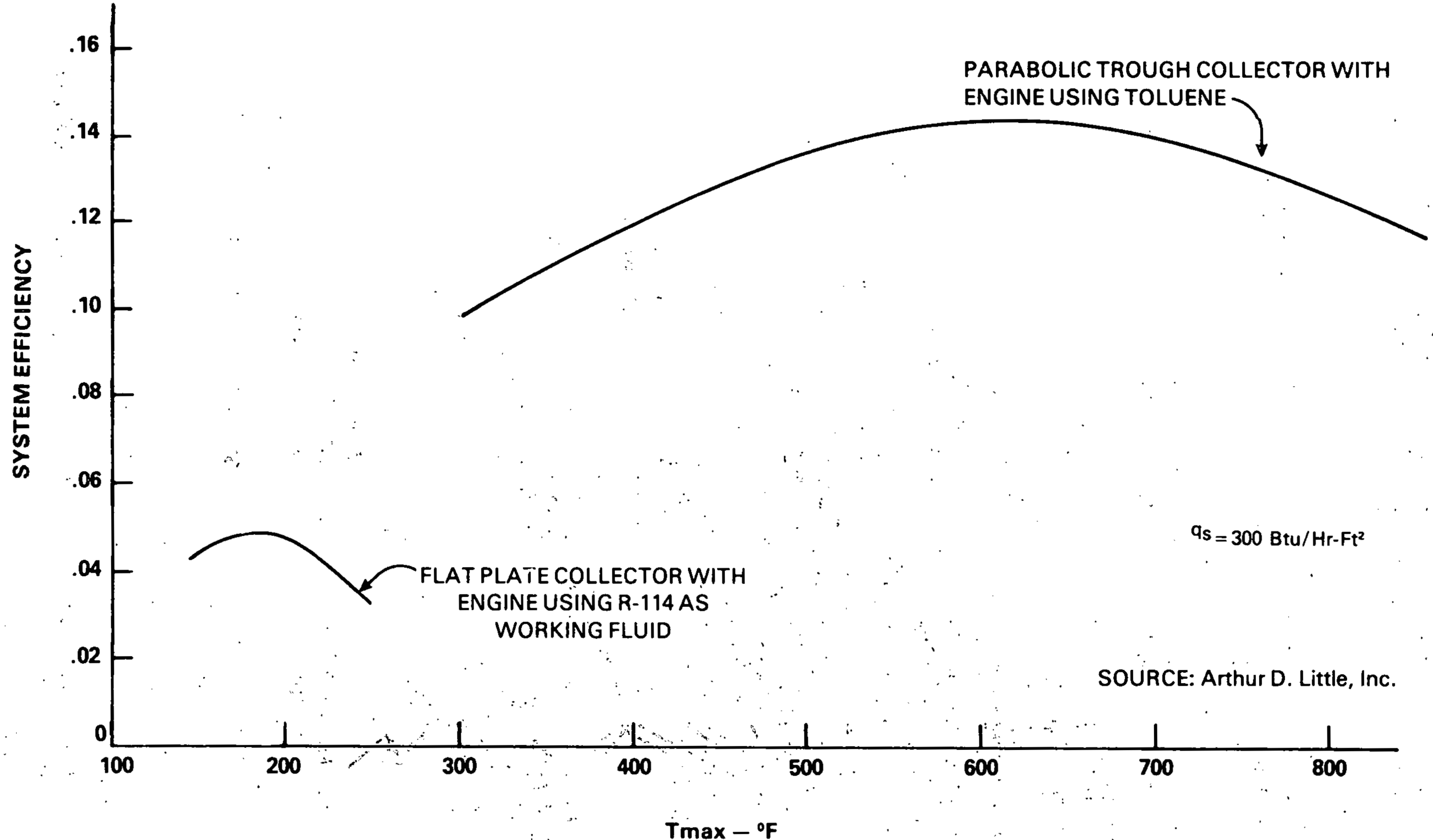


Fig. 22 Overall system efficiency

collector-engine combination) there is an operating temperature which maximizes system efficiency and, therefore, minimizes collector array area requirements for any specified output. For the design considered, the system efficiency under average solar flux conditions in Egypt is about 14 percent and occurs at an operating temperature of about 300°C. By comparison, the efficiency of a system using flat plate collectors would be only about 4 to 5 percent. The efficiency versus temperature curve is fairly flat, and there may be practical advantages for operating the system at as low a temperature as possible, consistent with acceptable efficiency levels. Such practical considerations include the ability to use a hot water thermal storage system (limited by operating pressures) and choice of construction materials, pumps, valves, etc.

3.2.3 Cost projections: To date, there has been very limited experience with establishing the commercial cost of solar thermal power systems. Thus, there is a wide variation in cost projections for the different system options.

The system options for which costs are probably best established is the parabolic trough/organic Rankine cycle engine combination. It is expected that these costs will be representative of other distribution system arrangements (segmented mirrors, CPC, etc.).

Manufacturers project that the cost of parabolic trough collectors might approach L.E. 70/m^2 in production quantities. The cost of organic Rankine cycle engines is expected to be in the L.E. 300 to L.E. 600 per kW range depending on capacity. The resultant system cost on an installed basis is estimated in figure 23. As indicated, installed system cost would approach L.E. 1,300 per kW (i.e., no storage), based on the assumptions shown. The installation costs are significant and are probably the most difficult to estimate due to variations in labor costs, site preparation, etc. The system could, however, be installed with Egyptian labor, thereby minimizing foreign exchange costs.

In the power tower system, the major cost factors are the heliostats used to redirect the solar energy to the centrally located receiver. Current heliostat cost experience is approximately L.E. 190/m^2 based on the purchase of 144 heliostats for a thermal test facility located in Albuquerque, New Mexico. However, ongoing low-cost heliostat development activities indicate that production cost goals of L.E. 47 to L.E. 100/m^2 can be achieved.

Based on this large-scale production cost estimate for heliostats, it is projected that the installed central receiver power system would have a cost of L.E. 870 to L.E. 1,000 per kW. Assuming successful operation of the Barstow pilot facility, these cost goals may be achievable by the mid to late 1980's.

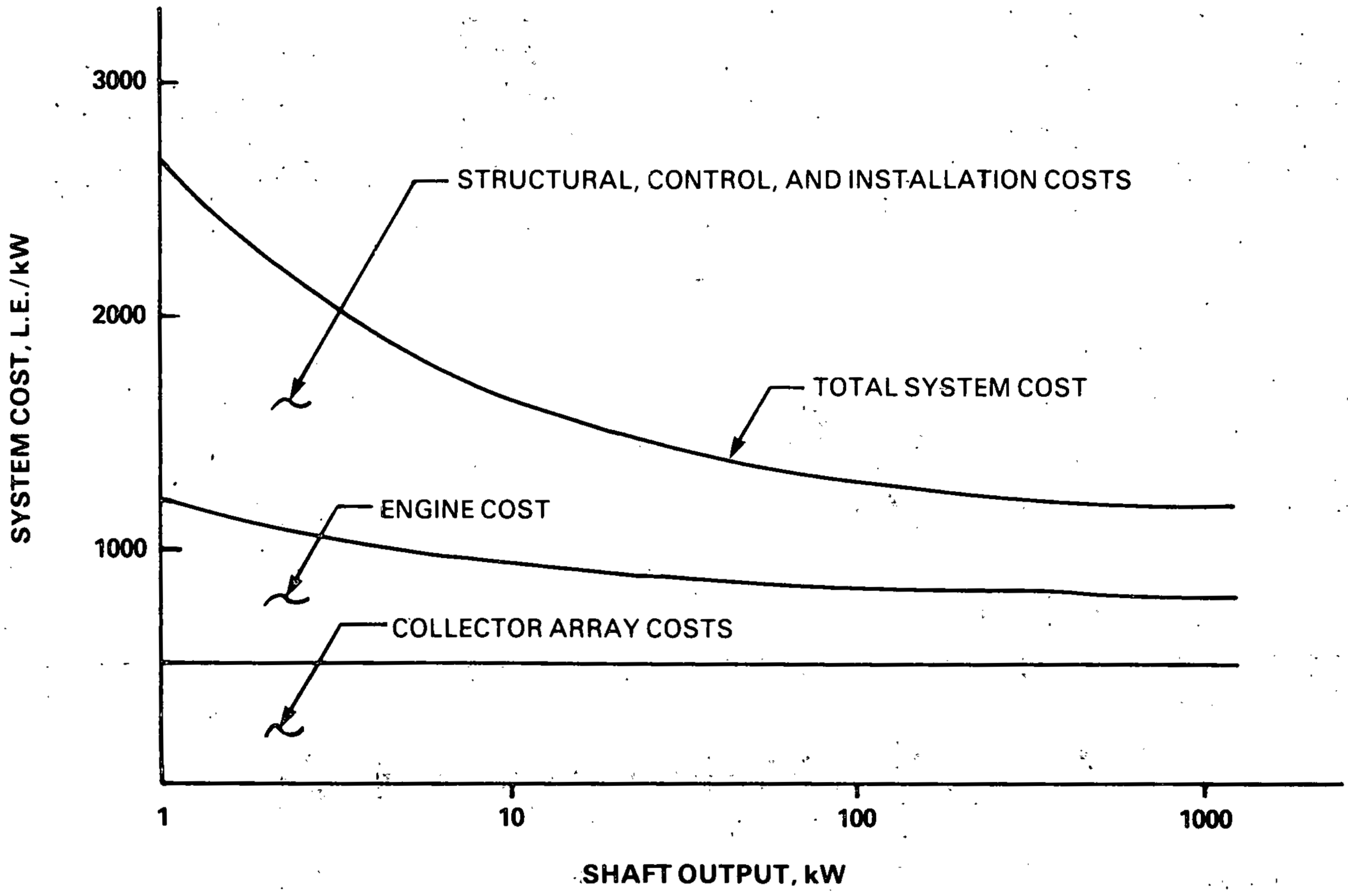


Fig. 23 Cost of a distributed solar thermal power system

3.2.4 Economic performance: The cost of power from a solar power unit is a function of many variables, including:

- o Initial cost
- o Annual power output
- o Operation and maintenance costs
- o Interest rates
- o Depreciation (useful life)

The cost of power generated by the parabolic trough/ORC engine system combination, when operating under the high solar flux regime of Egypt, is shown in figure 24, assuming:

- o Interest rate - 8 percent
- o Useful life - 25 years
- o Annual O&M cost of 4 percent

The cost of power produced by the system is in the 8 to 16 pt/kWh range if both labor and purchased component costs are considered. The cost of power decreases with increasing system capacity due to the economies of scale indicated on figure 23. This cost of power is still significantly higher than that from large central utilities but approaches that from the small diesel units often used for pumping and power generation in remote areas, particularly if anticipated increases in fuel costs occur. (See Section 4.0).

Power costs from larger central receiver power systems are projected to be in the 4 to 10 pt/kWh range if the lower end of the heliostat cost goals are attained. These relatively low power cost projections reflect, in part, the large size of these power units and the assumption of large scale production of key subsystems (in particular, the heliostats).

For both the distributed and central receiver solar power options, over 50 percent of the cost would be labor associated with subsystem manufacture and installation. If only foreign exchange costs are considered, substantially lower power costs than indicated above would result.

3.2.5 Implementation options: Most applications which are appropriate for solar thermal power systems also can be served by the photovoltaic power systems discussed in section 3.3. As a practical matter, therefore, these two technology options will be competing with one another over a range of applications including water pumping, air conditioning and refrigeration, village electrification, and, in later years, large-scale, grid connected electric power generation.

The types of systems that will be implemented to the greatest extent will depend on the relative progress made in lowering costs and on field experience with the different system options. For purposes of this preliminary study, solar thermal power and photovoltaics have been

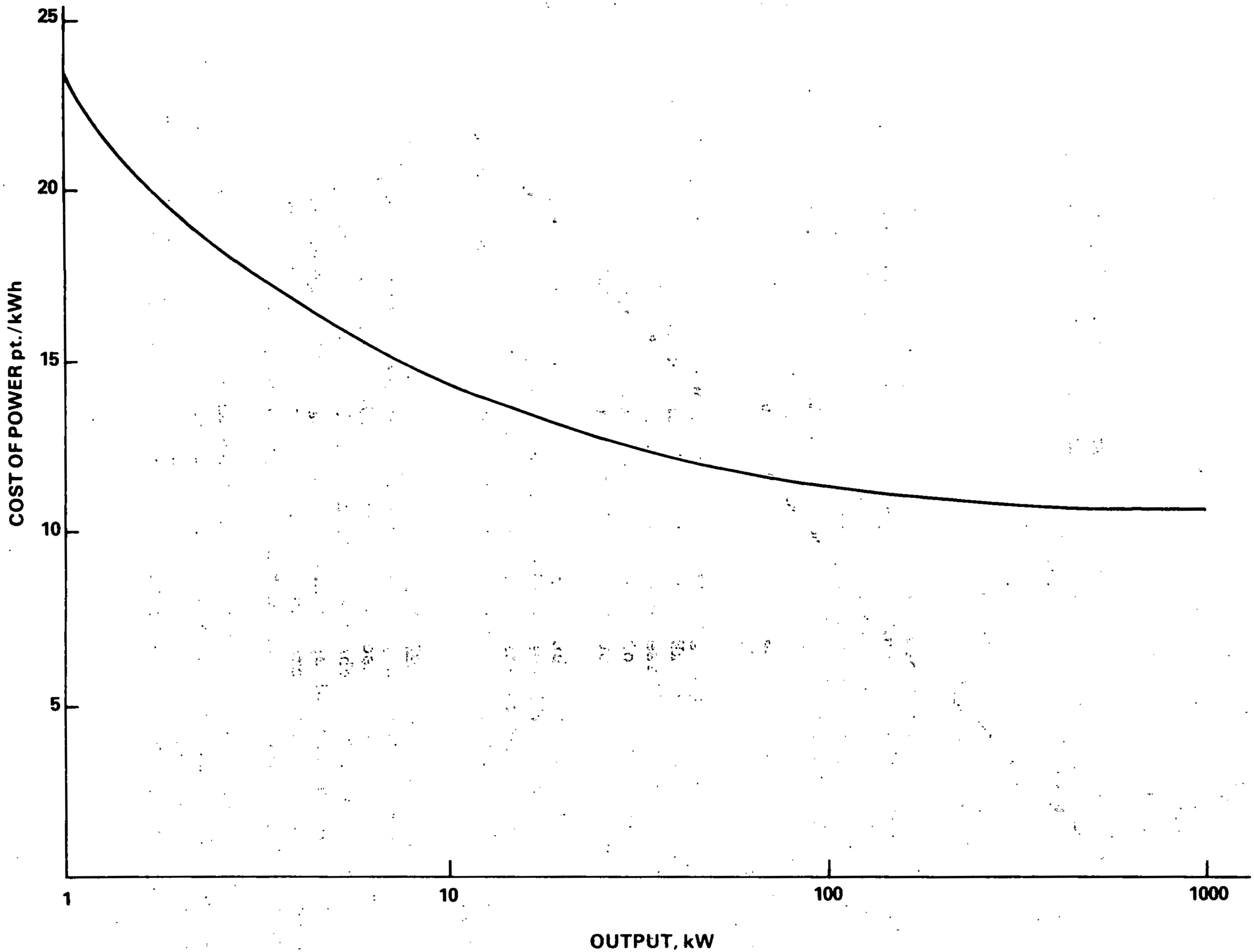


Fig. 24 Cost of electric power from solar thermal power systems

classified under the common heading of direct solar power systems (to differentiate them from the wind and biomass options). The implementation rate and impacts projected in section 3.3 for photovoltaics would, in practice, include a combination of photovoltaics and solar thermal systems and, therefore, no separate implementation scenario is developed here for solar thermal power.

Also, the requirements for reflectors, concrete foundations, support structures, etc., do not differ greatly for the collectors of a solar thermal system from those of a photovoltaic system using solar concentration (in fact, the concentrator subsystems could be identical). The resource requirements for the photovoltaic options are, therefore, assumed to apply also to the solar thermal option.

These simplifying assumptions will have to be reviewed in future program phases in order to more carefully indicate the relative merits of the solar thermal and photovoltaic power options given the environment and resources of Egypt.

3.2.6 Institutional/environmental considerations: No major institutional or environmental barriers to the widespread use of solar thermal power units are evident at this time. However, several issues which should be considered when planning for their implementation are discussed below.

3.2.6.1 Utility interface: The utility interface issues associated with all solar power units are discussed in section 3.3.

3.2.6.2 Environmental issues: Solar thermal energy systems are expected to be environmentally benign since there are no exhaust emissions resulting from their operation as with fossil fuel-fired plants or hazardous waste fuel disposal problems as with nuclear power units.

If a cooling tower is used in the reject heat system of larger plants, using a steam cycle power plant, the plume could have a minor effect on local climate; and the towers themselves could adversely affect the view of the landscape. If once through water cooling is used, care must be taken to avoid excessive temperature rises in local bodies of water. Also, for those systems using toxic organic working fluids in the engine or in the heat collector field transfer loop, care must be taken to avoid leaks into the cooling water stream. This issue could be particularly important for solar irrigation systems since the cooling water subsequently is used for irrigation.

3.2.7 Technical/economic issues: Although the technical feasibility of solar thermal power is well accepted, none of the approaches to solar thermal power has demonstrated the combination of long-term reliability, low cost, and technical performance required to justify widespread implementation. Future development and demonstration programs will be required to establish their competitive technical/economic performance and to identify which of the many approaches to solar thermal power have the best performance when manufactured and operated in Egypt.

A key technical issue which directly impacts economics is the effect of dust and sandstorms (common during parts of the year in Egypt) on the exposed reflectors common to many of the collector system options. The effect of dust and sand is twofold:

(1) The deposits of dust on the reflector surfaces reduces their reflectivity (easily by 5 to 20 percent) which leads to reduced power output.

(2) The air born dust and sand causes scatter in the solar radiation which reduces the amount of direct radiation required by high concentration systems, again leading to reduced output.

Sand and dust could significantly impact the relative performance of solar thermal system options, and therefore, future efforts should emphasize tests and demonstrations which quantify this effect, how it varies geographically, and the amount of cleaning required (with associated costs) to keep the loss in performance within acceptable limits.

3.3 Photovoltaics

3.3.1 Background: Solar cells are solid state semiconductor devices which directly convert solar energy into electricity, as depicted in figure 25. These devices require no moving parts, in contrast to thermal power systems, and they have demonstrated long-term reliability in both space and terrestrial applications. As such, they could find widespread application in Egypt, particularly in remote areas where reliable, maintenance-free operation is at a premium.

The present cost of terrestrial solar cell panels is L.E. 8 to 20 per peak watt,* depending on quantity purchased. In spite of this high cost, solar cell panels increasingly are being used for remote power applications, such as mountain top communication equipment and cathodic protection of pipelines. In 1977, the worldwide market for

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* Power output under high solar flux conditions associated with midday operation on a clear day (specifically 1 kW/m^2).

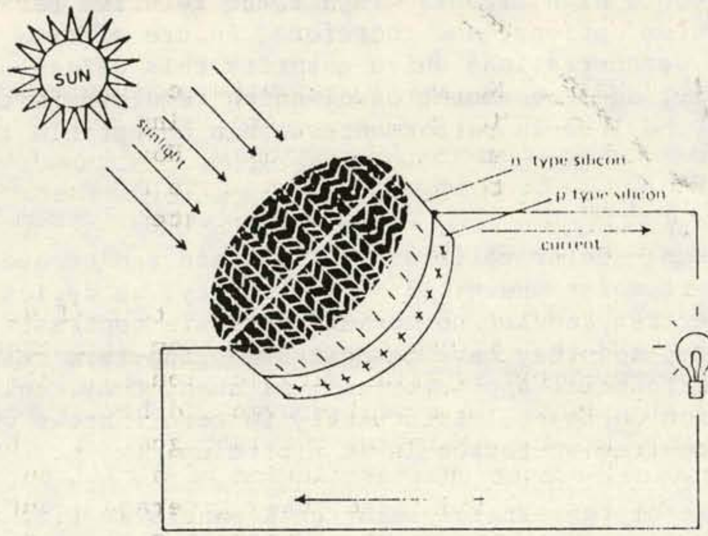

Fig. 25 Schematic of solar cell operation

such applications was estimated to be 750 kW annually; and it is projected to increase rapidly in the coming years. The cost of solar cell panels is expected to decrease dramatically over the next ten years, which would ensure their application for substantial power generation in sun belt countries.

The goal of the U.S. Department of Energy is to reduce the cost of solar cell panels to L.E. 1.3 per peak watt in 1982, L.E. .33 per peak watt in 1986, and L.E. .1 to .2 per peak watt in 1990 to 2000. The lower end of these cost goals will be difficult to achieve, given the very low per unit area costs they imply (about L.E. 10 to 20/m^2) and the need for rugged weather resistant construction. However, there is a high probability that a cost of L.E. .66 to 1.33 per peak watt can be obtained in the early 1980's by using solar cells in combination with solar concentration. By using solar concentration, costly solar cell area can be replaced by relatively inexpensive reflector (or lens) area. As is shown later, these relatively low risk cost objectives would result in economically attractive systems for many applications, given the highly favorable solar energy regime in Egypt.

An additional advantage of the concentrator-solar cell system configuration is that Egyptian industry could participate in a meaningful way in the assembly of the solar cell panels. This approach results in a substantial portion of the value of being added by Egyptian resources and would provide for initiating the training of Egyptian technical personnel in this critical technology field.

3.3.2 Technology status: Numerous photovoltaic material combinations involving several fabrication processes are being investigated by corporate, government, and academic organizations. However, most solar cell panels now in use for both terrestrial and space applications utilize single crystal silicon, due to its demonstrated high reliability, long life, and good efficiency levels.

It is expected that in the near to intermediate term (five to ten years), most solar cells will continue to be made from single crystal silicon using steadily improving material purification and cell fabrication techniques to lower costs. This well-proven and highly reliable material shows the potential for achieving the 1986 goal of L.E. .33 per peak watt. The electrical output characteristics of a silicon solar cell are shown in figure 26. As indicated, they generate about 0.5 volts (v) at the optimum efficiency point. Generating elevated voltages, therefore, requires connecting a multiplicity of individual cells in series. Common output voltages of solar cell panels which typically measure 2 feet by 4 feet, are 12 to 24v. The efficiency of individual cells in converting solar energy into electricity typically is 11 to 15 percent; however, when packing density of cells within a panel and resistance losses are taken into account, the efficiency of panels is usually 10 percent or less.

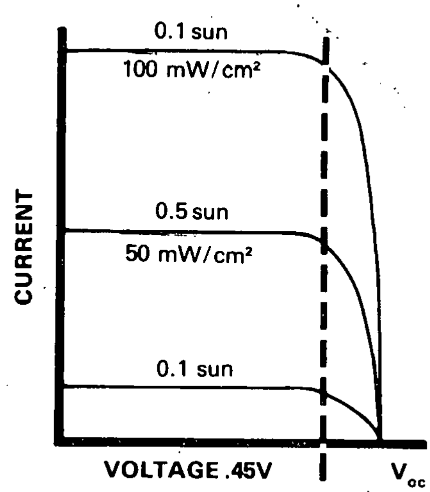

Fig. 26 Solar cell performance

Alternative materials to single crystal silicon which are in the most advanced stage of development are gallium arsenide, cadmium sulfide, and amorphous silicon. The primary incentive behind developing these alternatives is that they can be utilized effectively in very thin films (2 to 10) which is consistent with low cost manufacture.

Amorphous silicon (a-Si) of electronic quality is a relatively new material which originated in the late 1960's. The significance of the a-Si photovoltaic cell is its potential for low cost manufacture. The basic processes used in the manufacture of the a-Si photovoltaic cell are quite straightforward and are highly energy efficient. It appears, therefore, that with a strong technology development program, this film amorphous silicon solar cells have the potential for achieving the DOE 1990 cost goals of L.E. .1 to .2/peak watt with efficiency levels approaching 10 percent.

The CdS-Cu_2S system has been studied widely since its photovoltaic properties were discovered in 1954. The interest in this system has been sustained by the promise of at least two low-cost manufacturing technologies suited to very large-scale production, and the hope that further research would yield solutions to the early problems of low efficiency (3 to 4 percent for typical production cells) and poor life except under carefully controlled environmental conditions. However, it appears that the technological development of cadmium sulfide solar cells could result in cells that are consistent with the 1990 goals of DOE as defined above and, therefore, two firms in the United States (Solar Energy Systems and Photon Power) have indicated their intention to offer cadium-sulfide solar cells on a commercial basis.

Gallium arsenide, GaAs, is a nearly ideal photovoltaic material and devices of about 23 percent conversion efficiency have been produced. The ability of this material to work at high temperatures has favored its application in high concentration ratio systems.

GaAs photovoltaic cells of the single crystal type already have demonstrated superior performance at levels of concentration up to 2000 suns.

The present effort to produce thin film GaAs photovoltaic cells on low cost substrates eventually should yield efficiencies in the range of 14 to 18 percent. However, the area cost of such devices is not likely to drop below L.E. .66 to 1.50/peak watt, which means that concentration must be considered even for these cells. In this case, however, factors of 3 to 6 should be economically adequate, so that nontracking concentrators may be considered.

Solar concentrators are being developed over a wide range of concentration levels for use in solar thermal systems where the high temperatures resulting from concentration have thermodynamic advantages. For the most part, solar concentrators for use with solar cells will be similar to those developed for thermal systems (discussed in section 3.2), except that the thermal receiver placed in the focal plane will be replaced by a properly designed solar cell array.

Concentrator systems range from simple flat reflectors to refractive Fresnel lens systems and parabolic dishes. The type of concentrating system utilized is largely dependent on the level of concentration desired. The flat plate or passive reflector is basically a planar reflector for concentration ratios up to 2X. Compound parabolic concentrators are best suited for concentration ratios in the 2X to 10X range. Linear concentrators, such as parabolic troughs, can be utilized best for concentration ratios in the 10X to 40X range. Linear concentrators, such as parabolic troughs, can be utilized best for concentration ratios in the 10X to 40X range, systems using point concentrators (parabolic dishes, etc.) can be utilized.

3.3.3 System considerations: There are two important factors which must be taken into account in the design of a complete photovoltaic power system:

- Power is produced by the solar cells only when the sun is shining. The output of the solar cell array is, therefore, highly variable even on a clear day, peaking at solar noon and falling to about one-half the peak power 3 hours either side of noon. Little or no power is produced during periods of cloudy weather. The highly variable nature of power output from the solar cell array requires energy storage (batteries, hydro-storage, etc.) for applications.

- The output from the solar cell array is in the form of direct current power. Many on-site applications (irrigation pumping, refrigeration, etc.) can use DC power, however, before this power can be used by the consumer on the utility grid it must be converted to AC power at the appropriate voltages and wave form.

A schematic of a photovoltaic power unit capable of integrating with a utility grid which accounts for the above factors is shown in figure 27. This system consists of:

- A collector array consisting of solar cell power modules (shown as flat plate);

- o A mounting rack to properly orient the solar cell modules (tracking options would be used with concentrating systems);

- o Wiring to connect solar cell panels in the proper series-parallel arrangements;

- o A controller (consisting of DC switchgear and central circuits) which controls the selection of load alternatives between direct use and storage;

- o A storage subsystem to store excess power produced during peak solar flux periods for later use. The storage is shown as a battery pack which is the most likely storage approach in the near-term;

- o A DC-AC inverter to convert DC output of the solar cell array and/or the battery storage into AC power consistent with operation of conventional electrical appliances; and

- o AC switchgear to ensure a proper phasing of power supplied by the photovoltaic power unit and the utility power.

Most of the cost of solar cell power systems is associated with the solar cell array itself, due to the present high cost of solar cells. As the cost of the solar cells is reduced to the point where their use could become practical for general applications, the effect of the power conditioning and energy storage subsystem on overall system cost will become increasingly important.

These subsystems affect system cost in two ways: (1) they are, themselves, rather costly components, and (2) they all have inefficiencies associated with their operation which lower overall system efficiency, thereby increasing the area of solar cells required for a given power output.

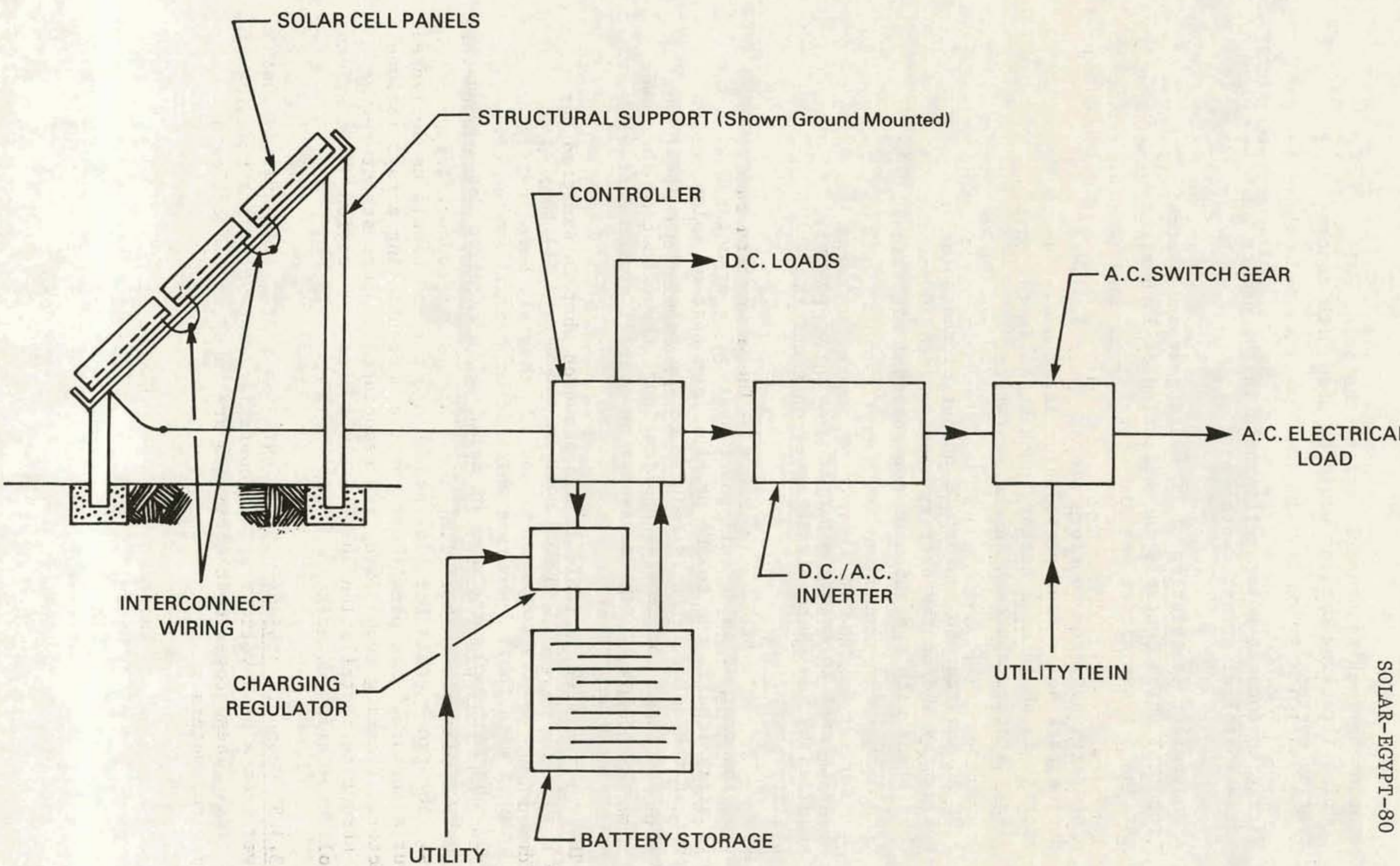

Fig. 27 Schematic of a photovoltaic power system

Even using a very efficient energy storage approach (batteries), systems which use energy storage and inverters will result in a 30 percent loss of power going through the batteries from the solar cell array to useful power output at the output of the inverter system. These system inefficiencies will significantly increase the solar cell area requirements (and therefore, cost) for a given net system output.

3.3.4 System costs: As indicated above, the cost of a system depends significantly on how much energy storage and power conditioning is required, as well as on the cost of the solar cell panels. Table 12 shows a typical cost breakdown for a sizeable (>10kWp) system based on two separate system designs as described below.

- o Case 1: No Storage or Inverters -- This system would use the power produced by the solar cell array directly, therefore, the array output is the system output capacity since there are no storage or inverter losses.

  This would be consistent with applications, such as water pumping and refrigeration, where no energy storage or power conditioning is required and the array output is used to drive DC motors directly.

- o Case 2. Full Storage Capacity -- The assumption used in defining this system is that all power must go through storage and the inverters. This would approach the case for a village electrification system where most of the load occurs in the evening or early morning hours.

The costs listed in table 12 are based on what is expected for those components in the 1980 to 1985 time frame based on moderate production levels.

The solar cell panel costs, including the installation and structure costs, are applicable to both flat panel arrays and concentrating arrays. The panel costs for flat panels are for the panels as delivered without structure. The panel costs of the concentrating arrays include reflectors, tracking mechanisms, and associated support structure. Panel structure/installation costs include site preparation, foundations, and collector array mounting.

3.3.5 Economic projections: Figures 28 and 29 indicate the cost of power from a photovoltaic system operating in Egypt, as a function of array cost. These power cost estimates are based on the following economic parameters:

Interest Rate	-	8 percent
Useful Life	-	20 years
O&M	-	2 percent

TABLE 12

SYSTEM COST BREAKDOWN - 1978 DOLLARS
($/kWp - output)

	CASE 1	CASE 2
Solar Cell Panels ($2/p-W)	$2,000	$2,800*
Battery Storage ($75/kWh)	--	400
Power Conditioning ($150/kW)	--	150
TOTAL (Components)	$2,000	$3,350
Panel Installation/Structure ($2/ft^2)	$ 200	$ 280*
Electrical Installation ($100/kW)	100	100
TOTAL	$2,300	$3,730
	L.E.1,530	L.E.2,480

* Increased area is due to maintaining output capacity with reduced system efficiency due to batteries and inverters.

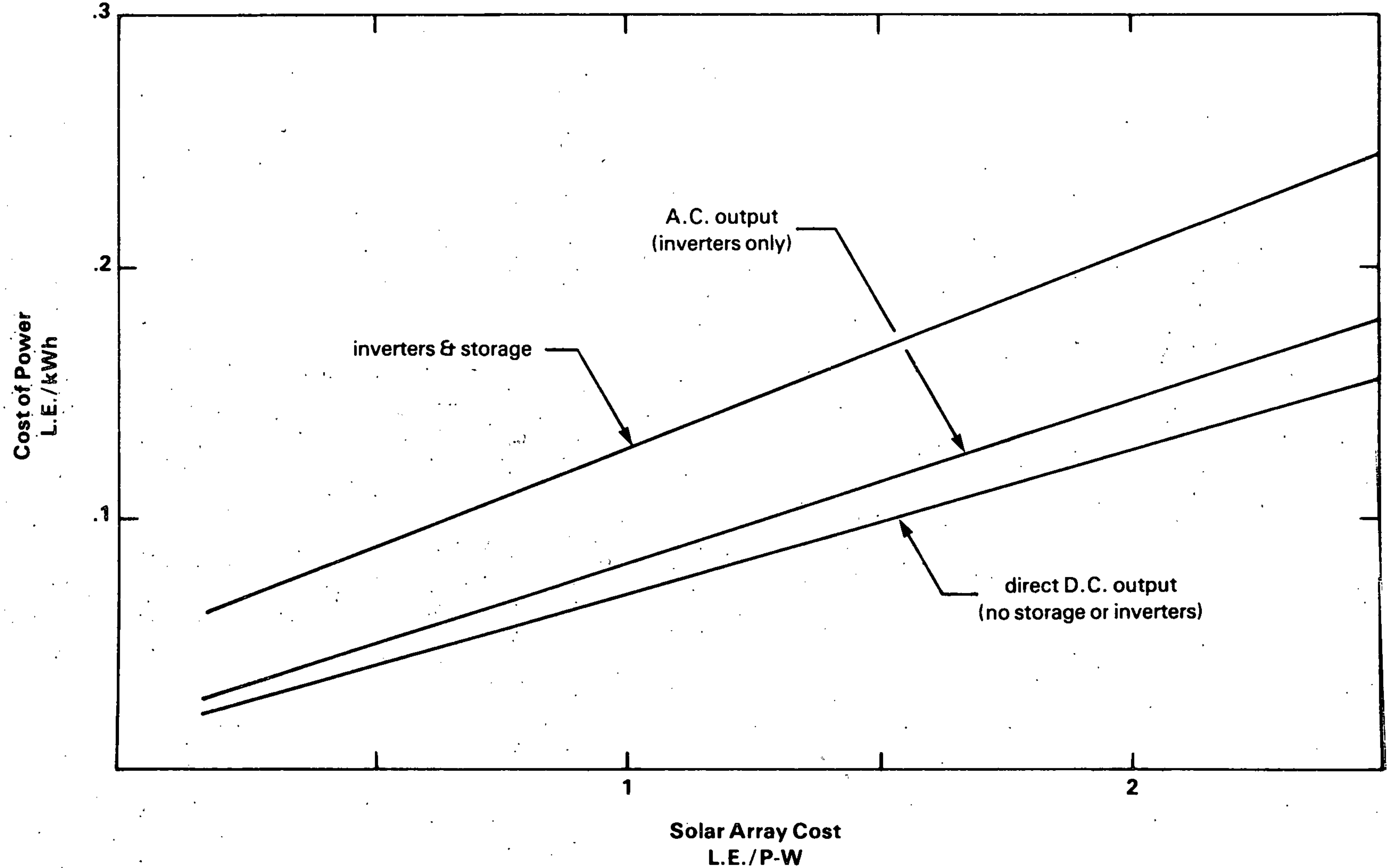

Fig. 28 Cost of power for a non-tracking system

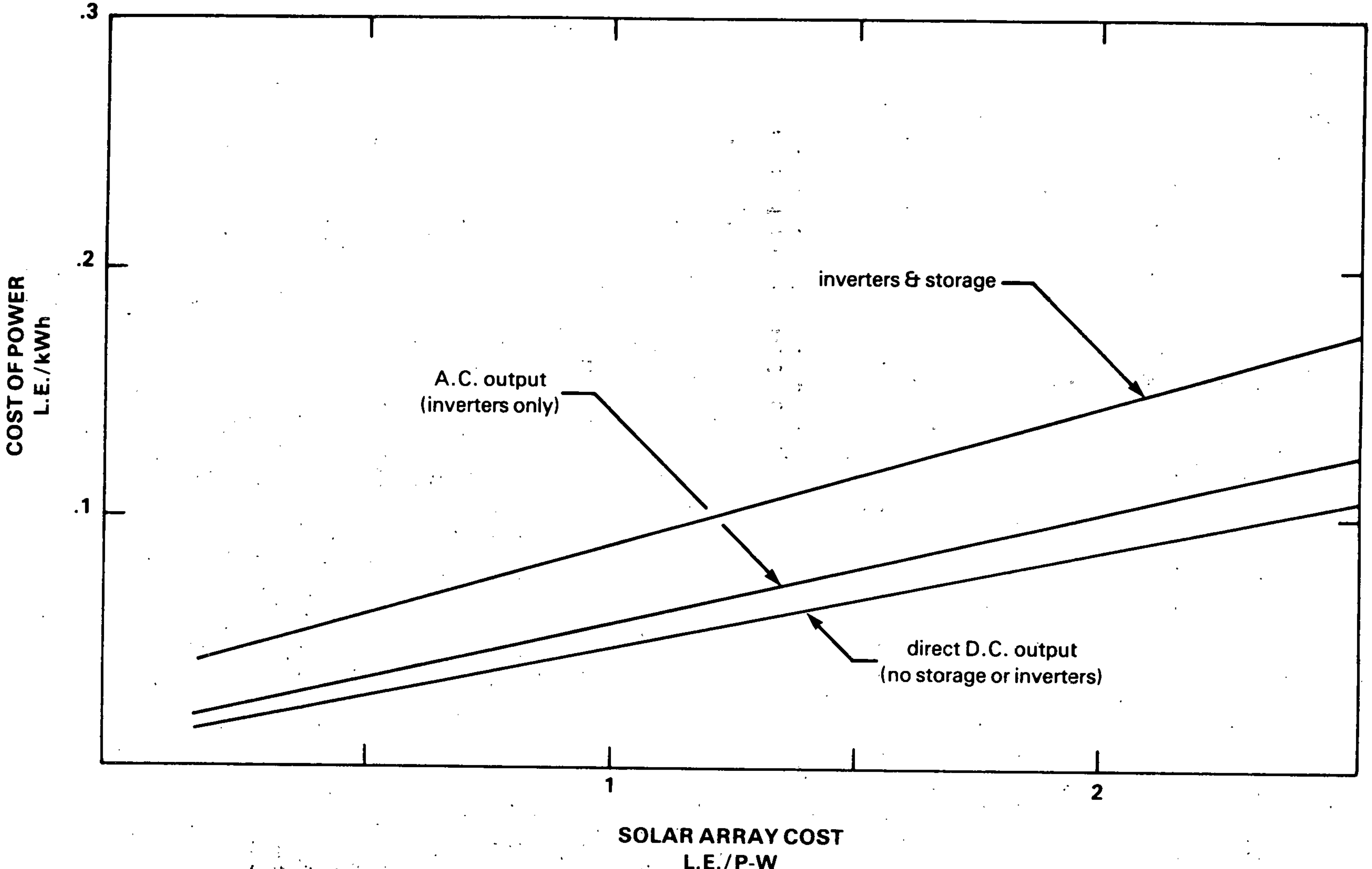

Fig. 29 Cost of power for a tracking system

At the current solar cell panel cost of L.E. 10/peak watt, the resultant power costs are prohibitive for widespread applications. As the costs of panels approach the L.E. 1.3/peak watt range, which is expected in the early 1980's, the cost of power from systems requiring minimal storage capacity becomes about 12 pt/kWh for a non-tracking system and about 9 pt/kWh for a tracking system. This cost is competitive with operating small diesel generators even at present fuel costs. The economics of photovoltaics, therefore, appear quite promising in an early to mid 1980's time frame for those applications where power is now generated by small diesel or gasoline engines. (See Section 4.0.) This represents a substantial market in Egypt, since many areas are not serviced by a utility grid.

If the 1986 goals of the United States Department of Energy were achieved, the cost of power from photovoltaic systems would be reduced to the 2 to 7 pt/kWh range. The wide range in these power costs is due to the range in the cost of storage and power conditioning that may be required, and whether the array is stationary or is tracking. At the lower end of this range, photovoltaic becomes competitive with all fuel fired power plants and is sufficiently close to competing with nuclear power that large scale implementation of photovoltaic power is a realistic option.

It is important to consider that significant implementation of solar cell power systems could be a realistic option in Egypt at solar cell panel costs of L.E. .6 to 1.5 per peak watt due to Egypt's excellent solar availability, limited utility grid systems, and the possibility of using internal labor and material resources. Therefore, the lowest cost goals (and also more speculative) of DOE for solar cells do not have to be achieved for widespread application in Egypt.

<u>3.3.6 Implementation options and energy impacts</u>: The economics of photovoltaic power systems show promise of becoming competitive with conventional power systems in Egypt, both as a result of decreasing solar cell costs and the increasing cost of conventional energy sources. It appears likely, therefore, that photovoltaic power units will be implemented in Egypt during the time period of interest. The extent of this implementation will depend on a number of factors including:

- Future increases in the worldwide prices of fuels used to operate conventional power systems;
- Government policies regarding the internal pricing of fuel forms (which are now heavily subsidized); and
- Any government policies which encourage the widespread implementation of photovoltaics through direct subsidies, participation in joint venture manufacturing operations or directives which require their use in specified applications.

As a result of uncertainties in all the above areas, it is difficult to project the implementation rate of photovoltaics with any degree of certainty. To determine the relative effect of the utilization of photovoltaics in Egypt, two implementation scenarios are presented in table 13.

The implementation rate of Case A is consistent with the situation where the government does not strongly support the development of a photovoltaic capability in Egypt. This scenario still would require that photovoltaic power units be subsidized in some way to equalize subsidies provided to conventional energy forms used to generate power (for example, the diesel fuel used in diesel generators).

The scenario of Case B represents the situation where the foreign exchange and industrial development benefits of photovoltaics induce the government to take a positive role in promoting their use.

The modest implementation rates of the early 1980's are consistent with relatively low power applications in remote areas where small diesel engines are the primary alternative. The more significant implementation rates after 1985 assume that voltaic power units are installed with substantial capacities to supplement power from larger fossil fuels (or nuclear) power plants.

As a result of the implementation scenarios of table 13, the cumulative capacity of installed photovoltaic systems is as indicated in figure 30. Based on the results of the scenario considered in Case B and Egypt's projected capacity requirements, photovoltaic power would satisfy 1 percent of Egypt's electric power in 1985, 2.5 percent in 1990, and 5 percent in 2000. (Per annual output projections of figure 31.)

3.3.7 Resource requirements: Table 14 provides a preliminary indication of the resource requirements of the implementation scenarios. The resource requirements indicated are consistent with the use of a 5X concentrator using the compound parabolic concentrator design.

The resource requirements that would be associated with systems using other solar cell panel configurations (i.e., flat plates, parabolic troughs, Fresnel lens, etc.) would depend on the material and labor requirements for the selected configuration. For example, with a flat plate panel the aluminum used for reflector area would be replaced by solar cell area. If solar cells are to be imported, this would increase the foreign exchange component of system manufacture.

For the case considered, the major material requirements are for steel, glass, aluminum, and concrete. The steel is used for both structural support and as an enclosure for the solar cell and reflector subassemblies. Concrete is required for the collector support foundations.

TABLE 13

PHOTOVOLTAIC IMPLEMENTATION SCENARIOS

	CASE A	CASE B
1980	Demonstration - 20 kWp	Demonstration - 50 kWp
	Small systems for remote water pumping and power functions	Government requires solar or wide range of remote applications
	Average size - 10 kWp Number of units - 100 Capacity - 1,000 kWp	Average size - 25 kWp Number of units - 2,000 Capacity - 50,000 kWp
1990	Larger systems for remote villages and pumping applications	Small central utilities to replace fossil fuel stations, plus continuation of small on-site installations
	Average size - 100 kWp Number of units - 400 Capacity - 40,000 kWp	Average size - 200 kWp/25 kWp Number of units - 500/2,000 Capacity - 100,000/50,000 kWp
2000	Increase in 1990 installation rate	Increase in 1990 large system installations
	Average size - 150 kWp Number of units - 800 Capacity - 120,000 kWp	Average size - 200 kWp/25 kWp Number of units - 1,000/2,000 Capacity - 200,000/50,000 kWp

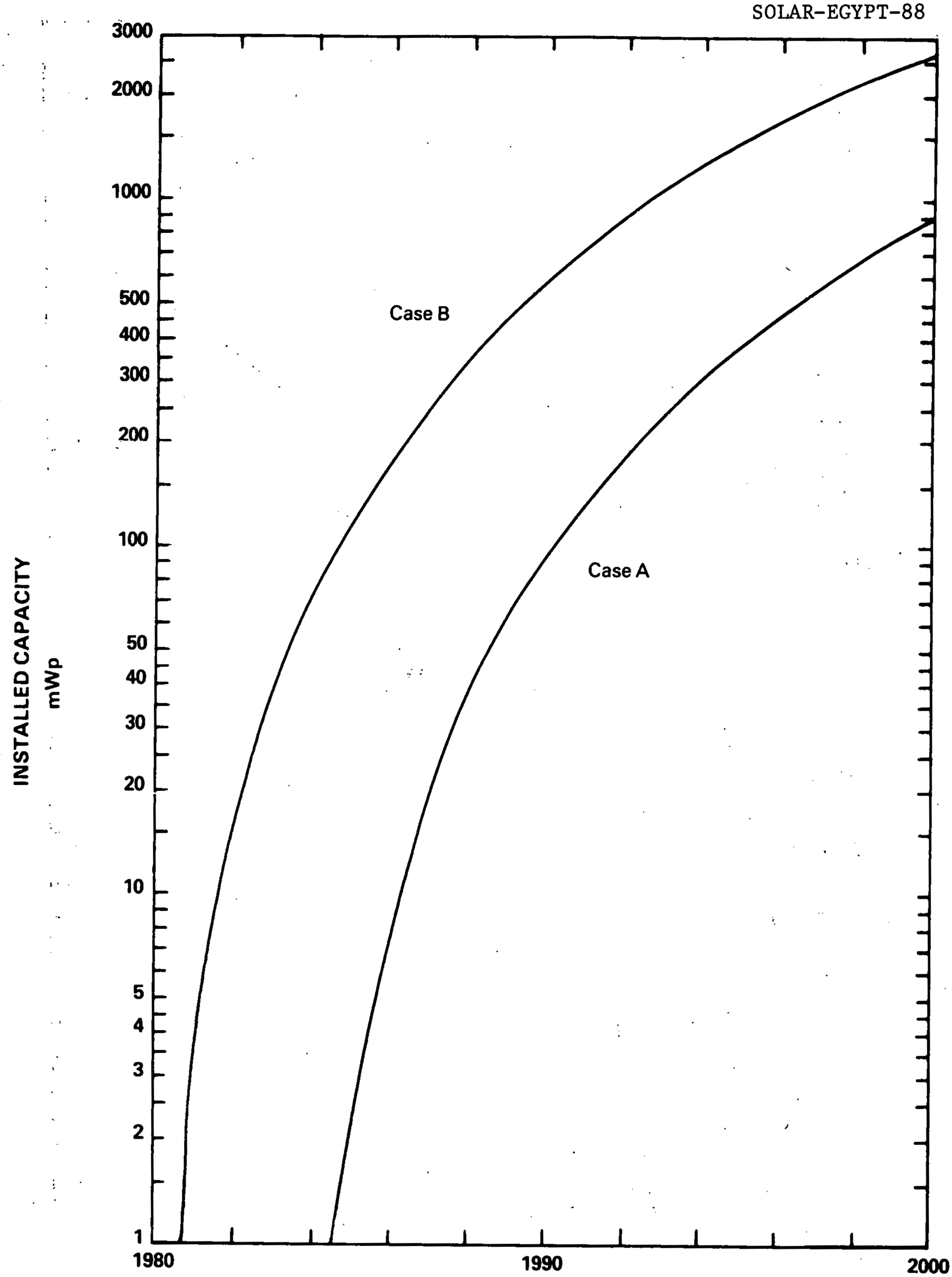

Fig. 30 Photovoltaic cumulative capacity

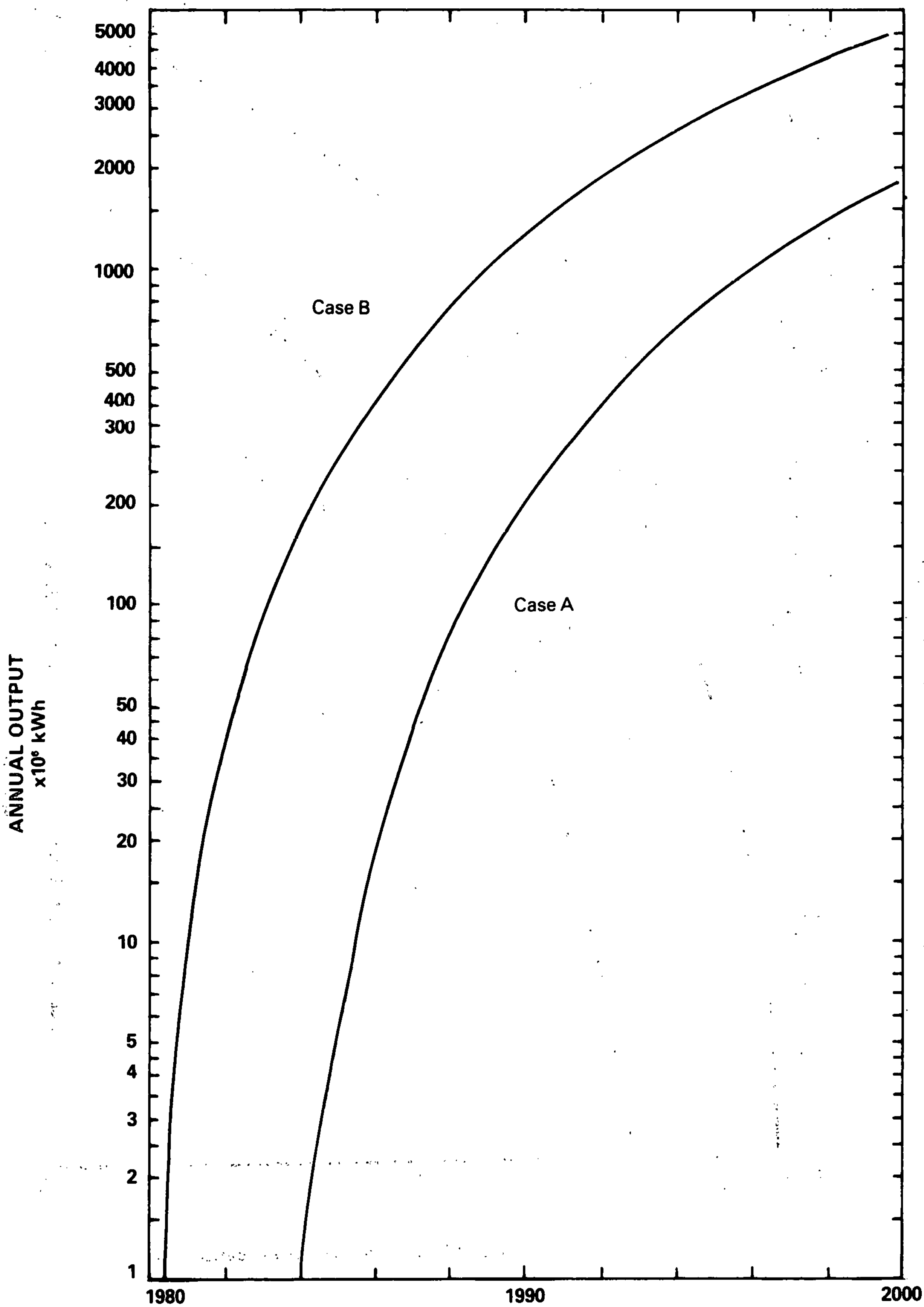

Fig. 31 Photovoltaic cumulative output

TABLE 14

RESOURCE REQUIREMENTS OF PHOTOVOLTAIC IMPLEMENTATION SCENARIOS

	1985 (1.33L.E./pW)*		1990 (.67L.E./pW)*		2000 (.33L.E./pW)*	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
ANNUAL MATERIAL REQUIREMENTS (tons)						
Glass	135	6,750	5,400	20,250	16,200	33,750
Aluminum	72	3,600	2,888	10,830	8,666	18,050
Steel	195	9,760	7,810	28,300	23,400	47,100
Copper	15	775	620	2,325	1,860	3,875
Cement	220	11,000	8,800	33,000	26,400	55,000
ANNUAL MANPOWER REQUIREMENTS (man-years)						
Management/Technical	4	190	150	500	450	830
Production & Installation	30	1,550	1,250	4,800	3,750	8,000
Operations & Maintenance	6	290	200	1,230	1,600	4,700
ANNUAL FINANCIAL REQUIREMENTS (1978-L.E. X 10^6)						
Solar Cells	.27	13	5	20	8	17
Materials & Components (Exclusive of Solar Cells)	.36	18	14	53	42	88
Labor (Fabrication & Installation)	.22	11	8	32	26	53
O&M	.04	2	1.4	9	12	33
TOTAL	.89	44	28.4	114	88	191

*Cost of delivered solar cell modules used in concentrators

The assembly and installation of solar power units would provide employment for about 8,000 people if the accelerated solar strategy is pursued. An additional 4,700 workers would be required to operate the systems and perform maintenance functions. These O&M functions would range from periodic cleaning of collector panels to replacement and/or repair of faulty solar cell modules.

A major portion of the financial requirements are associated with labor or materials other than solar cells. In fact, the percentage of total costs associated with the solar cells decreases with time as the cost of solar cells decreases due to worldwide research and development efforts and increased production quantities. This system (common with other arrangements using concentration) has the advantage, therefore, of having a large (and increasing) value added by Egyptian resources.

3.3.8 Institutional/environmental considerations: There are several institutional/environmental issues which may affect the implementation of photovoltaic power systems in Egypt. Several of these are discussed below.

Land Use. Most of Egypt (other than the Nile Valley) is very sparsely populated. There is, therefore, little problem in finding sufficient land area for larger scale units that would tie in with the utility since most locations in Egypt are only a few miles away from desert areas.

However, several of the most attractive applications of photovoltaics, particularly in the near-term, involve smaller units that would be used locally to drive irrigation pumps, refrigeration units, or to provide small amounts of power for use in villages. As a practical matter, these systems would have to be located in close proximity to the loads being served and therefore, land use requirements could be important since these applications would tend to be centered in areas of high population and/or extensive agricultural activities.

About 10 m^2 of collector panel area is required per peak kW of output capacity. The resultant land use required for a 10 hp pumping system (which is typical of the capacity of engine driven pumps now utilized extensively) would be about 240 m^2 if collector panel spacing requirements to avoid shading are taken into account. In Egypt, about 0.1 kW of pumping capacity is required per feddan of land. A 10 hp (7.5 kW) pumping unit is, therefore, sufficient to irrigate over 75 feddans of land so that the collector area is less than .1 percent of the land being irrigated. The impact of land requirements for the solar cell array for this application appears, therefore, to be minimal.

For larger applications, such as village electrification, the effect of land requirements would have to be evaluated in more detail. However, based on a typical dwelling requirement for 2 to 3 kWh per day, it appears that the area requirement of the collectors would be only about 20 percent of the roof area of the dwellings being served. In most cases, therefore, it appears that land use requirements for solar cell arrays will not be a major problem.

Utility Interface. The early and limited implementation of photovoltaics often will be in non-grid connected applications where the economics of photovoltaic power are particularly favorable. However, if the cost of photovoltaics decreases as expected (and as assumed in the implementation scenarios), their use will become competitive with conventional power use leading to the installation of grid connected systems.

The installation of significant photovoltaic power capacity will have a significant effect on utility operations since the output of the photovoltaic units is highly variable and often unpredictable due to partial cloud cover. The widespread use of photovoltaics will require therefore, that careful attention be given to the utility interface issue and how the use of photovoltaics could impact the optimum mix of conventional power systems, the need for energy storage (possibly by means of pumped hydro), and utility rate structures.

Rural Developments. An important aspect of government development policy is to improve living standards in rural areas and to develop remote areas which presently are sparsely populated. In many cases this process requires providing electric power for residential, pumping, and commercial applications. Photovoltaic power units are ideally suited for providing power in remote areas where extending the utility grid or operating engine/generators is particularly costly. Photovoltaic power (and other solar power units discussed in other sections) should, therefore, be considered within an overall rural development planning context.

GENERAL REFERENCES

1. The Mitre Corporation "Systems Descriptions and Engineering Costs for Solar-Related Technologies, " Volume VIII, June 1977. USERDA Contract E(49-18)-2322.

2. Spectrolab, Incorporated "Final Report - Photovoltaic Systems Concept Study," USERDA Contract E(11-1)-2748, April 1977.

3. Arthur D. Little, Inc. "Final Report - Conceptual Design and Analysis of a Compound Parabolic Concentrator Collector Array," ANL Contract 31-109-38-3855, August 1977.

4. Communication with Mr. G. Jones, Sandia Laboratory; Albuquerque, New Mexico.

3.4 Wind Power Generation

3.4.1 Introduction: Wind power generation is the process of converting the kinetic energy contained in the wind into electrical or mechanical energy via some intermediate device. Various types of equipment have been proposed, but by far the most common and furthest developed is the conventional horizontal axis wind turbine, figure 32, a configuration that has been in use for decades.

There are essentially two size ranges of wind power units currently being manufactured or developed. Small units, with rated outputs in the 1 to 15 kW range, are now used to produce power in remote areas which are not serviced by a utility and where it would be very expensive to operate small engine generators. Large units, with outputs in the 100 to 5,000 kW range, are under development in the United States for generating power in large enough quantities to supplement conventional utility systems.

Several smaller wind turbine designs are in use today and their performance and reliability are well demonstrated: new designs will require a brief testing period to achieve similar reliability. Several systems in the 100 to 200 kW range are in operation presently, as part of the United States wind program and are performing within design limits. The cost and performance of wind turbines, therefore, can be projected with a higher degree of confidence than most other solar options, where low cost and long term operational reliability are still to be demonstrated.

As indicated in section 2.2, both the Red Sea coast and Mediterranean Sea coast have wind regimes that are suitable for wind power generation. Improving the prospects for wind energy conversion in these areas is the fact that existing population centers (such as Mersa Matruh) in coastal regions use relatively costly diesel generators for power production, and there are plans for increased development of these areas to enhance commercial activities (such as the tourist industry) that will increase further the demand for electricity.

As indicated in following sections, the cost projections for wind energy conversion are sufficiently low that power can be generated at costs competitive with fossil fuel fired systems in the higher wind areas of the Red Sea and Mediterranean Sea coasts. Large scale implementation of wind power systems could be a realistic option in Egypt for the 1980-1990's.

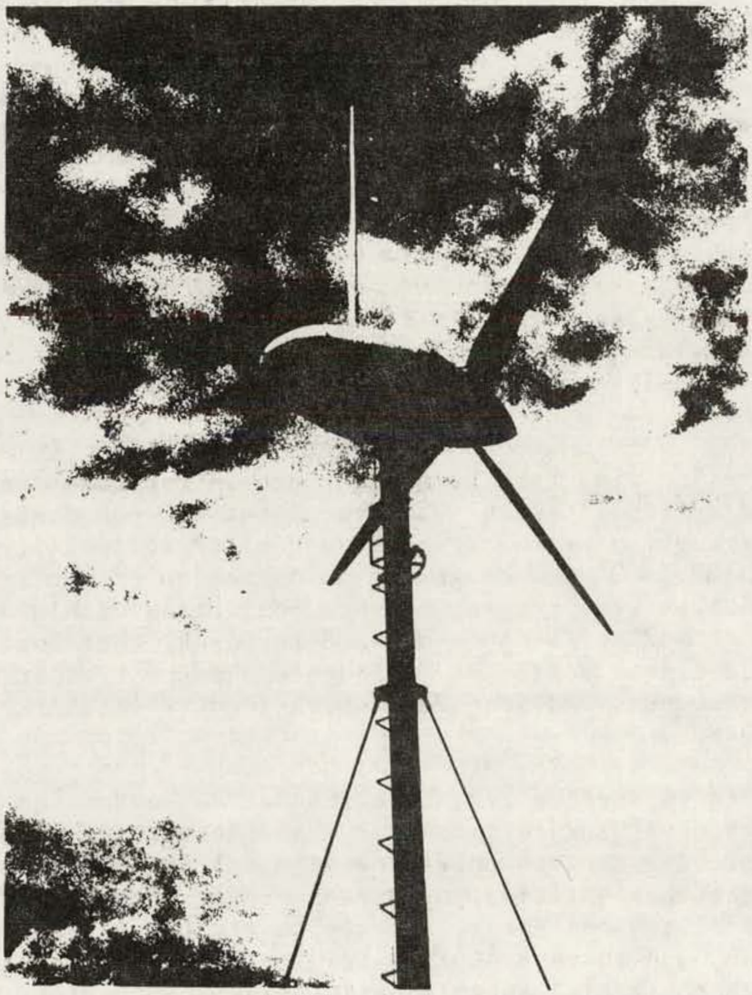

Fig. 32 Horizontal axis wind turbine
Source: University of Massachusetts

3.4.2 Design options: There are several types of wind turbines which can be used in Egypt. Figure 33 shows a multi-bladed water pumping system, which has been used for decades for pumping irrigation water, etc., in remote areas of the United States and Australia. Such systems also have been used in Egypt, in coastal regions near Alexandria. Although most of the Egyptian systems are inoperable now, due to a number of mechanical problems, the multi-bladed systems are well-suited for direct water pumping applications, because of their simple construction and low speed, high torque operating characteristics.

For electric power generation applications, modern high speed wind turbines such as shown in figure 32, are usually utilized. Commercially available units usually have two or three blades with diameters in the 1.5 to 8m range and generally operate between 100 and 300 rpm.

One of the larger systems under development for utility scale power generation purposes is shown in figure 34. The 100 kW system (output in an 8 m/s wind) undergoing performance testing has a rotor diameter of 38.1m, while the larger MW size units under development will have 60 to 90m rotor diameters. Typically, these larger systems will operate at 30 to 40 rpm.

Of recent interest is the Darrieus design, figure 35, which is a vertical axis machine. Due to the relatively immature status of vertical axis wind turbine technology (blade fabrication and static loading analysis, dynamic performance, start-up and generator systems, etc., are areas being investigated), virtually all large-scale power systems (> 200kW) being proposed today are of the horizontal axis type. The Darrieus type of equipment may have practical advantages over the horizontal axis machines discussed above for some applications. However, the differences between horizontal and vertical axis machines are not expected to be sufficiently large enough to affect the basic economics of wind power in this analysis. Therefore, for the purposes of this study, it has been assumed that wind turbine installations will be of the more conventional horizontal axis design.

Figure 36 shows a schematic drawing of a complete small-scale wind turbine unit as it might be tied in with a small diesel generating facility such as those commonly used in areas not serviced by a utility grid. As indicated, the wind power unit might require some amount of battery storage (to flatten transients), and an inverter, if the system were to supply AC power from storage. A large wind turbine system would be basically the same, except that the inverter would not be used, since the output of the wind turbine already is constant frequency power.

For water pumping applications, no storage is required, which favors the economics of this application. Even when the wind turbine generates electricity (per figure 36), the amount of storage can be decreased by assuming that the conventional generating system takes over under prolonged low wind conditions. This is also the operating philosophy associated with the design of most grid-connected, large-scale wind power generation systems.

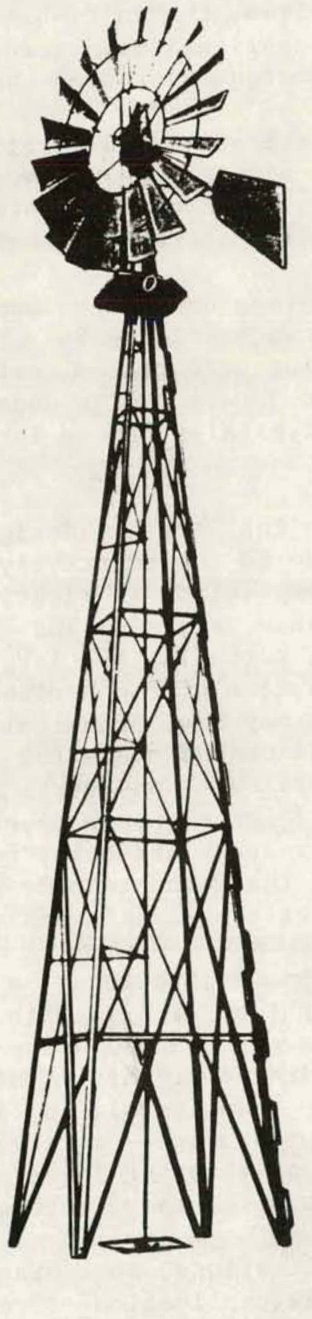

Fig. 33 Multi-blade, low-speed water pumping unit
Source: Aeromotor., Inc.

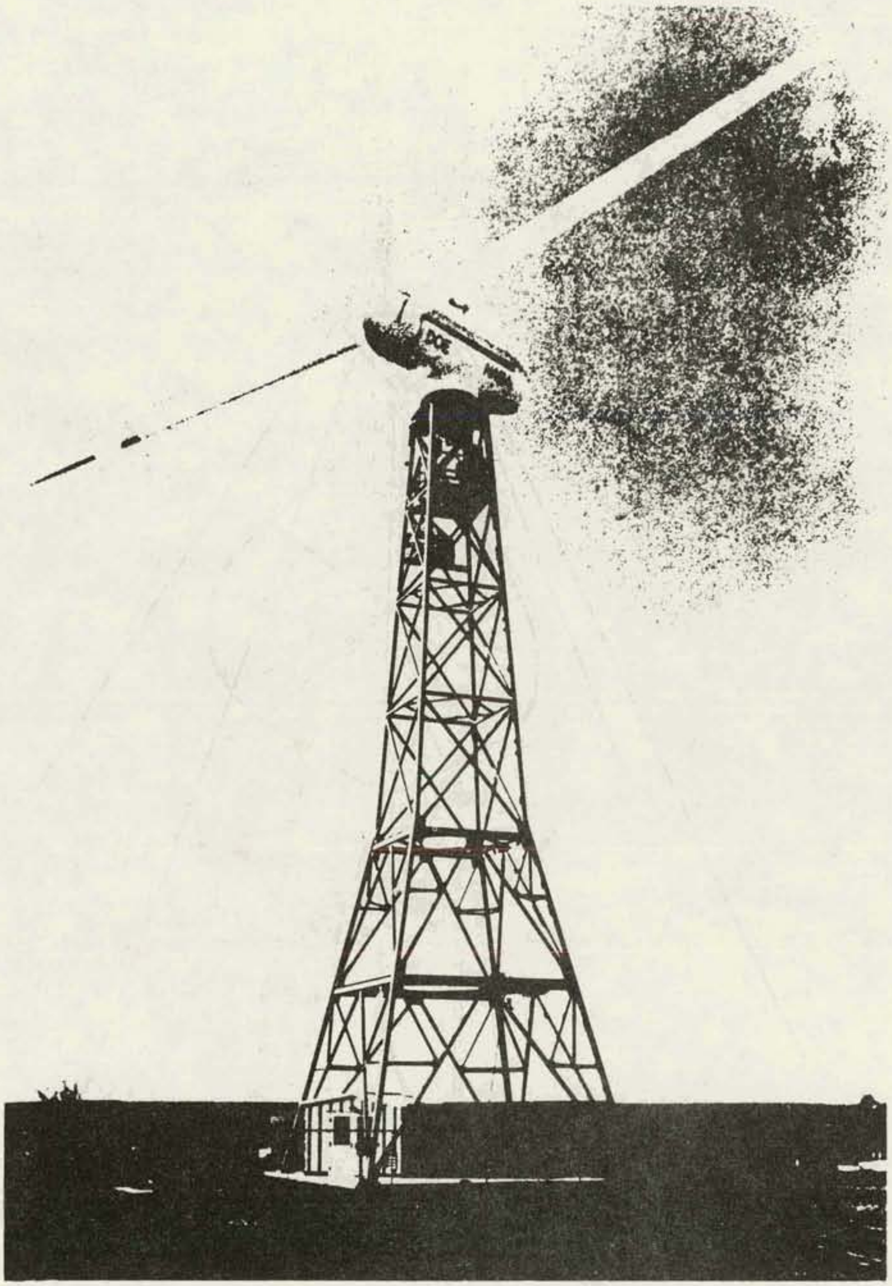

Fig. 34 100-kilowatt wind turbine generator

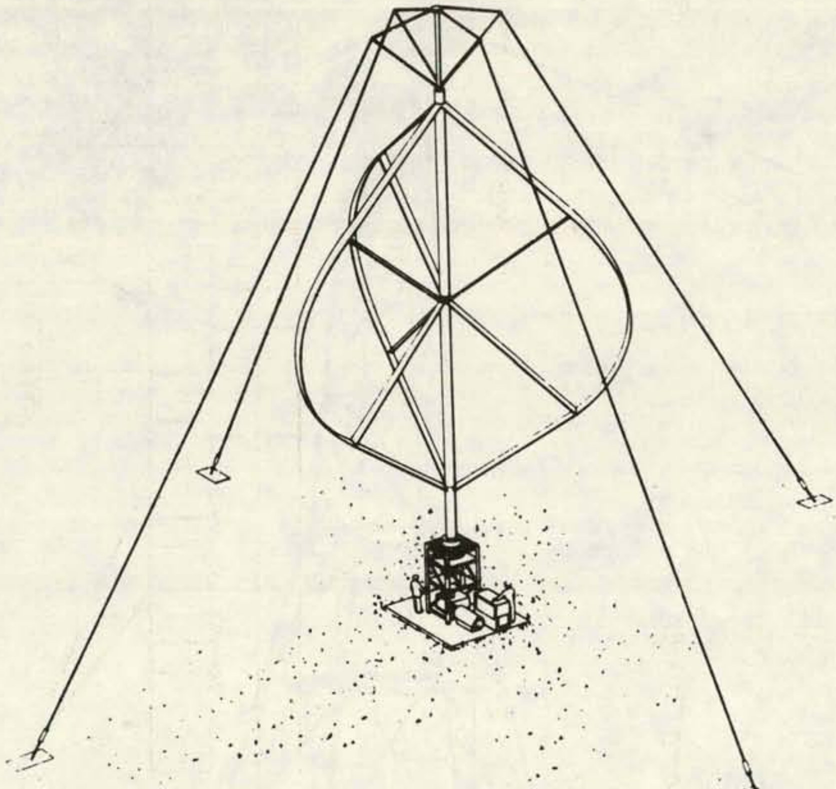

Fig. 35 Vertical axis wind turbine

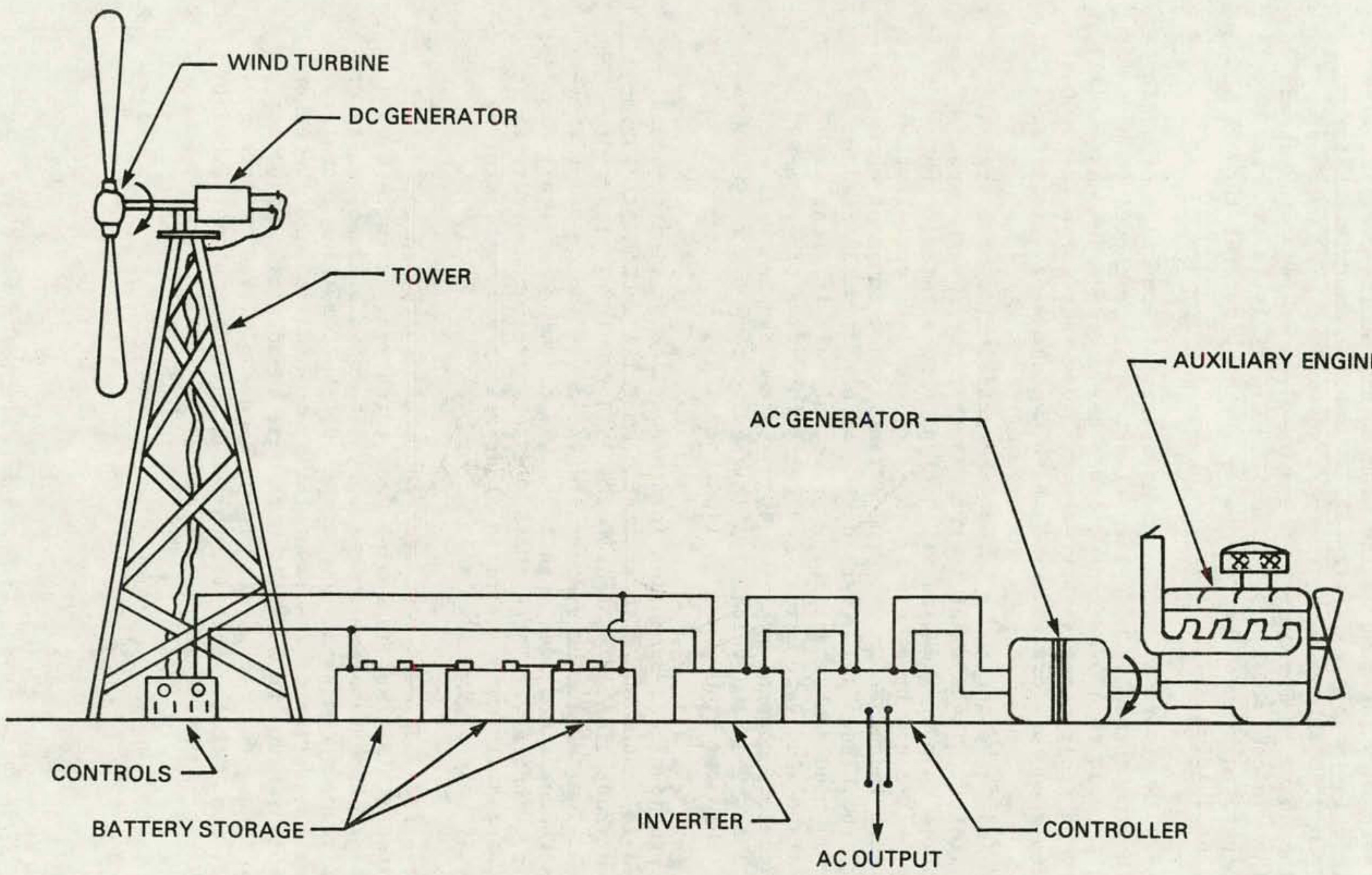

Fig. 36 Schematic of a wind power system

SOLAR-EGYPT-99

3.4.3 Cost estimates and system economics: Table 15 lists some manufacturers of commercially available wind turbines. The design and performance characteristics of selected systems, along with their costs, are shown in table 16. The cost of the wind turbine units over the size range of interest is indicated in figure 37. Small commercial units cost L.E.1,300 to 3,300/kW based on their rated wind speeds, which are generally in the 10 to 15 m/s range. Costs based on average wind speeds of about 6 m/s are closer to L.E.3,300 to 10,000/kW. It is expected that these equipment costs can be reduced by 20 to 40 percent through manufacture in production quantities.

As indicated in figure 37, there are substantial economics of scale associated with wind turbines. The larger systems are expected to have a cost in the L.E. 530 to 800/kW range, once they are made in substantial numbers, with some projections as low as L.E. 350/kW for large (2-5,000 kW) systems, designed for locations with high average wind velocities.

Figure 38 indicates the power output characteristics of a typical small wind generator. The salient feature is that the power output increases with the cube of the wind velocity up to the rated output (which usually is limited by generator capacity for cost optimization reasons). Further increases in wind speed result in a constant output by "feathering" the blades. The very strong effect of wind speed on output results in wind generators being practical only in areas with rather high average wind velocities, generally in excess of 4.5 m/s. As previously indicated, coastal areas of both the Red Sea and Mediterranean Sea have average wind velocities in the 5.5 to 7 m/s range, which makes them suitable for wind power applications.

Table 17 provides cost summaries for three sizes of wind turbines. The 6 kW system is consistent with present commercial equipment, assuming a 25 percent reduction in present costs as a result of higher production levels. The two larger systems are based on studies of utility-sized systems produced in modest quantities and assuming no significant improvements in technology. These costs are relatively conservative, and could be reduced if improvements in blade design and manufacturing techniques, etc., take place.

The first series of costs represent equipment purchased and installed in the United States (not including land purchases, taxes, etc.). The second series of costs assumes that only the rotor blades, generator, and power conditioning equipment are purchased; the remaining costs are based on the selling price of the raw materials needed to make the other system components (which are assumed to be made in-country) and do not include labor. Thus, the second set of costs can be viewed as foreign exchange costs, money that either leaves the country or is sacrificed by the internal use of materials.

TABLE 15

MANUFACTURERS OF COMMERCIAL WIND ENERGY CONVERTERS*

Amercian Wind Turbine Company

Electro G.m.b.H., Switzerland

Grumman Energy Systems

Dunlite Electrical Company PTY., Australia

Dominion Aluminum Gabricatng, Ltd., Canada

Lubing Maschinenfabrik, Germany

Sencenbaugh Wind Electric Company

Aerowatt S.A., France

Dyna Technology, Incorporated

Aermotor Water Systems

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*Several more companies (both large and small) have recently entered the wind turbine field. It is expected that by 1985 many more small wind machines will be available than today.

TABLE 16

COST OF WIND GENERATOR SYSTEMS

PARTIAL LIST OF COMMERCIALLY AVAILABLE WIND MACHINES

MANUFACTURER	MODEL	OUTPUT RATING (kW)	RATED WINDSPEED (m/s)	SWEPT AREA (m/s)	EQUIPMENT[1] COST (L.E)	ESTIMATED OUTPUT IN 6.25 m/s WIND (kW)
Aerowatt	150 FP7	0.1	7.2	3.27	2,375	0.08
Wincharger		0.2	10.3	2.63	430	0.05
Aerowatt	300 FP7	0.275	7.2	8.35	3,830	0.25
Aerowatt	1100 FP7	1.1	7.2	20.3	6,870	1.0
Electro	WV 15G	1.2	10.3	7.07	2,025	0.31
Kedco	1200	1.2		10.5	1,200	–
Dunlite	2000	2.0	11.2	12.3	3,090	0.46
Aerowatt	4100 FP7	4.1	7.2	68.7	15,260	3.5
Electro	WV 35G	4.5	10.7	15.1	3,710	1.10
Electro	WV G50G	6.0	13.4	19.6	4,180	1.21
Grumman	WINDSTREAM	15.0	11.6	45.6	14,580	3.30
DAF[2]	6.1m	7-14		29.2	10,000	

1 Includes tower, generator, and controls.

2 Vertical Axis Wind Turbine, available as prototypes only.

Sources: 1) J. Obermier and H. Townes. "An Economic Evaluation of Small Scale Wind Powered Electric Power Generation Systems," American Society of Mechanical Engineers Paper No. 76-WA/ENER-1, December, 1976.

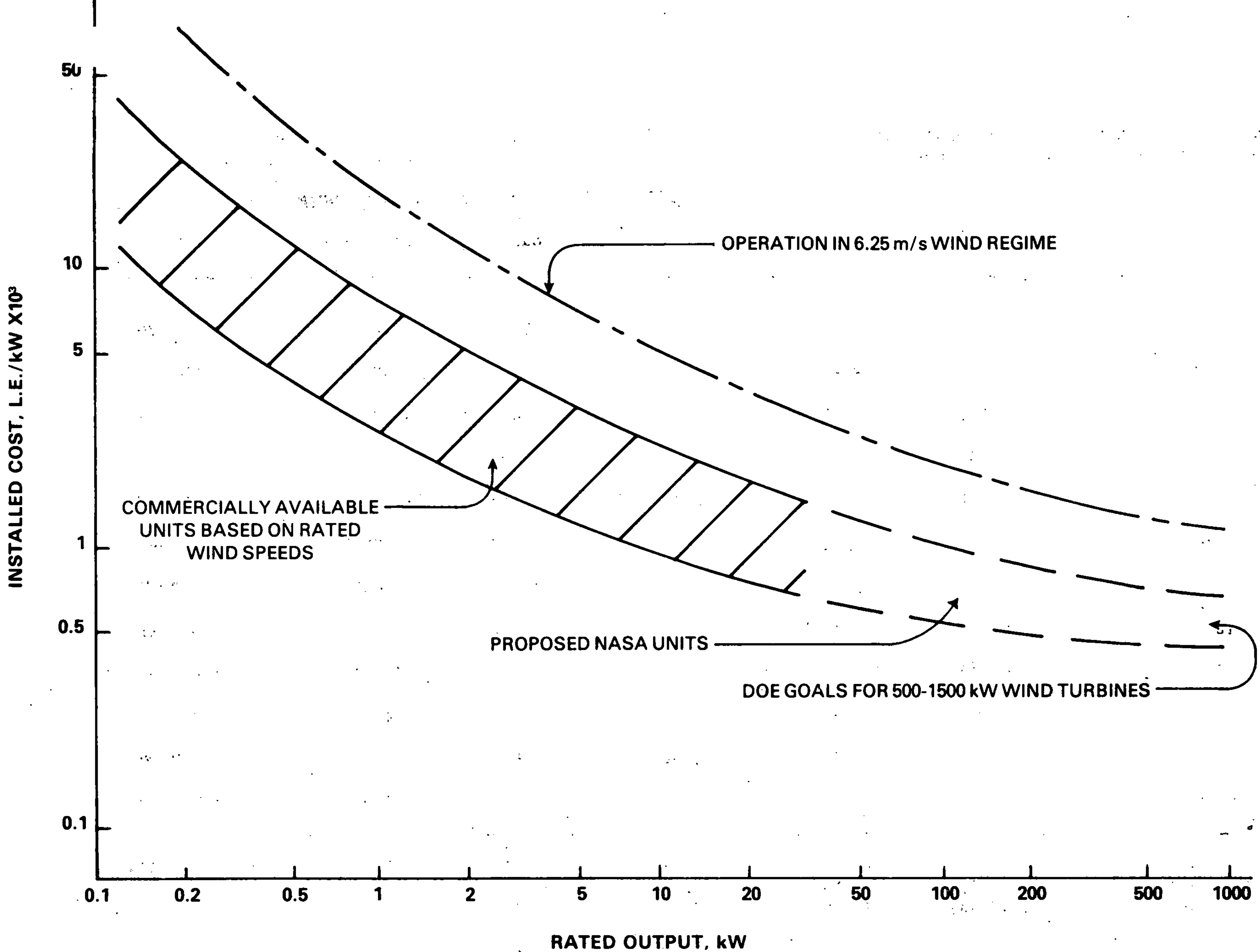

Fig. 37 Cost of wind generators

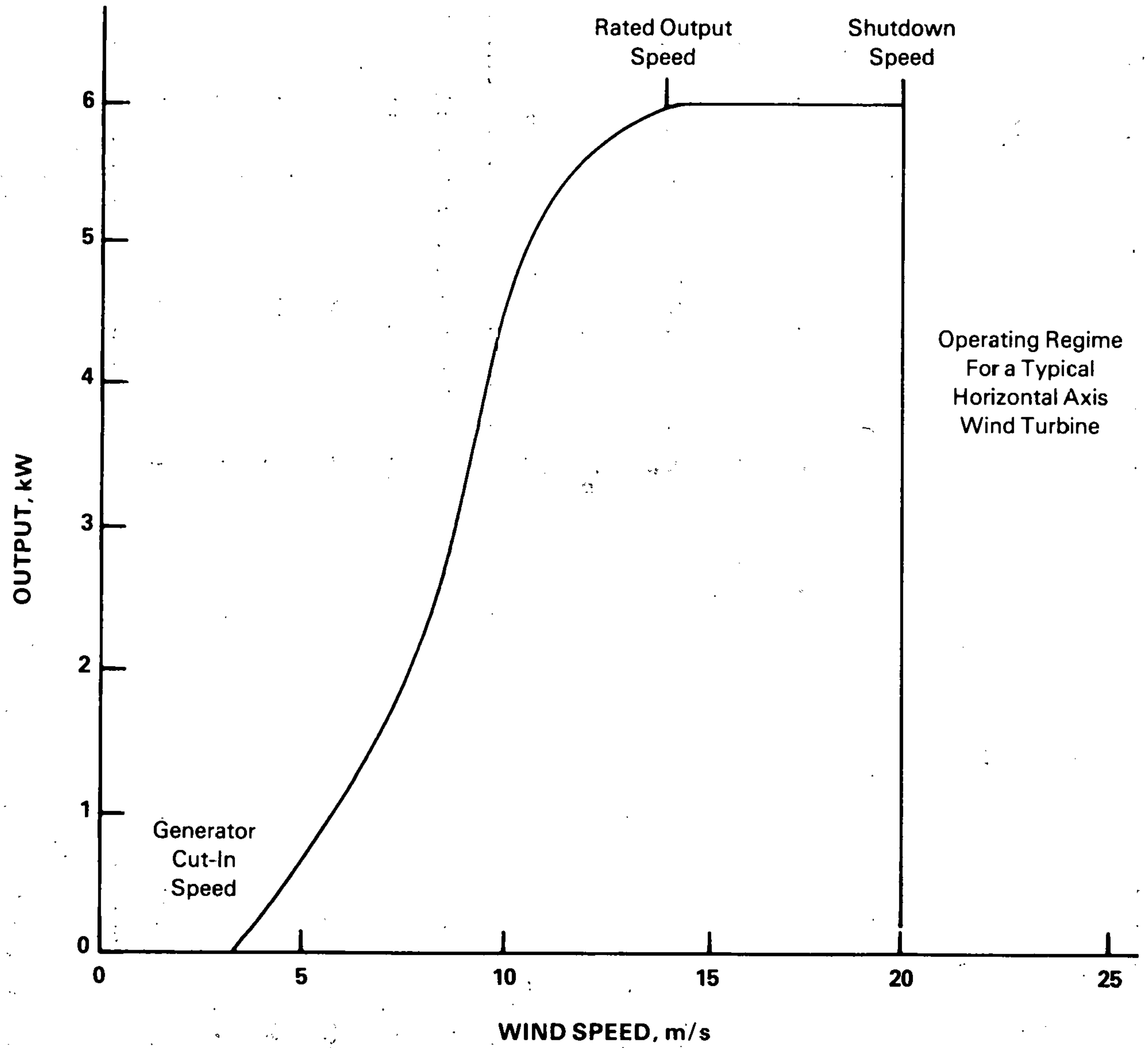

Fig. 38 Effect of wind speed on power output for a commercially available wind turbine

TABLE 17

EXPECTED COST SUMMARY FOR 3 SIZE WIND TURBINES (in L.E./kW)

Nameplate Rating	6 kW	100 kW	1,000 kW
Rated Wind Speed	13.5 m/s	8 m/s	8 m/s*
Output in 8 m/s Wind	2.5 kW	100 kW	1,000 kW
Component Cost for System			
Rotor (Blades, Pitch Change, Hub)	-	465 (45)**	295 (50)
Mechanical (Gear Box, Bed Plate, Yaw Control, Shafts)	-	185 (18)	125 (22)
Electrical (Generator, Controls, etc.)	-	110 (11)	45 (7)
Wind Turbine	1,065	760	465
Tower and Foundation	165	265 (26)	125 (21)
Total Equipment Costs	1,230	1,025	590
Transportation, Site Prep., Installation & Testing	670	500	75
TOTAL COST	1,900	1,525	665
COSTS, ASSUMING PURCHASE OF BLADES, ELECTRICAL EQUIPMENT, AND MATERIAL ONLY			
Blades	265	235	150
Electrical & Power Conditioning	165	105	45
Steel	65	45	25
Concrete	35	20	5
TOTAL EQUIPMENT COST	530	405	225

* Measured at 15 m height.

** Percent of total equipment costs.

TABLE 18

ECONOMIC PERFORMANCE OF 3 SIZES OF WIND TURBINES

	Cost of Power in Hurghada pt/kWh		
	6 kW	100 kW	1,000 kW
Installed Cost (USA)	5.0	4.6	2.0
F.E. Cost*	1.1	0.87	0.53
	Cost of Power in Mersa Matruh pt/kWh		
	6 kW	100 kW	1,000 kW
Installed Cost (USA)	8.2	7.5	3.3
F.E. Cost*	1.5	1.4	0.80

ASSUMPTIONS:

- Total costs shown in table 3.4.3.
- 4 percent annual operation and maintenance is 3 percent labor, 1 percent materials; labor applies to installed system (USA) costs only.
- 8 percent mortgage.
- 30-year life of equipment.
- 6 kW system uses no batteries or inverters.

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* F.E. Cost refers to foreign exchange costs associated with materials and purchased components.

Table 18 summarizes the economic performance of the wind turbine candidates outlined in table 17, when operating in the wind regimes of Hurghada on the Red Sea and Mersa Matruh on the Mediterranean.

As indicated, the higher average wind velocity available on the Red Sea coast favors the use of wind power in this area. The cost of power based on total installed system costs is about 6 pt/kWh for small systems and decreases to 2 pt/kWh for the larger systems.

If only the cost of materials and purchased components is considered, the cost of power ranges from 0.5 pt/kWh to about 1.1 pt/kWh. The cost of power from wind systems of advanced design appears to be very favorable in these coastal regions, particularly based on the foreign exchange portion of overall system cost (materials and components).

It should be noted that if storage and AC power are necessary (to run certain types of motors, etc.), extra components for the 6 kW system will be necessary, and the cost of power will increase 15 to 50 percent, depending on the type and size of inverters and storage batteries needed.

Table 19 indicates the use of materials and labor to fabricate and install wind energy systems. All figures have been normalized to 1 kW of capacity and use the 100 kW system and the 1,000 kW system for the

TABLE 19

MATERIAL AND LABOR REQUIREMENTS FOR MANUFACTURE AND INSTALLATION

MATERIAL	100 kW	1,000 kW
Steel	400 lbs/kW	200 lbs/kW
Copper	5 lbs/kW	2 lbs/kW
Concrete	1,500 lbs/kW	650 lbs/kW
Fiberglass & Resin	50 lbs/kW	25 lbs/kW
LABOR*	**100 kW**	**1,000 kW**
Manufacturing	137 person-hrs/kW	100 person-hrs/kW
Foundation	5 person-hrs/kW	4 person-hrs/kW
Site Preparation	2 person-hrs/kW	2 person-hrs/kW
Transportation	1 person-hrs/kW	1 person-hrs/kW
Assembly & Installation	10 person-hrs/kW	8 person-hrs/kW
	155 person-hrs/kW	115 person-hrs/kW

* Based on large quantity production and Egyptian labor practices.

baseline designs. Wind generators are primarily an assemblage of fabricated steel parts, which require only a modest technology input for their manufacture. Exceptions may include the large, high precision blades (presently made mostly of aluminum, with fiberglass and resin also being considered) and the hermetically sealed generator subsystems. The blades and hub for the WTG require the most labor of all the components of the system. The assembly and erection would require trained crews, especially for the final assembly and checkout. It has been estimated that a United States crew would consist of 50 persons; and each crew would assemble, erect, and check out 10.5 units per year.

<u>3.4.4 Implementation scenarios</u>: The economics of wind power units appear to be reasonable as compared to the operation of small engine-driven generators or pumping systems. With appropriate government policies and incentives, small, internally manufactured wind turbines of conventional design could be implemented in Egypt in an early 1980's time frame. The manufacture and installation of larger wind turbines of 200 kW to 1 MW capacity could be initiated in the mid-1980's, once they have been fully developed and tested in the United States.

The comparison case scenario (Case A) of table 20 assumes that only wind power units of small capacities (typical of present commercial practice in remote areas) are used until the mid-1980's. This modest implementation rate still would require that the government subsidize wind power units to the same extent as fuel used in engine driven generating equipment.

The accelerated wind power scenario assumes that a commitment is made to use wind power on a large scale to supplement power from conventional sources. In this scenario, large units (500 to 1,000 kW) are installed in significant numbers in favorable areas of the Red Sea and Mediterranean coasts.

The Case B implementation rate of figure 39 results in an installed capacity for an 8 m/s wind site of about 32 MW in 1985, 272 MW in 1990, and 1,048 MW in 2000. The average capacity factor at this nameplate rating is 0.5 for the Red Sea area and 0.3 for the Mediterranean coast. Assuming a 2/3 to 1/3 split between these locations, the annual power generation corresponding to the implementation rate of figure 39 is shown in figure 40.

<u>3.4.5 Resource requirements</u>: The implementation scenarios outlined above result in the annual resource requirements outlined in table 21. This use of materials for the accelerated option represents only 0.5 percent of projected steel and less than 0.1 percent of cement production for 1990. The labor requirements indicated are quite modest, even for the high implementation rate scenario, and therefore, labor availability should not be a constraining factor.

TABLE 20

WIND TURBINE IMPLEMENTATION SCENARIOS

THROUGH THE YEAR:	CASE A SMALL*	CASE A LARGE**	CASE A TOTAL	CASE B SMALL*	CASE B LARGE**	CASE B TOTAL
1980						
Number	10	0	10	100	0	100
Capacity (kW in 8m/s wind)	25	0	25	250	0	250
1985						
Number	260	0	260	1,700	160	1,860
Capacity (kW in 8m/s wind)	650	0	650	4,500	28,000	32,500
1990						
Number	920	155	1,075	2,000	570	2,570
Capacity (kW in 8m/s wind)	2,300	45,500	47,800	9,500	263,000	272,500
2000						
Number	2,420	1,125	3,545	7,800	2,160	9,960
Capacity (kW in 8m/s wind)	6,050	357,500	364,000	19,500	1,029,000	1,048,500

* Refers to units typical of present commerical status 2 to 3 kW in 8 m/s wind.
** Refers to units in the 100 to 1,000 kW capacity range.

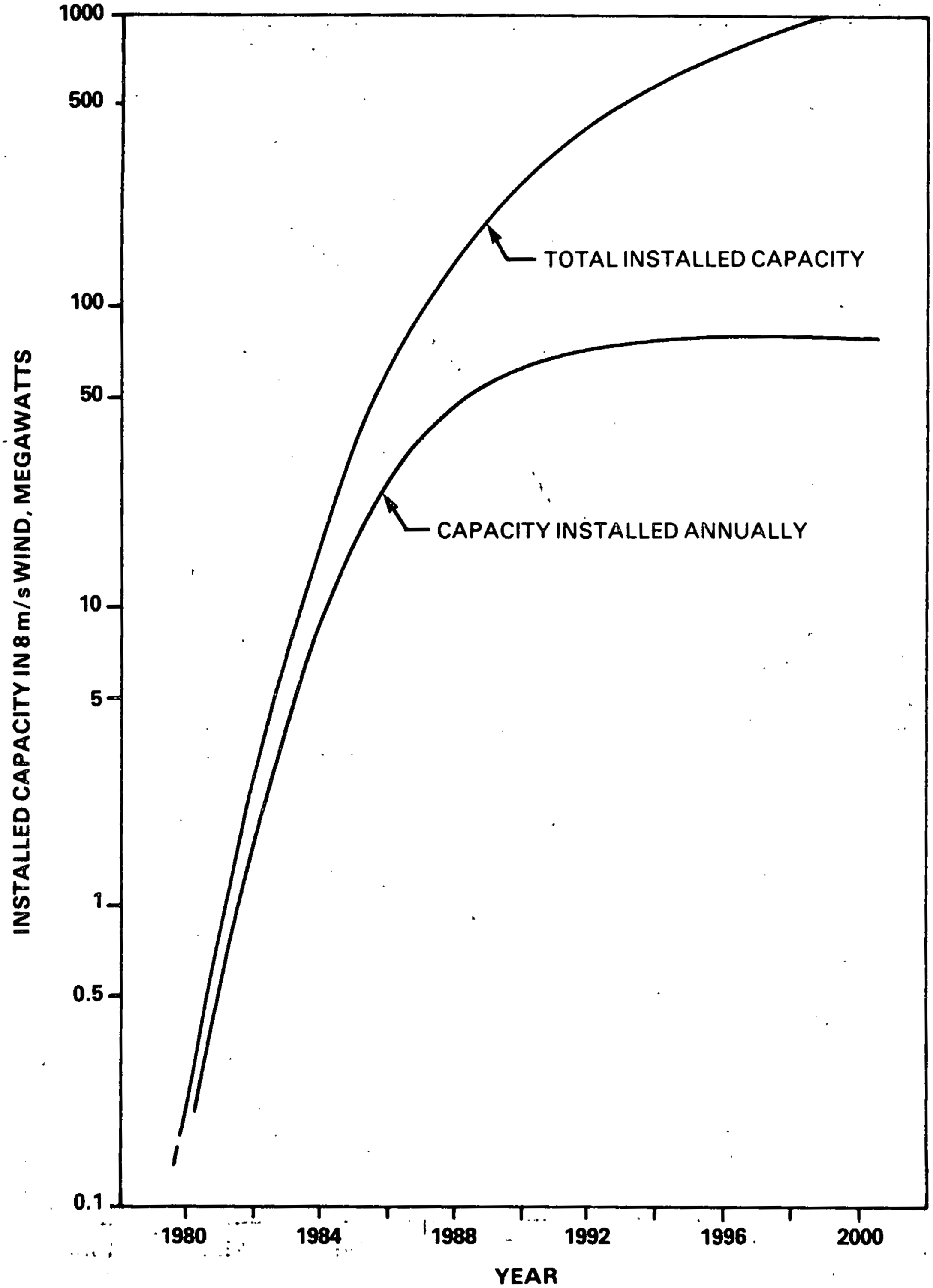

Fig. 39 Accelerated wind turbine installation scenario

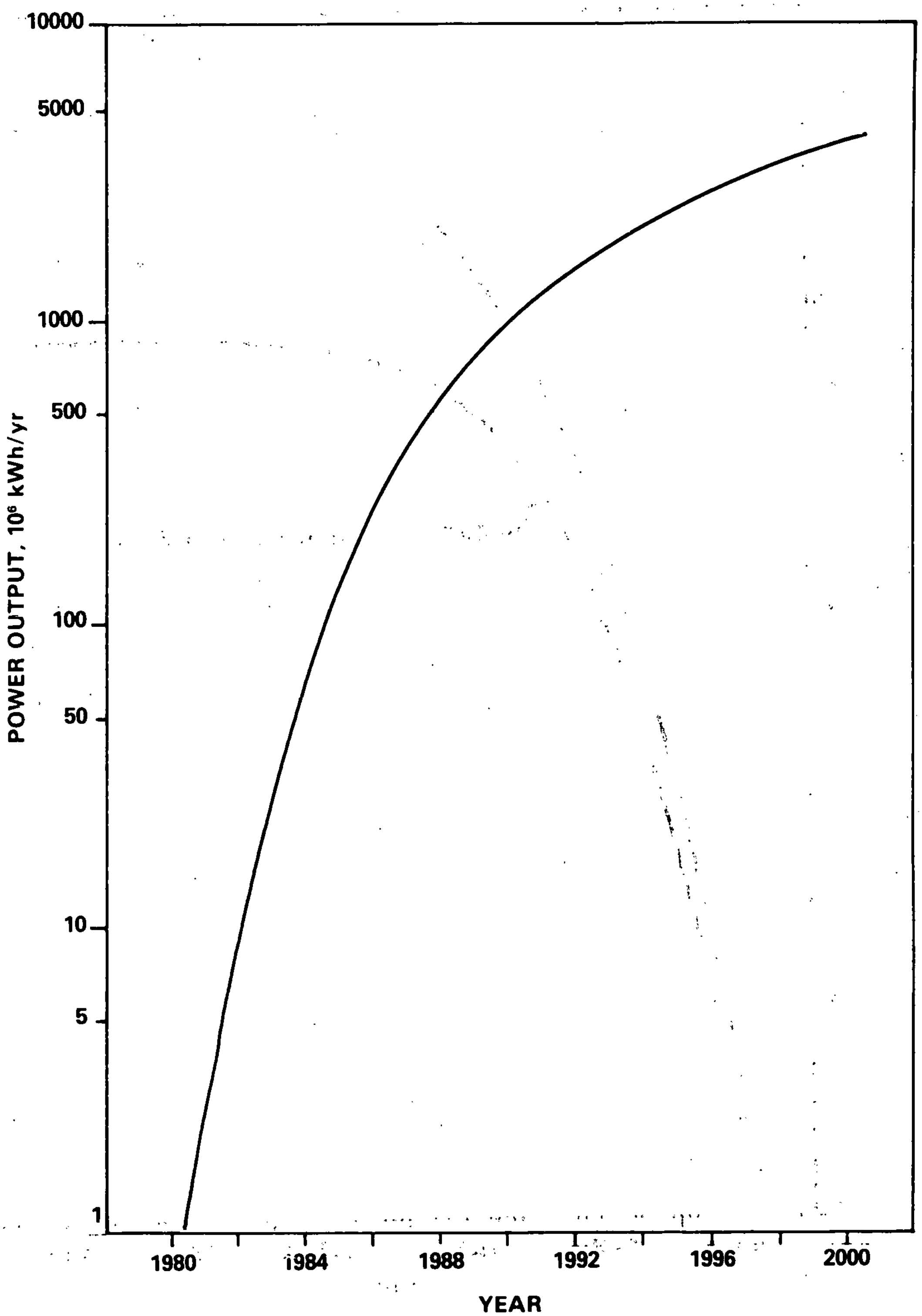

Fig. 40 Annual power output for accelerated wind power program

The operation and maintenance requirements associated with the installation scenarios also are indicated in table 21. For the rapid implementation scenario in the year 2000, a total of 5,400 people are needed to operate and take care of the country's wind turbine installations. This is a slightly greater portion of the labor force than will be used to manufacture the wind tubines installed in that year. This is primarily due to the cumulative nature of equipment installations, i.e., equipment is only fabricated once, but it must be operated and maintained throughout its useful life.

Based on a commitment to large-scale use of wind power, a more in-depth study of resource requirements should be implemented to verify the results outlined above.

3.4.6 Land use: Figure 41 indicates the total area of land used for Case B wind energy conversion through the year 2000. The wind turbines are assumed to have a spacing of 15 rotor diameters between units. Based on the distribution of wind units outlined in the previous section, approximately 1,430 km^2 would be utilized around Hurghada and 830 km^2 around Mersa Matruh. However, it is important to note that the land at the base of the towers still could be used, for example, for agricultural purposes, if suitable, since the wind turbine will be placed at a high enough altitude to assure even wind flow, and would not pose a problem for ground based activities.

3.4.7 Institutional/environmental considerations: Wind power is a relatively benign energy source. There would be no air or water pollution, either particulate or thermal. As indicated above, the land around the base of the tower still is available for other purposes. As with any large structure, wind turbines will have an impact on the local scenery. In addition, concern has been expressed that the large rotating blades (particularly if they are of all metal construction) will have an adverse affect on local communications, such as radio and TV broadcasts, etc., and also that such systems might have an effect on migratory birds. Certainly, such issues deserve attention before large scale implementation of wind power systems; however, in light of current concerns over fossil and nuclear fueled power plants, these considerations do not seem to be of great significance.

3.5 Biomass Utilization

3.5.1 Introduction: Presently, biomass in the form of agricultural residues is the major energy form used in rural areas for cooking and for heating water. In a sense, therefore, Egypt already makes use of its major biomass resource as an energy form. However, the present use

TABLE 21

RESOURCE REQUIREMENTS FOR WIND POWER INSTALLATION SCENARIOS

	1985		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
MATERIAL REQUIREMENTS (Short Tons)						
Steel	80	2,900	3,600	8,200	4,700	10,000
Copper	2	38	40	90	50	110
Cement	44	2,000	2,400	5,400	3,200	6,600
Fiberglass & Resin	0	300	420	940	550	1,200
FINANCIAL REQUIREMENTS (L.E. 10^6)						
Materials & Purchased Components	0.11	5.6	8	18	10	22
Labor	0.27	14.4	17	37	22	46
O&M*	0.03	1.2	1.8	10	14	40
MANPOWER REQUIREMENTS (Persons)						
Technical/Management	5	70	100	220	120	280
Manufacturing/ Installation	30	1,210	1,730	3,920	2,180	4,960
O&M	4	180	250	1,400	1,880	5,400

* Includes both materials/components and labor.

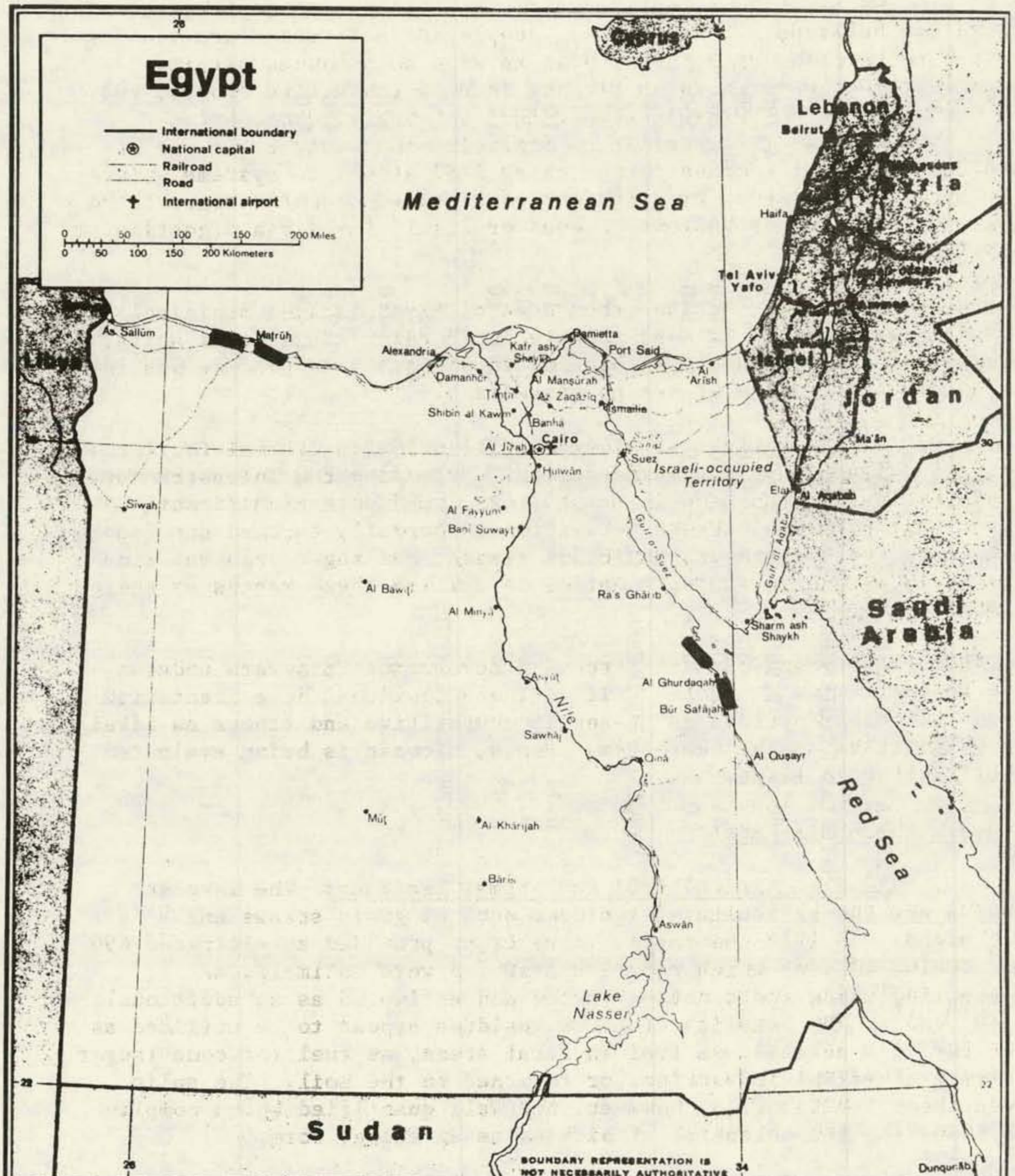

Fig. 41 Land area use for wind energy conversion systems (accelerated installation case, year 2000)

of biomass in Egypt often involves open fire stoves which are inconvenient to use and may pose a health hazard due to heavy concentrations of smoke in the building. Consequently, people in rural areas are tending to switch to kerosene or butane stoves as soon as finances permit. Also, the present ways in which biomass is used (open fire stoves, mud oven, etc.) are very thermally inefficient (probably 10 percent or less). The above factors provide an incentive to consider the use of agricultural-residue biomass resources as feed stocks to systems which either burn the feedstock by efficient power systems and/or convert the biomass to clean and convenient gaseous or liquid fuels via digestion or pyrolysis processes.

Sources of biomass in the urban area of Egypt include municipal solid wastes, which can be used to fire incinerator/steam power units, and municipal sewage, which can be used in digesters to produce gas for operation of I.C. engine driver power units.

The principle problems of biomass utilization in central facilities are in its collection and transportation. Providing the infrastructure for this collection function in rural areas could pose significant institutional problems. Where collection is normally carried out (such as municipal wastes-garbage, municipal sewage, and sugar cane and rice processing), it can be a simple matter to utilize these wastes as energy resources.

The current aggressive research and development programs underway in the United States to better utilize these residues have identified various technology options as presently competitive and others as likely to be competitive in the near-term. Hence, biomass is being evaluated for utilization in Egypt.

3.5.2 Resource base:

3.5.2.1 Agricultural and animal residues: The largest resources are the agricultural residues such as grain straws and cotton stems. In 1974 the energy value crops provided an estimated 690 X 10^{15} joules (J), of which some 230 X 10^{15} J were estimated as residues (including roots not harvested and estimated as an additional 35 X 10^{15} J)*. The totality of these residues appear to be utilized as fodder for farm animals, as fuel in rural areas, as fuel for some (sugar and rice processing) industries, or returned to the soil. The split between these functions is, however, not well quantified which complicates assessing the potential of biomass as an energy form.

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*Rural biomass availability estimates obtained from, A Preliminary Assessment of the Egyptian Enery Outlook, February, 1978.

Animal residues are usually collected locally and either dried and burned or returned to the soil for fertilizer. Animal residues are estimated to be the equivalent of 40 to 80 x 10^{15} J, annually. The combined energy value of agricultural and animal residues is, therefore, 270 to 310 x 10^{15} J.

<u>3.5.2.2 Urban biomass resources (sewage and municipal solid wastes)</u>: Human wastes contained in urban sewage systems are a potential source of energy. The potential annual energy available would be approximately 2 to 3 X 10^{15} J assuming only those urban areas served by central sewage systems.

Wastes of human activities contain organic material arising from food, newspaper, packaging, and similar sources. In the United States, this resource is generated at the rate of about 2.5 kg per person per day. Assuming that Egypt is substantially less wasteful than the United States, the per capita availability in Egypt may be about .25 kg/day per capita which results in about 17 X 10^{15} J of energy value from municipal wastes in urban areas.

The biomass resources in rural areas, as a result of agricultural activities, are seen to be an order of magnitude higher than the resources in urban areas. However, the sewage and municipal wastes already are collected at central locations as part of the normal treatment and/or disposal procedures thus greatly facilitating use of these wastes in energy conversion systems.

It should be emphasized, however, that people in developing countries collect and recycle much of what is considered "urban wastes" in industrialized countries. Consequently, even the relatively low per capita waste generation indicated above, will have to be verified before accurate assessments can be made of the potential of this energy source.

<u>3.5.3 Technology status</u>: The two most practical ways of utilizing biomass as an energy resource in Egypt are direct combustion and digestion.

<u>3.5.3.1 Direct combustion</u>: The present use of agricultural residues as fuel for stoves and ovens is one form of direct combustion. An alternative use of the energy value of the biomass would be to use it in modern incinerator/boiler systems. The steam so produced can be used to operate steam turbine systems to generate electric power. Such systems are used increasingly in large cities of industrialized countries as a means of disposing of municipal solid wastes, and in conjunction with large pulp and paper facilities where large quantities of wood wastes are available as part of normal operations.

There are two types of systems in general use in comparable numbers, the spreader stoker and mass burning. The first method requires the sorting and grinding of the refuse before burning and therefore produces steam more efficiently but requires more operational maintenance. These systems, however, usually use some coal to keep firing while the mass burning method does not. This second mode of incineration requires no refuse preparation and so saves on O&M, but has a lower ratio of stove input to steam output.

Similar systems also could be used in Egypt using municipal wastes or agricultural residues as feedstocks. There are economics of scale associated with incinerator/steam turbine systems which make it uneconomical to operate very small units. The land requirements to supply relatively modest sized units of 5 MW and 25 MW using agricultural residues are indicated below assuming 5 tons/yr of biomass availability per feddan, a capacity factor of 0.7, and that 80 percent of the land in the area is producing biomass.

	5 MW No. of Crops	25 MW No. of Crops
No. of feddans	8,720.0	43,600.0
Area, km^2 app.	36.0	178.0
Radius, km	3.3	7.5
Daily mass required (kg)	86,700.0	434,000.0

The radial distances, assuming the plant to be in the center of the dedicated land area, are reasonable for the size of plant considered. Hence, collection in areas with a high concentration of farm animals and crops with a high percentage of residue appear feasible. The collection problems remain formidable as indicated by the large mass of biomass required per day for system operation.

The population required to supply municipal solid wastes to the above plants would be about 350,000 for the 5 MW plant and 1,750,000 for the 25 MW plant. It appears, therefore, that municipal wastes are limited to firing plants in the capacity range of 10-40 MW.

3.5.3.2 Digestion: Agricultural residues and cow droppings can be used as a feedstock for an anaerobic digester (essentially an enclosed tank containing an aqueous slurry of biomass material) where the decomposition of organic materials results in a gas mixture of carbon dioxide and methane. The resultant gas has a heating value of 18,600 kJ/m^3 (500 Btu/ft^3), or about half that of natural gas. The gas so produced can be used to operate gas stoves (in place of butagas or kerosene) or could be used to operate a specially modified I.C. engine/ generator (per figure 42). The operation of digester units for both family and small village use has been demonstrated using a variety of feedstocks (livestock droppings, night soil, shredded agricultural residues, etc.) with the largest use occurring in China with over 30,000 family-size units.

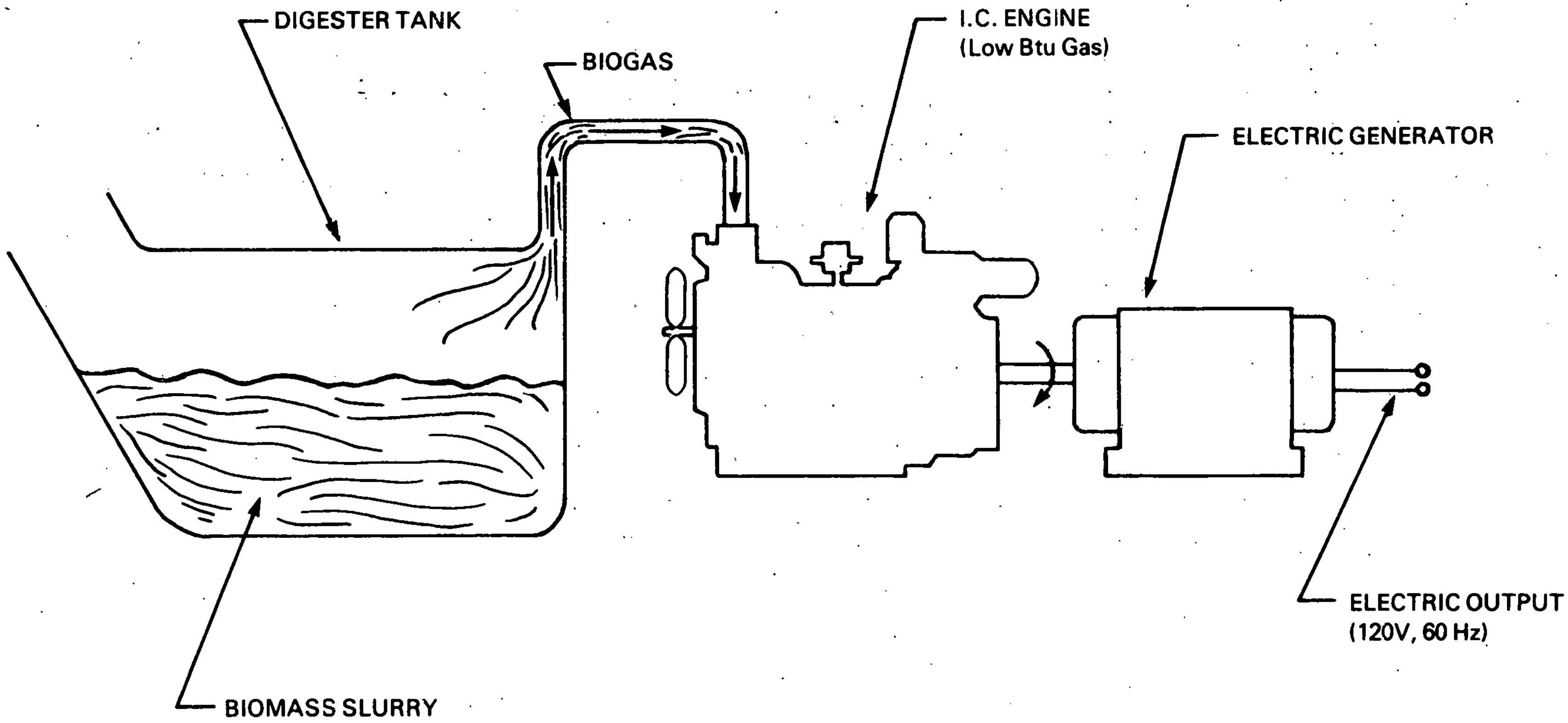

Fig. 42 Biomass fueled power system

An alternative use of the gas is to pipe it (probably via plastic pipes) to villagers' homes for use in place of butagas or kerosene in stoves. This application has advantages over the generation of electric power in that the overall system is considerably simplified, and the output is serving a real need now satisfied by expensive fossil fuels. The disadvantages of this arrangement include the relatively short distances from the digester that the gas can be piped (due to its low heating value) and institutional complications which may result from apportioning gas to different households in a measurable and fair manner.

There are several design options associated with a biomass digester system. The digester tank itself may be built of steel or concrete and the gas produced can be stored in an inverted steel tank over the digester, called floating top storage, or can be compressed and stored in a small pressure tank. The biomass itself can also be mixed periodically by an agitator within the digester to speed gas production. Intermittant agitation (here, stirring the biomass for one hour twice daily) can reduce the digester tank volume for a given capacity system by 50 percent. Also, a hammermill for chopping large chunks of residues before putting it in the digester is sometimes necessary to facilitate the digestion of the biomass. Possible drawbacks to the hammermill and agitation are (1) addition to system costs; (2) an increase in operational complexity; and (3) the need for power to operate.

A design for a village-size biogas unit utilizing agricultural and cattle residue is presented in figure 43. The unit shown would be capable of operating a 3 to 6 kW power unit or of supplying gas to over 70 families for cooking and lighting. These units are constructed of concrete except for a steel cover serving as a floating gas holder. The steel gas holder is approximately one-third of the materials cost. This system would require about 500 kg of biomass per day for its operation.

Figure 44 shows a schematic drawing of a simpler biogas generator typical of designs used as family units in China. Due to their considerable size, flexibility, and relatively straightforward operation, the use of such systems could be quite advantageous in Egypt, particularly if village-sized units are developed and the social/institutional issues associated with providing the feedstock and apportioning the output (gas or electric power) can be overcome.

A major advantage of digestion is that the sludge resulting from the digestion process retains all of the soil conditioning value of the original biomass feedstock and can, therefore, be returned to the soil. This is in contrast to systems where the biomass is consumed by combustion processes (including present use in open fire stoves). The use of the biomass as both an energy form and a soil conditioner can significantly enhance its value by reducing foreign exchange losses associated with fuel and fertilizer use.

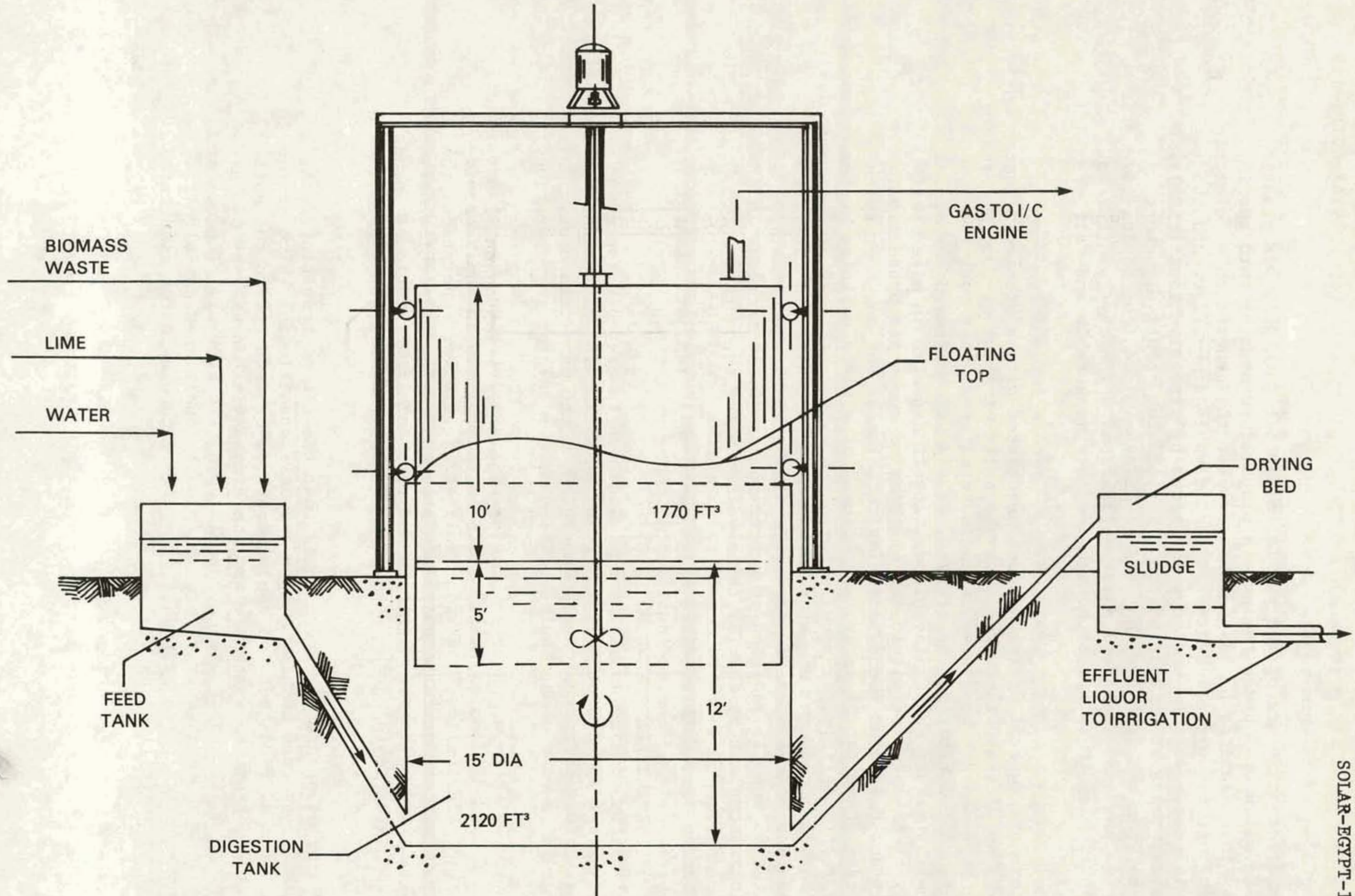

Fig. 43 Conceptual process flow diagram for anaerobic digestion of biomass wastes

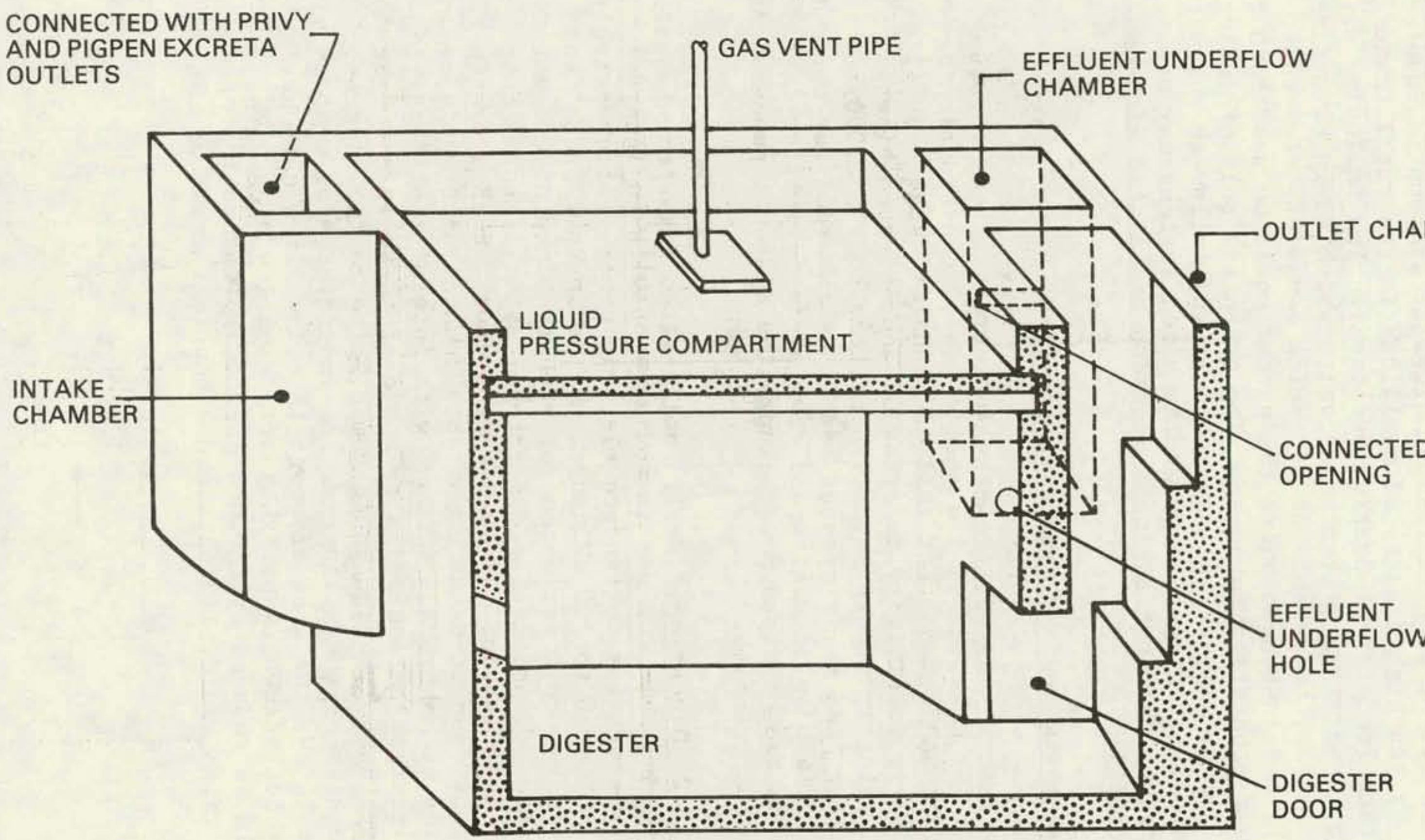

Fig. 44 Enclosed biogas plant section

Most digesters installed to date in developing countries have served individual families and have used human and or animal wastes as their feedstock. The incentive behind such digesters has often included improved hygenic conditions as well as generating gas for household cooking use. The use of such individual digester systems in Egypt may be complicated by the high density of dwellings in the rural towns (to save valuable farm land for productive purposes). The following discussion, therefore, emphasizes village size units which would have flexibility as to location, be capable of accepting a variety of feedstocks (crop residues), and instances where the output could be used both for cooking and power generation purposes. The potential role of individual digesters should not, however, be neglected in any follow-on activities since the technical advantages of community sized systems may often be more than off-set by the institutional problems associated with operating cooperative facilities.

3.5.4 Cost estimates and system economics:

3.5.4.1 Incinerator: Large incinerator/steam turbine systems (1 to 10 MW) make the most economic use of construction materials such as steel and cement, but their demand for large quantities of biomass limits their feasibility to areas of concentrated biomass availability. Typically, these installed systems cost $30,000/ton refuse burned daily, and their present use in urban areas (as part of disposing of municipal solid wastes and sewage) is indicative that for urban applications the combined power generation disposal process can be made economically attractive.

3.5.4.2 Digestion: Small family-sized digester systems are not economically favorable for use in conjunction with an internal combustion engine-generator to produce electric power. Alternatively, larger systems in the 10 to 100 kW range, may be in some cases feasible. Figure 45 shows cost estimates for such combined digester-I.C. engine power systems composed of a concrete digester, intermittent agitator, steel floating top, and engine-generator. Such a system design is chosen because it makes comparable demands on Egypt's cement and steel supplies at an overall minumum with intermittent agitation. Figure 46 demonstrates the economics to scale of these larger systems. These cost numbers do not assign an economic value to the biomass delivered to the site by the villagers. As indicated, for systems with capacities above 10 kW, the cost of power is below 12¢/kWh (9 pt./kWh) and reduces to about 6¢/kWh (4 pt./kWh) at a capacity of 100 kW. These power costs could be reduced by the design and implementation of a manual agitator which would eliminate the electrical drain on the systems output.

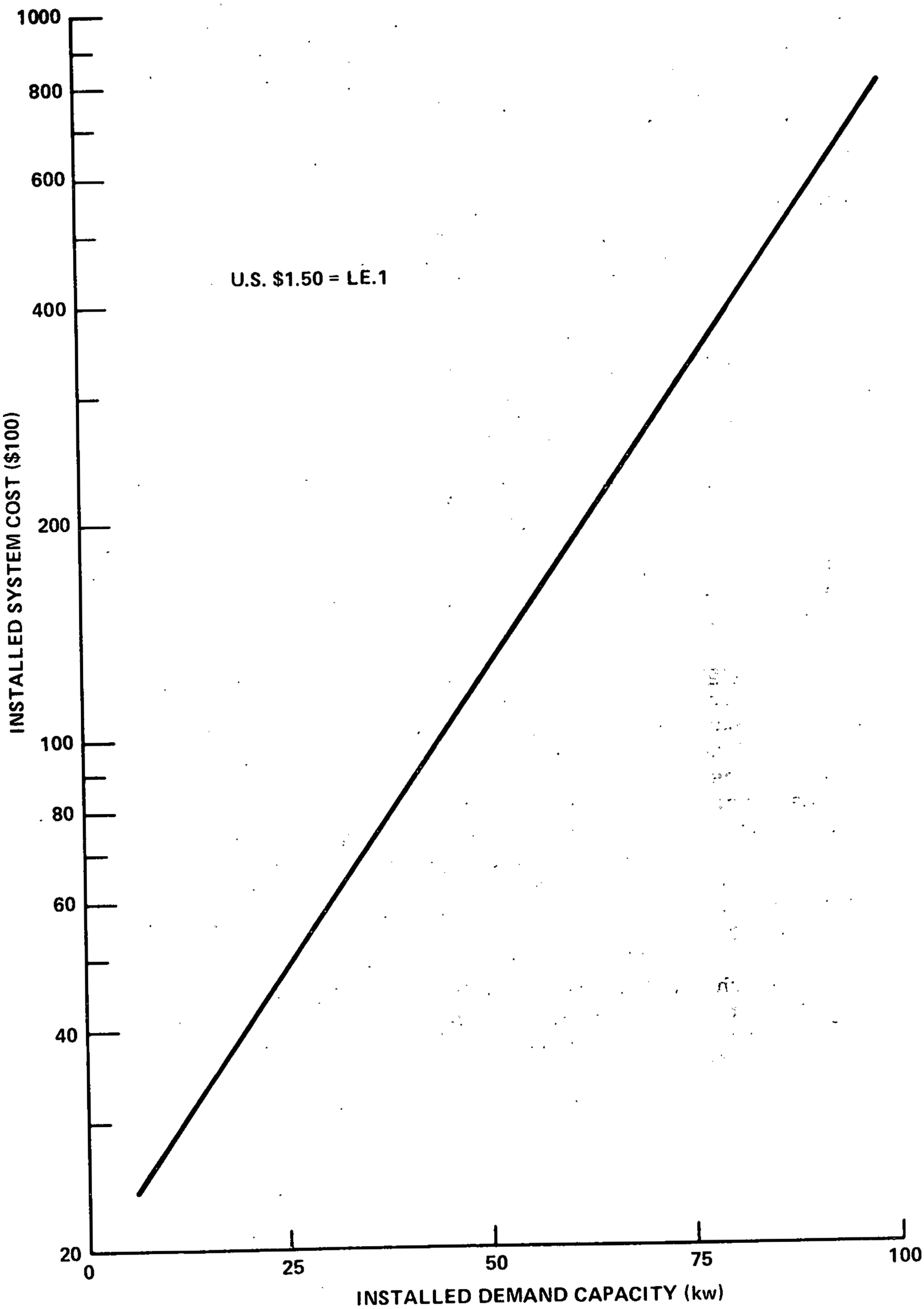

Fig. 45 Installed system cost vs. capacity

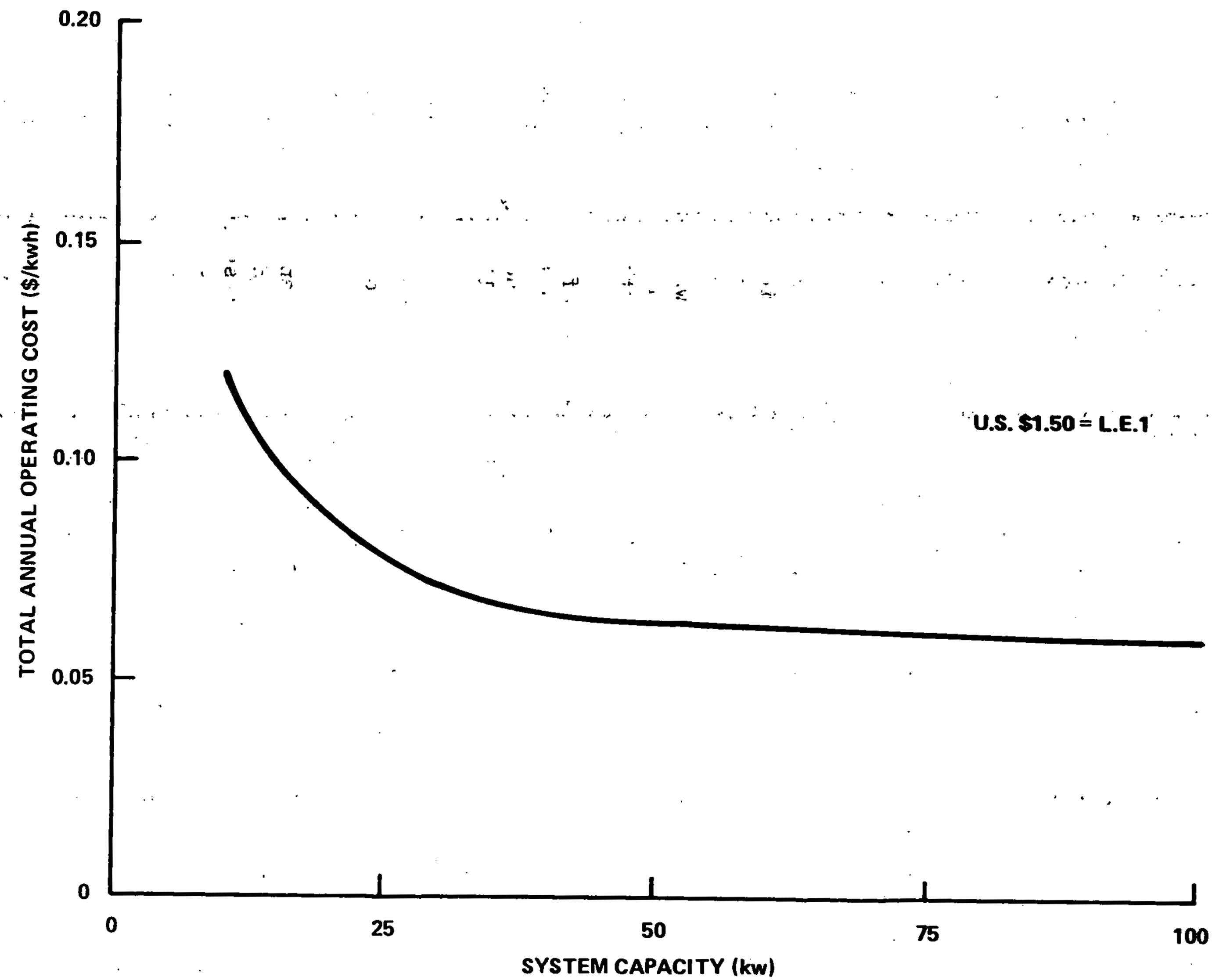

Fig. 46 Annual operating cost vs. system capacity

The cost range of Figure 46 is well within that of diesel generators and indicates the potential of biomass generators in rural areas if the institutional problems associated with biomass collection can be successfully addressed.

3.5.5 Implementation options: The potential of biomass as an energy source is large compared to Egypt's overall energy utilization. For example, if all the agricultural and cattle residues were used to operate power systems, the resultant installed capacity would be about 3,600 MW or comparable to conventional (hydroelectric and thermal) capacity. As a practical matter only a relatively small portion of the biomass probably can be collected and used in biomass conversion systems, due to the competing uses for agricultural residue and the social/institutional problems associated with collection and operation of village- or district-sized units.

The implementation scenario of table 22 requires the collection rate of agricultural residue and manure indicated in table 23 for use of urban wastes (solid wastes and sewage). These contribute up to 25 percent of the total biomass for the accelerated case.

The impact potential of biomass resources (table 24) is seen to be considerable even if the percent utilization of agricultural residues is quite modest. For example, in the accelerated case about 4.5×10^9 kWh of electrical energy could be generated, which is roughly 4 percent of the total requirements of that time. Figure 47 shows the capacity installed annually and the cumulative capacity for both biomass installation scenarios. Their resultant power output is plotted in figure 48.

The scenario of figure 42 assumes all the output of digesters is used in electricity producing functions. As previously indicated, it may be preferable to use the gas for cooking and water heating functions thereby reducing the use of kerosene and butagas. If all the gas produced in Case B in the year 2000 were used for these functions, the equivalent savings in kerosene would be 108 joule quads (JQ). The best way in which to use the output of digesters will require careful study of the needs of individual villages and accurate cost comparisons of system options under Egyptian conditions.

The resource requirements for the implementaion scenarios are outlined in table 25. The material used for the accelerated option constitutes about 0.46 percent of projected steel and less than 0.19 percent of cement production for 1990, making the implementation of biomass systems in Egypt a viable energy option.

TABLE 22

IMPLEMENTATION SCENARIOS

	A			B		
	#	SIZE	CAPACITY	#	SIZE	CAPACITY
1985	14	25 kW	.35 MW	320	25 kW	8 MW
				30	100 kW	3 MW
	14		.35 MW	350		11 MW
1990	280	25 kW	7 MW	480	25 kW	12 MW
	50	100 kW	5 MW	110	100 kW	11 MW
				12	1 kW	12 MW
	330		12 MW	602		35 MW
2000	600	25 kW	15 MW	600	25 kW	15 MW
	100	100 kW	10 MW	150	100 kW	15 MW
	5	1 kW	5 MW	10	1 MW	10 MW
				2	10 MW	20 MW
	750		30 MW	752		60

TABLE 23

AGRICULTURAL COLLECTION RATES
(percent of available residues)

	COMPARISON CASE A	ACCELERATED BIOMASS CASE B
1985	0.01%	0.6%
1990	4.0%	5.5%
2000*	3.5%	10.0%

TABLE 24

ENERGY IMPACT OF IMPLEMENTATION SCENARIO

	1985		1990		2000	
	CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
Installed Capacity (MW)	.42	21	33	180	240	680
Annual Power Generation (10^9 kWh)	.003	0.14	0.21	1.2	1.5	4.5

3.5.6 Social/institutional considerations: The major biomass resources are agricultural and cattle residues generated in rural areas. The rural village residents now have an incentive to collect those residues used within their own household. However, the operation of a village-sized incinerator or digester system will introduce a number of institutional considerations such as who pays for the installation, how to compensate individual villagers for delivered biomass, training and renumeration of operating personnel, and apportionment and rate structure of delivered outputs (gas or electricity).

The use of biomass conversion processes in urban areas will have the positive effect of disposing of municipal waste and sewage in an environmentally accepted manner in addition to the generation of power. This advantage could become increasingly important as the population increases, thereby putting more pressure on urban waste disposal facilities.

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*Assumes increasing levels of agricultural production.

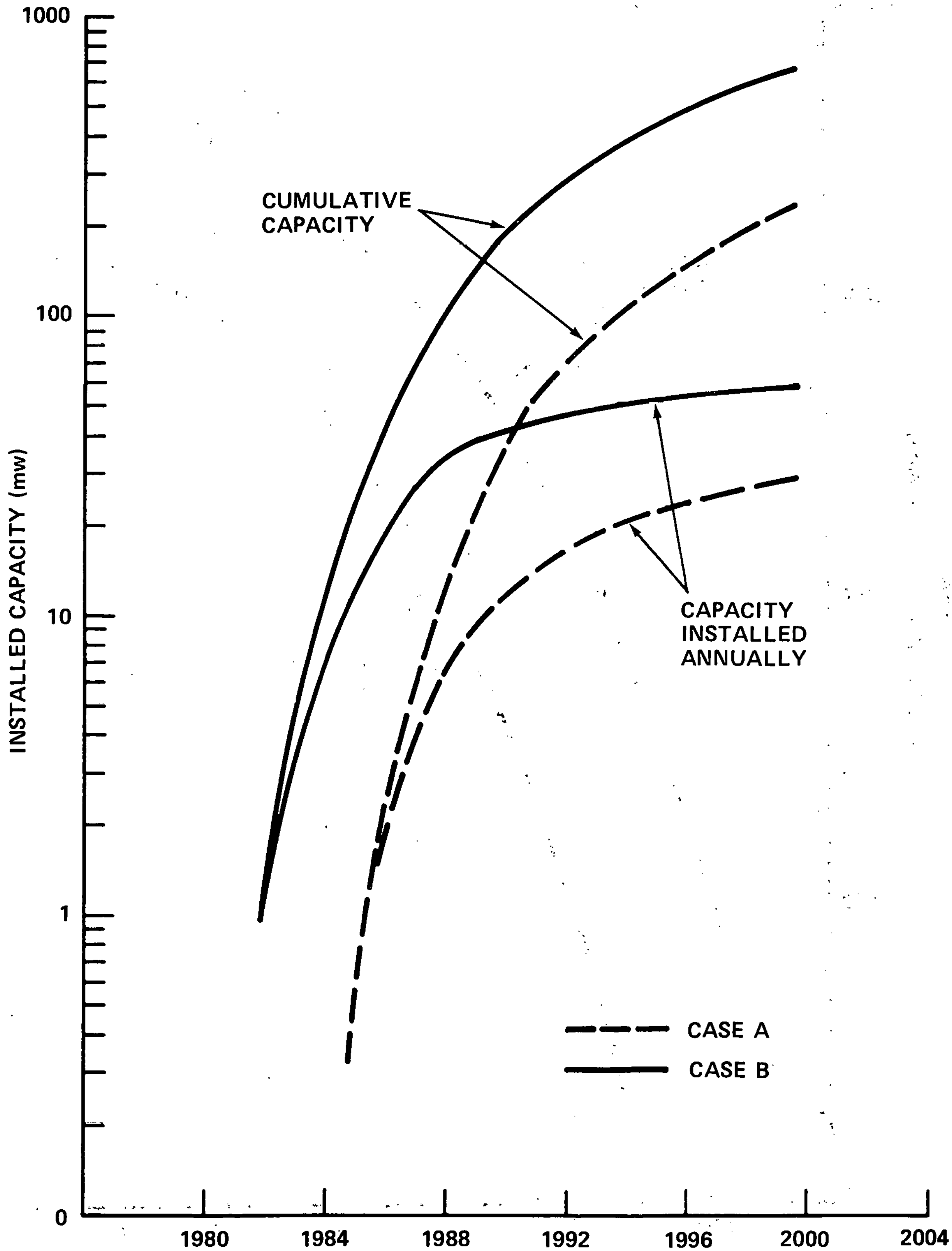

Fig. 47 Biomass installation scenarios

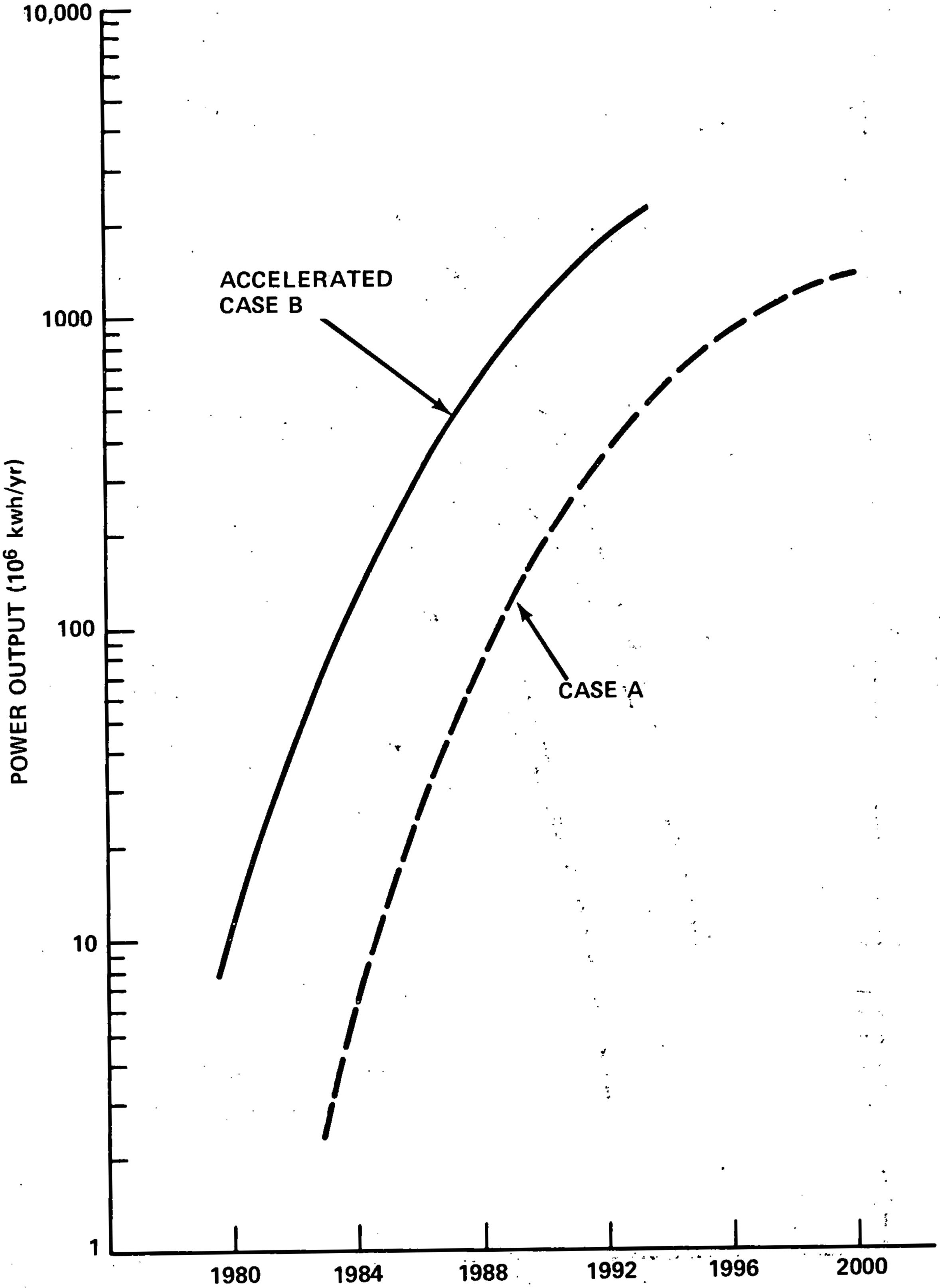

Fig. 48 Annual power output for biomass implementation scenarios

TABLE 25

RESOURCE REQUIREMENTS FOR BIOMASS INSTALLATION

	1985		1990		2000	
	A	B	A	B	A	B
MATERIAL REQUIREMENTS (tons)						
Steel	150	4000	4200	8500	9000	12200
Cement	160	5000	5400	10600	11400	14800
Cooper	.9	25	25	55	55	80
FINANCIAL REQUIREMENTS (L.E. X 10^6)						
Materials/ Purchased Components	.5	14	15	31	36	60
Labor	.3	10	10	20	23	20
O&M	.1	2.9	3.1	6.3	7.5	14
MANPOWER REQUIREMENTS (person-yrs)						
Technical/ Management	2	84	90	184	240	320
Manufac- turing/ Installa- tion	60	1700	1740	3660	4800	6400
O&M	18	480	480	1100	2000	2300

3.5.7 Technical/economic issues: Large-scale incinerators and digesters for use in urban areas are well developed and present few technical or economic uncertainties.

The use of a variety of agricultural residues in digesters, on the other hand, still is not demonstrated at the village level and digester designs and operating procedures must be developed which will allow for a variety of biomass inputs (different combinations of grain straws, stalks, cattle droppings, etc.) while still maintaining effective operation (usually measured by average retention time).

As the use of rural biomass resources increases, a portion of the units which produce power will be connected into the utility grid with the resultant utility interface issues. However, the nature of this utility interface is different than for direct solar or wind power units since biomass-fueled power systems can be operated on demand, similarly to conventional systems.

3.6 Desalination

3.6.1 Background: Many communities remote from the Nile Valley face a scarcity of fresh water for human consumption and for carrying on commercial and agricultural activities. In some coastal areas (particularly on the Red Sea) fresh water is brought in by tanker, while in other areas fresh water is transported by tank truck or produced by small oil-fired desalination systems. All these approaches are costly; thus they inhibit further development in remote areas.

Presently, relatively little energy is used in desalination facilities in Egypt, and large-scale desalination units appear to be considered only for use in conjunction with power plants which are planned for the Mediterranean coast. However, the present emphasis of the government on developing new lands could result in increasing needs for fresh water beyond that available from local resources and, consequently, desalination could be an important aspect of future development plans.

Solar energy is well-suited for driving desalination processes due to its universal availability in Egypt and the favorable economics of being able to store output in the form of fresh water.

The distilling of seawater and brackish water was one of the earliest practical applications of solar energy. A system was built in Chile in the late 1800's and systems are operating today in Greece, Mexico, and Australia. There still is a great deal of interest in this subject and one of the groups engaged in research and development is the National Research Center in Egypt. To date, however, solar desalination has not been used to any significant degree in Egypt.

Most solar distillation units (solar stills) have utilized some form of the humidification process. This system arrangement is shown schematically in figure 49. The operation of this system is the essence

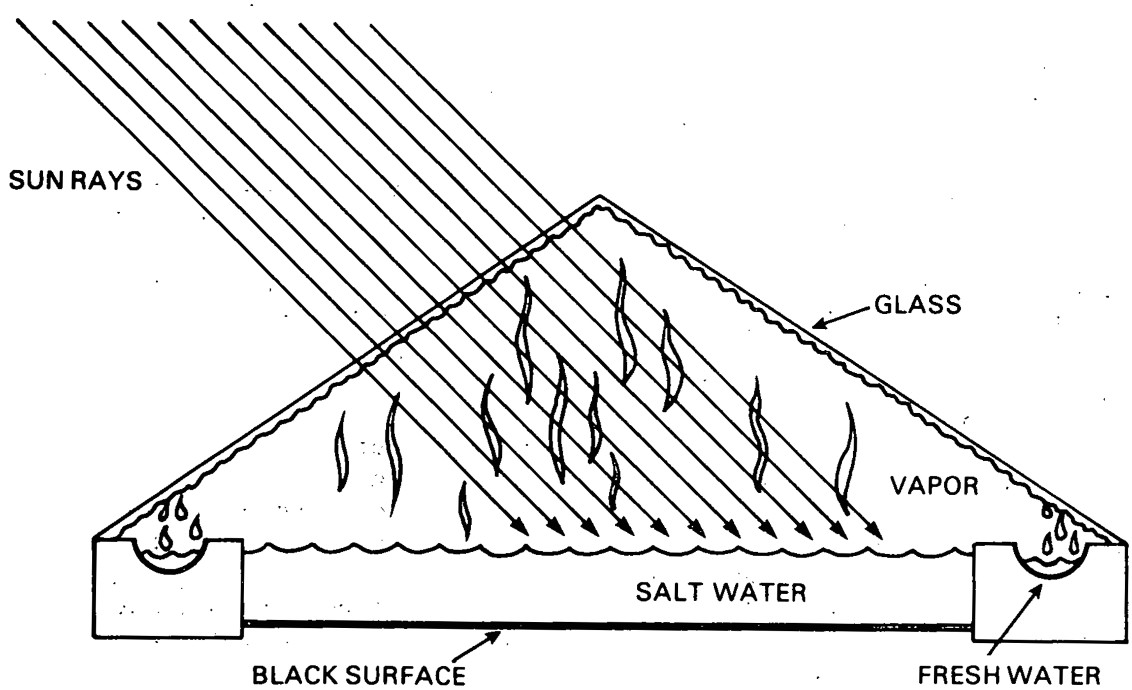

Fig. 49 A simple solar still

of simplicity which helps explain its predominant role in solar desalination. Solar energy passes through the glass (or plastic) cover and is absorbed by the water contained in a shallow pond.

The vapor above the solar heated water (typically at a temperature of 45 to 70°C) condenses on the relatively cool cover plate and dribbles down to a trough and then to a collection point. Much work has been done to lower the cost and improve the efficiency of the solar humidification process. The performance of this arrangement is, however, subject to several fundamental limitations.

- Since there is one stage of evaporation, each kilogram of water requires over 555 kcal of energy input for the purification process, and

- The basic heat transfer processes are such that the thermal efficiency must be in the 40 to 60 percent range.

As a result, the humidification process requires at least 0.2 M^2 of collector area for each liter per day of capacity. Even with the above limitations, desalination with the solar humidification process is a reasonable choice for systems of limited capacity, because of its simple construction and operation.

For larger systems, however, which might service entire communities it may be preferable to utilize solar energy to drive more energy efficient desalination, reverse osmosis, and vapor compression of the simple distillation process previously described.

The multi-stage flash distillation process requires heat as the primary energy input. This heat could be supplied directly by a solar collector field. The primary energy inputs to the reverse osmosis and vapor compression processes is in the form of mechanical power. This mechanical power can be easily supplied by internal combustion engines or electric motors when conventional energy sources are used to operate the desalination units. With solar energy, this power can be supplied by solar thermal, photovoltaic, and wind turbine power systems.

<u>3.6.2 Technical discussion</u>: There are many different processes for water desalination either in use or in development. Three types of systems which are in general commercial use are:

- Multi-stage Flash Distillation

- Vapor Compression

- Reverse Osmosis

In addition, simple solar stills are in limited use for small-scale desalination functions. These approaches to desalination are described briefly, below.

Solar Still (SS). A solar still is the simplest of all the desalination processes. The sun rays pass through the glazing (plastic or glass, figure 49) without losing a significant amount of energy, and the absorber surface at the bottom of the water becomes warmer, and in turn, heats adjacent water. Some of the water evaporates and rises to the glazing, which is not as hot as the vapor, and condenses on the cooler surface. The condensate then trickles down the glazing and is collected at the sides, leaving a more concentrated brine solution in the bottom of the still. Various design configurations of solar stills are shown in figure 50. The rate of evaporation of water depends upon the temperature of the water and the relative humidity of the air space above the water. Therefore, the control of heat and vapor leaks is important.

A typical efficiency curve of SS is shown in figure 51. Aswan, Egypt has an average solar radiation of 592 cal/cm^2-day, which corresponds to SS efficiency of 38 percent and productivity of 3.7 liter/m^2-day. This is considered a high level of productivity for a single-effect SS.

Solar stills presently in operation have capacities ranging from 400 to 28,000 liter/day. Their sizes range from 100 to 8,000 m^2 and average production is 2.86 liter/m^2-day. These are found in industrial countries, like the USA and the USSR, as well as in developing countries like Spain, Greece, India, the West Indies, etc. Most of them were built in the sixties or early seventies and all are single-effect SS. Multi-effect solar stills have higher yield, but these are complex and expensive; and the technology has not yet progressed beyond the laboratory stage.

Multi-stage Flash Distillation (MSFD). Figure 52 shows a MSFD unit coupled with a solar collector array. In the unit shown, seawater is preheated to about 80°C by the vapor and finally heated to about 88°C by the solar collector array. Typical operating temperatures for fuel-fired units range from 88 to 150°C. The seawater enters the first chamber which is maintained at a pressure slightly below atmospheric. Some of the water boils instantly or flashes to vapor, and in so doing cools the remaining salt solution. This salt solution is then pumped into another chamber of lower pressure and temperature, where again, some of the water flashes to vapor and is drawn off. Several stages are used (typically 5 to 20) at successively lower pressures to permit the needed boiling at lower temperatures. The condensation of the flashed vapor occurs when it is passed through the condensers cooled by the incoming ocean water. As a result of using multiple distillation steps, these units require only 15 to 40 percent of the heat input per kilogram of water desalted as do simple solar stills with corresponding decreases in collector area requirements if suitably designed collectors are used. At the relatively modest temperatures required of MSFD

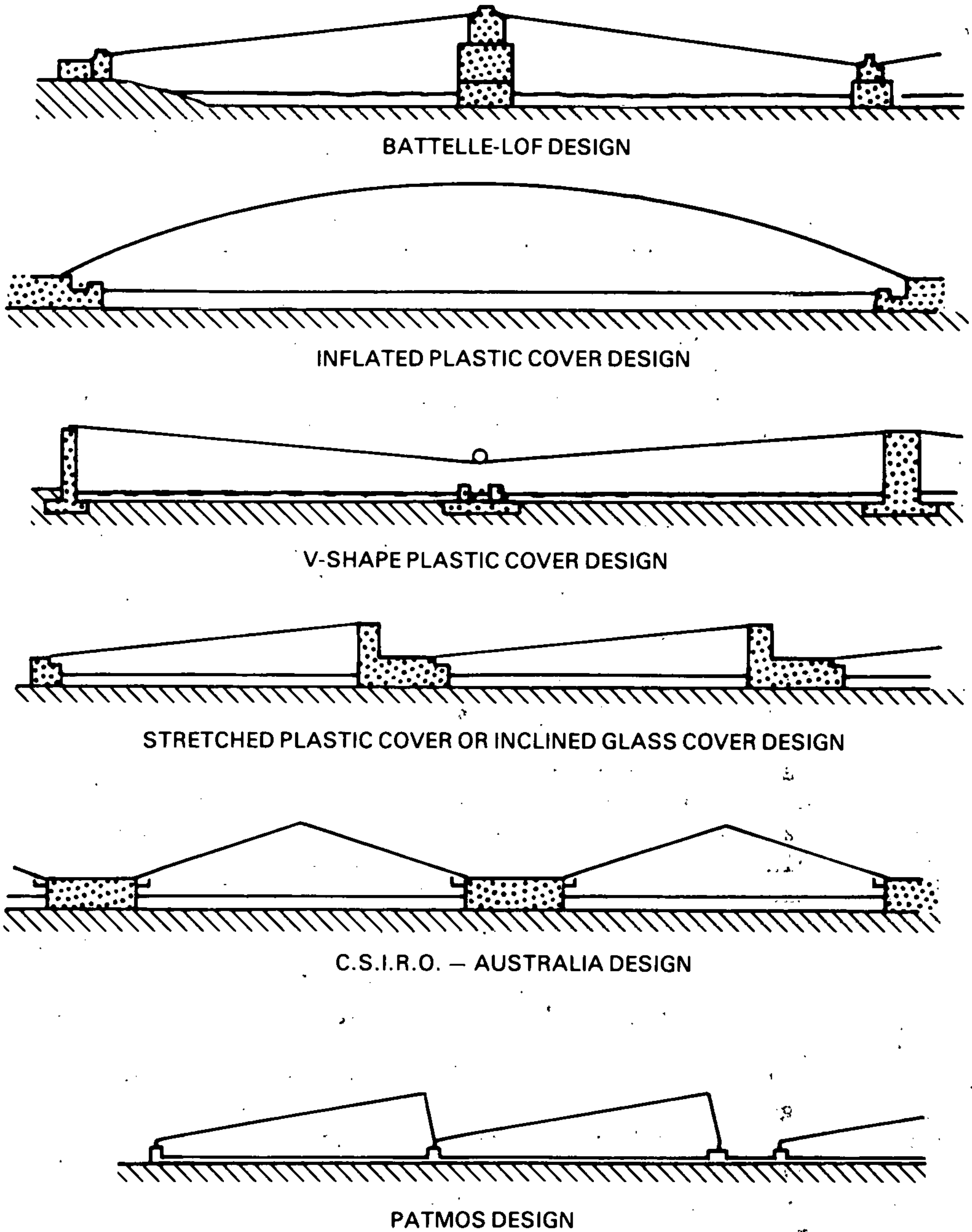

Fig. 50 Typical basin configurations

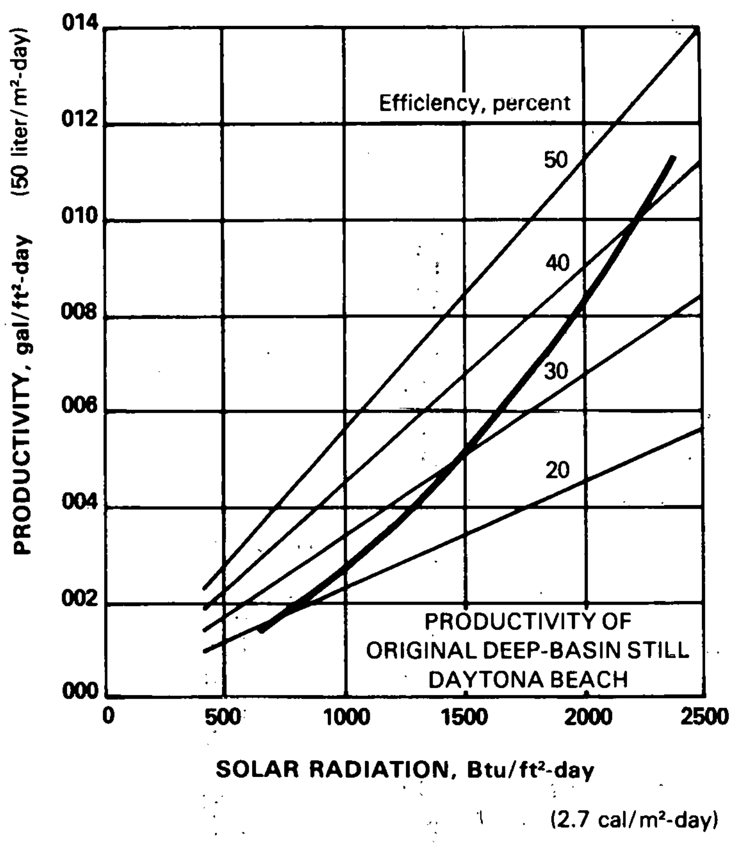

Fig. 51 Solar still efficiency

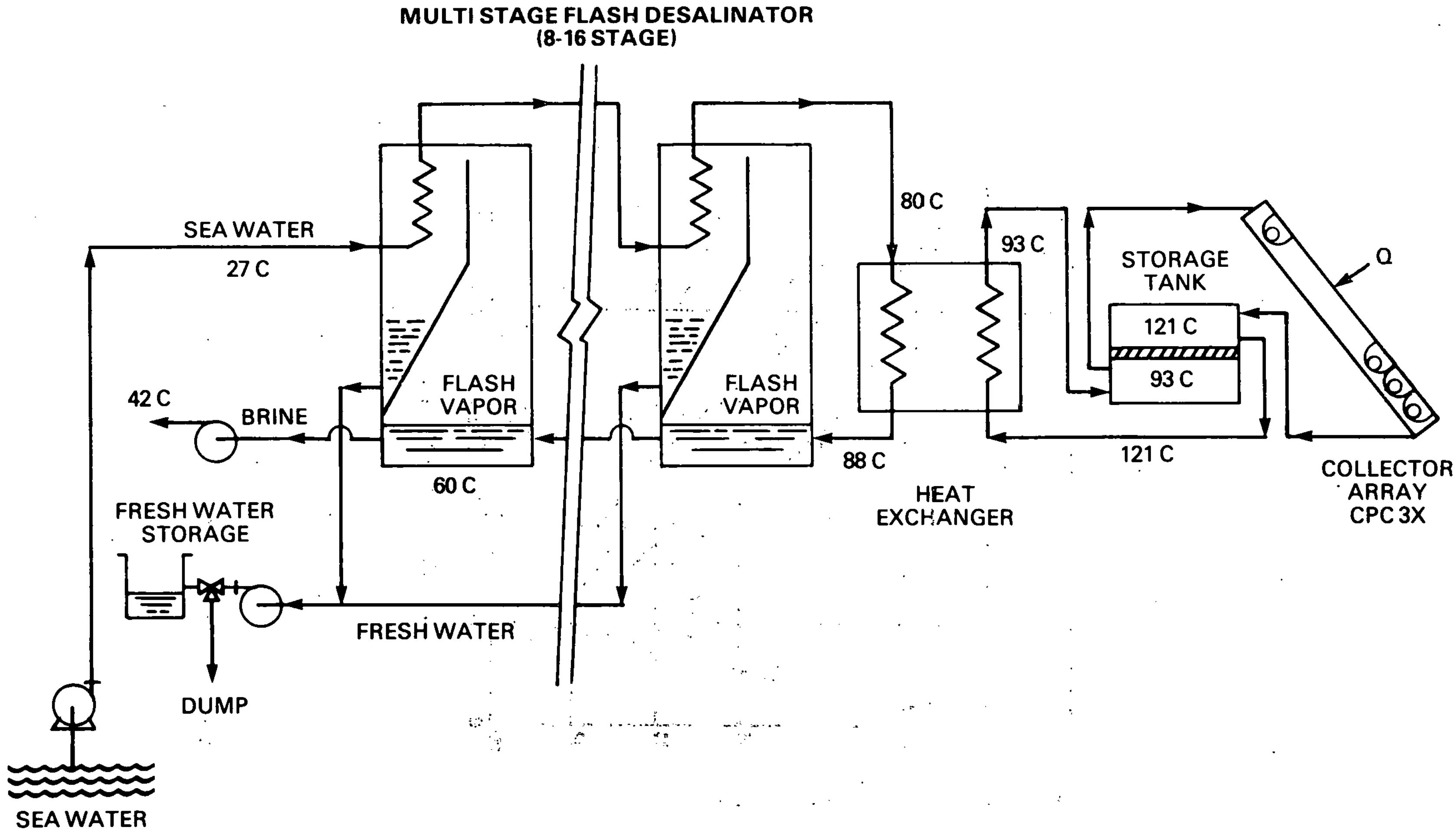

Fig. 52 Multi-stage flash distillation (MSFD)-solar

systems, collectors using low levels of concentration such as compound parabolic concentrators, parabolic troughs, or linear Fresnel lenses could be used. Capacities of multi-stage flash distillation units run from 40,000 liter/day to 4,000,000 liter/day.

Vapor Compression and Reverse Osmosis. In vapor compression units, water vapor is compressed adiabatically, resulting in a rise in temperature of the vapor, which provides heat for distillation of incoming seawater; the vapor, in turn, condenses to produce fresh water.

In reverse osmosis processes, one side of a membrane (typically cellulose acetate) is supplied with saline water at a high pressure (14 to 105 kg/cm^2). The membranes are semi-permeable, resulting in the diffusion of pure water leaving the strong brine behind. The pressure difference required across the membranes increases with the degree of salinity, which is one reason why reverse osmosis systems usually are used with brackish water with salt levels well below that of ocean water (such as often found in desert wells).

Both vapor compression and reverse osmosis systems require power input for operation, which could be supplied by solar thermal power units, photovoltaic generators, or wind turbine systems. Typical size ranges for these types of units are 20,000 liter/day to 4,000,000 liter/day.

3.6.3 Cost estimates and economics: Actual cost of solar stills in the sixties varied from L.E./13 m^2 in developing countries to L.E. 19/m^2 in industrial countries according to a Bechtel report.* At present these costs are expected to be in the range of L.E. 21 to 40/m^2. Based on the lower end of this range, the resultant cost of water from solar stills is estimated to be about L.E. 1.94/1000 liters assuming a useful life of 20 years and an interest rate of 8 percent.

The cost of water from solar fired MSFD systems is shown in figure 53 as a function of capacity. This analysis assumes:

- Collector Costs (5X CPC)
- Cost of MSFD Units.

As indicated, the MSFD units are more economical in larger sizes primarily due to the energy efficiency associated with multiple stages of evaporation as compared to a single evaporation process in a solar still.

The cost of water from the solar-fired MSFD units is about the same as from an oil-fired system with an oil cost of L.E. 0.07/liter (about equal to world oil prices). The economic advantages of the solar-fired systems should, therefore, increase with time as fuel prices increase, particularly in remote regions where fuel transportation costs also must be considered.

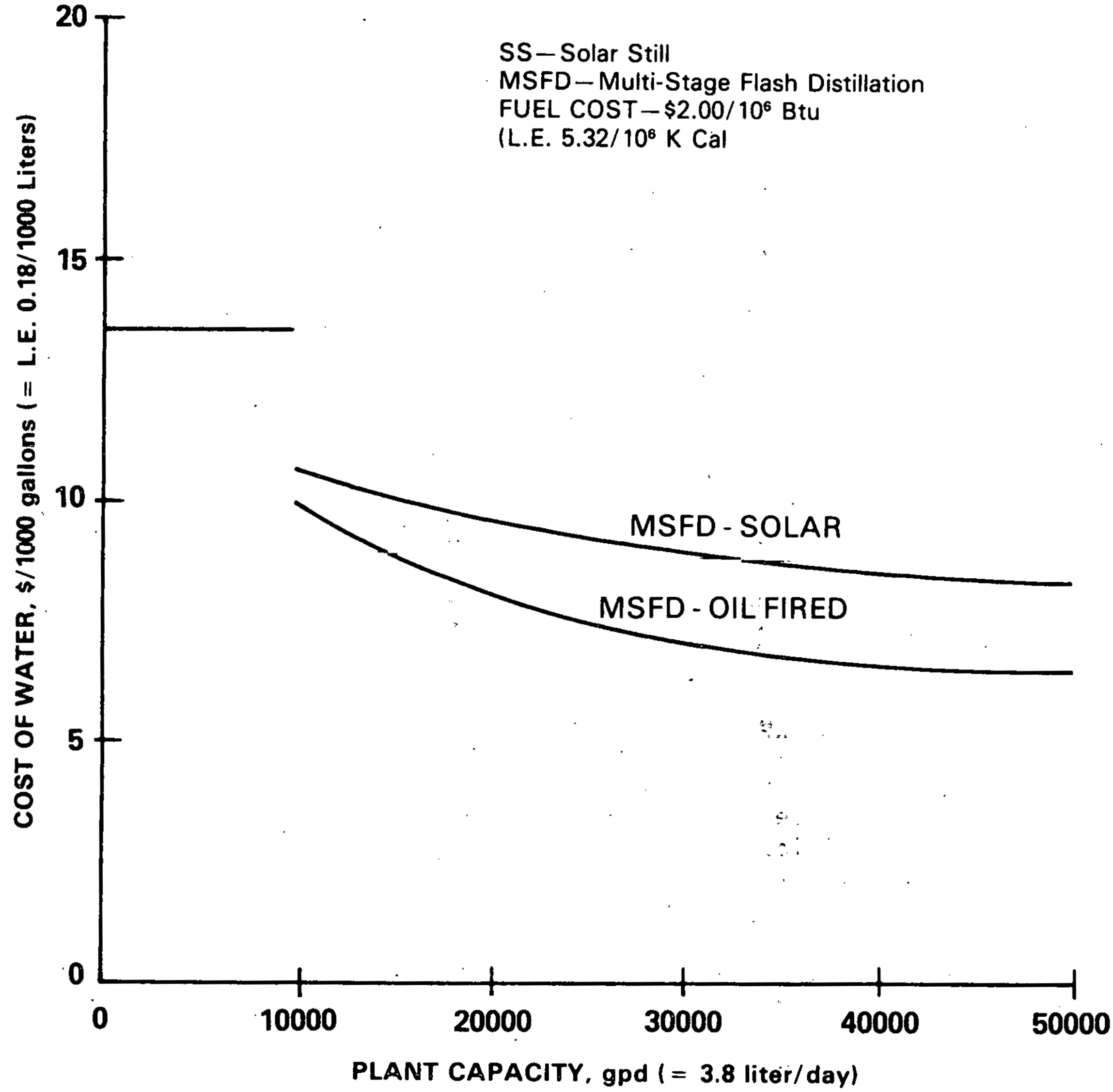

Fig. 53 Cost of product water

Most of the figures in the above study were obtained for preliminary assessment and hence no rigorous optimization of cost or sophisticated analysis in economics were done. It is believed that for MSFD-solar, labor cost may be 50 percent of the total. If Egypt decides to fabricate some portions of the solar collectors and the storage tanks, cost due to labor will be considerably lower. This will decrease further the cost of water produced by MSFD-solar.

In addition, the cost of water from solar- or wind-operated reverse osmosis and vapor compression units should be established, so that the most economical approaches for producing fresh water can be identified for a variety of sizes, locations, and water characteristics.

3.7 Solar Air Conditioning and Refrigeration

3.7.1 Background: Use of solar energy for air conditioning has been considered an attractive application due, in part, to the tendency for high air conditioning load to occur under conditions of high solar flux. The equipment used to provide air conditioning often is similar to that required for refrigeration (both chilling of fresh foods and freezing) so that developing solar air conditioning capability should lead to a solar refrigeration capability (and vice versa).

Presently, neither air conditioning nor warehouse refrigeration are large energy users in Egypt. This situation probably will change as living standards increase and the use of food preservation facilities to reduce storage and transportation losses become more widespread.

As indicated below, solar cooling is basically a special application of one of the solar power or heating options discussed in previous sections. This application is, however, discussed as a separate issue due both to the special interest consistently shown in this subject and its special characteristics which benefit economic performance.

3.7.2 Description of system options: There are a number of approaches for providing a cooling effect with solar energy. These include:

- Production of power via a solar power arrangement and operation of vapor compression units. In this arrangement shaft power may be coupled directly to a compressor (figure 54) or electricity can be generated which drives a motor operated compressor (figure 55;)

- Use of solar heat to operate absorption cooling units; and

- Use of evaporative cooling arrangements.

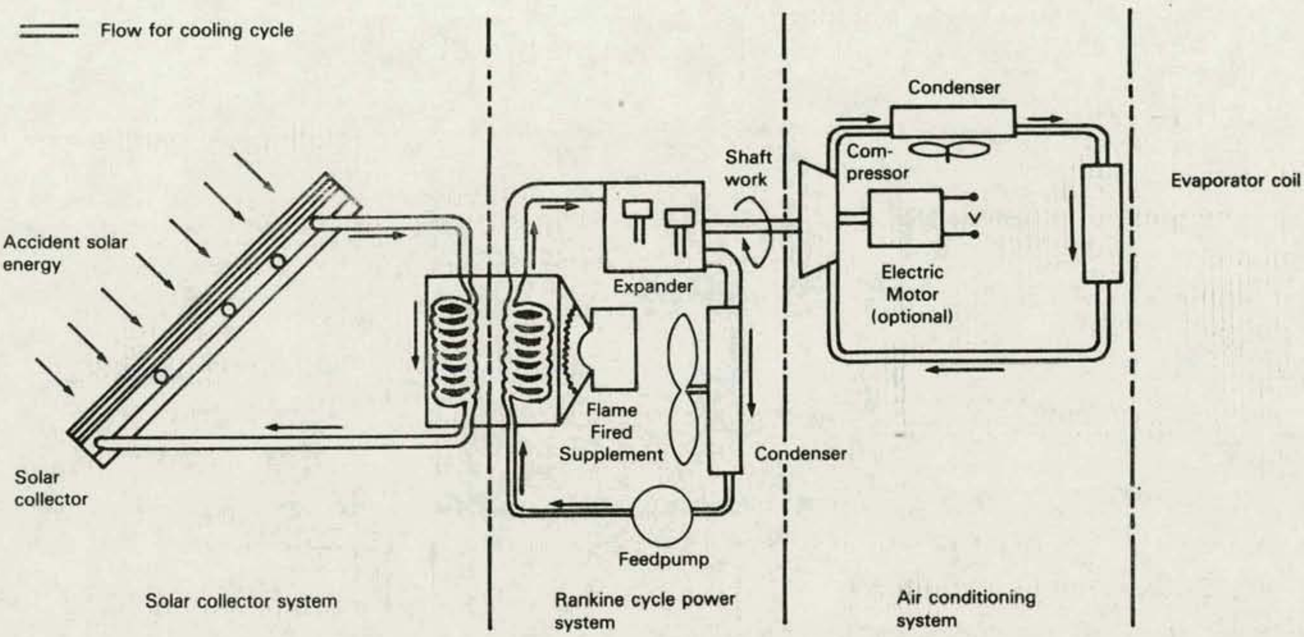

Fig. 54 Schematic of a Rankine cycle engine-powered cooling system using a solar energy heat source

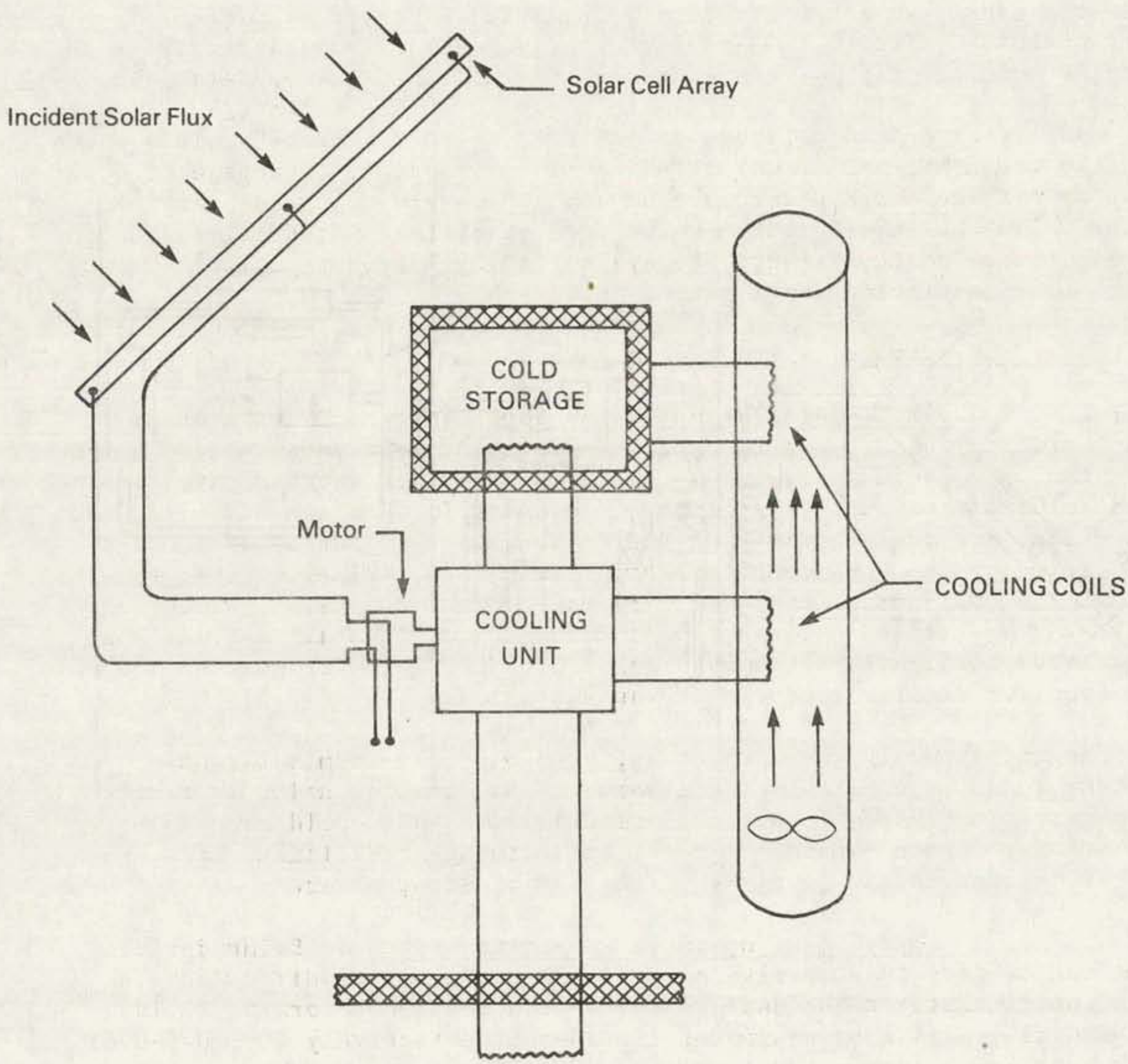

Fig. 55 Solar cell-powered cooling system

The latter arrangement commonly is used in arid regions with low humidity to provide some degree of cooling for small buildings. As such, it may be appropriate for use in many parts of Egypt. However, only the first two arrangements are amenable to provide cooling for large bulding units (which are more likely to be air conditioned) or to provide sufficiently low temperatures for refrigeration applications.

Both figure 54 and figure 55 indicate a "cold storage" volume which usually would be chilled water. This is an important advantage of solar cooling systems where power is produced to operate vapor compression units. The ability to store in the form of chilled water eliminates the need for more costly battery storage units thus favoring this application over power generation applications in general.

3.7.3 System costs and economics:

3.7.3.1 Solar driven vapor compression: Those systems which utilize solar power to drive conventional vapor compression units have the same basic economics as the solar thermal, photovoltaic, and wind turbine generator arrangements discussed in sections 3.2, 3.3, and 3.4. That is, the economics of the solar power generation options is unaffected by the end use of the power except to the degree that the need for storage or other auxilliary equipment (inverters, switchgear, etc.) can be reduced. The economic analysis sections all assumed that attractive applications (such as solar cooling) were stressed so that the need for auxiliary equipment was minimized.

As indicated in these sections, even the near-term solar power systems could be used to operate conventional cooling units in remote areas at a lower cost than diesel generators. This could make solar cooling for remote hotels, clinics, cold storage facilities, etc., one of the most attractive early applications of solar power.

3.7.3.2 Solar operated absorption system: Solar derived also can be used to directly operate absorption air conditioning systems, particularly those using lithium-bromide as the working fluid. Commercially available equipment can operate effectively (COP 0.5-0.6) with heat input temperatures in the 190 to 220^{o}F range. These temperatures cannot be attained efficiently and reliably with the simple flat plate collectors normally used for water heating. However, either flat plate collectors of advanced design (good selective coatings, high transmission covers, evacuated tubes, etc.) or those using some degree of solar concentration (linear Fresnel lenses, parabolic troughs, etc.) can effectively operate at the required temperatures. Over 20 systems using solar-driven absorption units have been built and operated in the United States, thereby demonstrating this approach to solar air conditioning. Figure 56 shows an absorption system scheme.

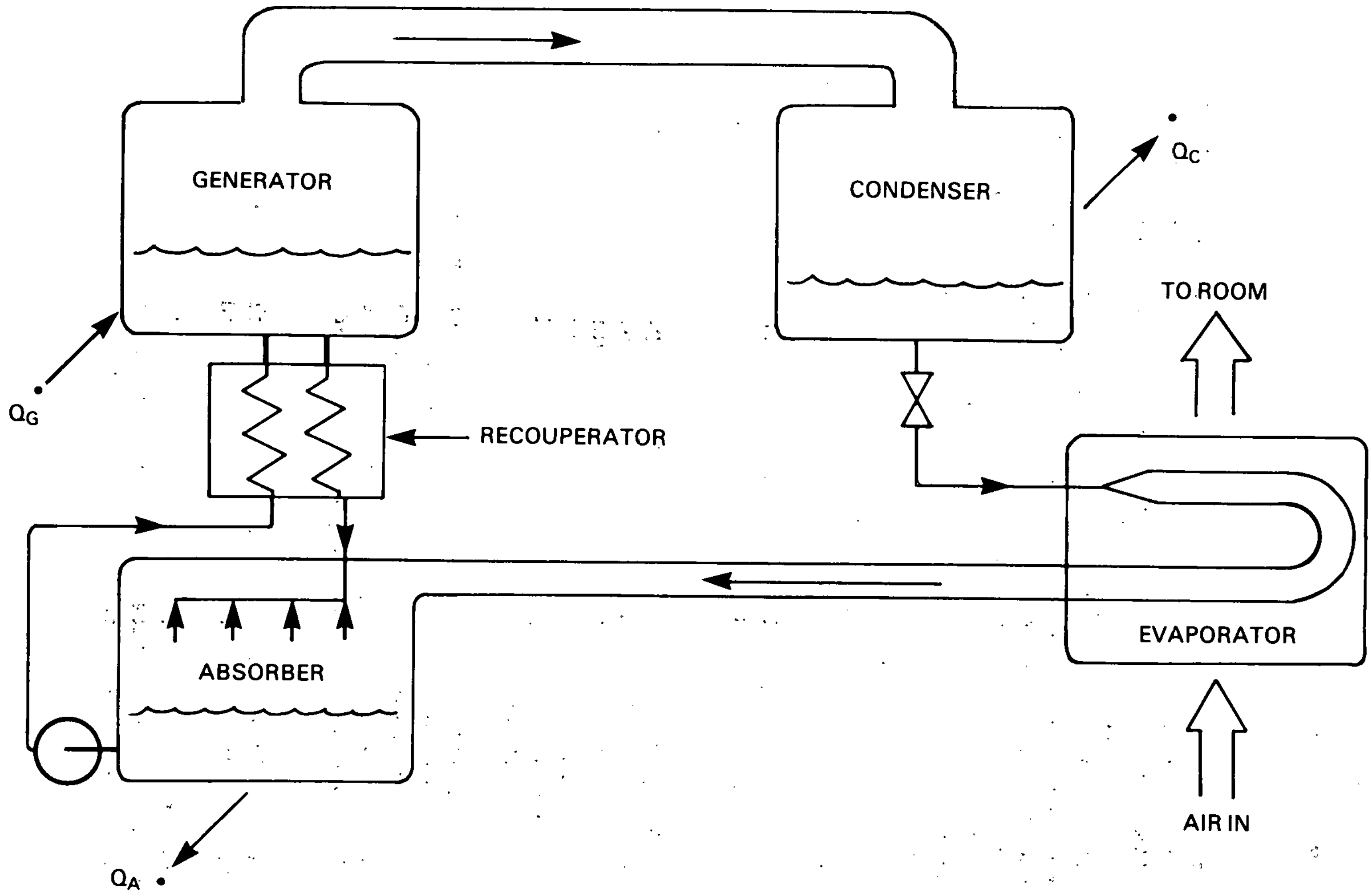

Fig. 56 Absorption system schematic

A solar-operated absorption cooling system is basically a solar hot water system firing a commercial lithium-bromide absorption unit. The absorption unit also could be operated with a gas- or oil-fired burner. As such, the economics of the solar-fired unit is indicated by the cost of solar delivered heat as compared to supplying heat by conventional sources.

The collector configurations which can supply heat at the required temperature level are usually more costly than simple water heaters. Manufacturers of high performance collectors project a production cost of about L.E. 72/m^2. The resultant installed system cost for a hot water delivery system capable of operating absorption cooling systems would be about L.E. 100 to 120/m^2. Using the same economic parameters of section 3.1, the cost of heat delivered by the high temperature solar water system (to drive the absorption unit) would be L.E. 4 to L.E. 5 per 10^9 J. By comparison, the cost of delivered heat from 6.8 pt/liter oil (approximate world price) would be about 3.7 per 10^9 J. The cost of solar-driven absorption units, therefore, approaches being competitive with fuel operated systems with the breakeven cost being about 10 pt/liter. This fuel cost probably is already typical of that in remote areas if the costs of transportation and storage are considered.

As with the solar hearing systems of section 3.1, most of the solar collector configurations could be made in Egypt, further improving the economics of solar cooling.

3.7.4 Comparison of options: The solar driven vapor compression units offer a higher degree of flexibility than the absorption systems, since any form of solar power (photovoltaics, wind generators, etc.) can be used for their operation. Also, vapor compression cooling systems are already in wide use within Egypt, which would facilitate their eventual manufacture, installation, and repair.

The performance of solar driven absorption units, on the other hand, presently is better demonstrated than the other solar options and the economics of this arrangement, therefore, better defined than systems, such as those using photovoltaics, which require significant cost reductions to be practical. Drawbacks to the absorption units, however, include:

- Their relatively limited use and resultant lack of in-country personnel experienced with their operation; and

- Their requirement for a cooling tower for reliable operation, which could be a significant problem in Egypt due to lack of water and/or high maintenance requirements.

3.7.5 Institutional/environmental considerations:

3.7.5.1 Institutional: There are several institutional considerations favoring solar cooling applications in Egypt, particularly for food preservation applications. Presently, food preservation facilities are in very limited use; this leads to significant spoilage. Furthermore, the need for food preservation can be particularly acute in remote regions where rapid access to transportation either to export or import food is limited. In the near-term, solar refrigeration could provide much needed cold-storage facilities in remote regions, thereby enhancing living standards in these areas where the government hopes to settle an increasing percentage of the population.

3.7.5.2 Environmental: As with most solar applications, there are no known negative environmental impacts. Positive impacts include the reduction in emissions from conventional power facilities.

4.0 COST OF POWER FROM DIESEL ENGINES

4.1 Background

Where the need for small-scale power generation has arisen in the past, the conventional mode has been to install a small fuel-fired engine generator or pump, generally a diesel engine. It is with these technologically advanced engines that renewable power generating systems (photovoltaics, solar thermal, biomass, and wind turbines) are assumed to compete in a 1980's time frame, when the price of fossil fuels rises and the cost of these new technologies falls. It would therefore be instructive to examine the costs of power associated with diesel engine generators for comparison to the costs of renewable energy generators discussed in Section 3.0.

4.2 Economic Performance

The installed cost of engine powered generating systems is a function of the system's location, application and size. A diesel electric generator with backup in a very remote area, for example, requires fuel storage, circuit breakers, relays, and a protective building which can more than double the installed system cost over the generator cost. Alternatively, a simple water pump can operate in the open without most of the ancillary equipment listed above.

The cost of power from diesel power units is a function of many other variables such as fuel efficiency, fuel cost, useful life, and maintenance costs. For purposes of this analysis it was assumed that;

- Engine costs range from \$100/kW (L.E. 67/kW) for very small systems to less than \$300/kW (L.E. 200/kW) for very large systems,

- o Engine costs have been multiplied by an average factor of 1.5 to account for installation and subordinate equipment,
- o The engine runs at a 33 percent capacity factor (equivalent to full capacity operation for 8 hours/day),
- o A major overhaul is needed every 5000 hours with costs at 30 percent of initial engine cost,
- o Resultant engine life is 10 years,
- o Engine efficiency is 25 percent for smaller units and 30 percent for the very large units,
- o Diesel fuel has a heat content of 140,000 Btu/gal (39×10^6 joules/liter), and
- o There is an 8 percent interest rate on borrowed money.

Figure 57 shows the cost of power versus diesel generator size for three diesel fuel costs. The $0.50/gallon (8.7 pt./liter) is consistent with the world market cost of fuel, and $1.20/gallon (2.1 pt./liter) is presently appropriate to remote areas where the transportation costs become significant, and in a future time frame will be appropriate to world market oil prices.

For many remote areas in Egypt, a delivered fuel cost of $0.80/gallon (14 pt./liter) may be more applicable. The associated power cost for a small pumping or electricity generating system (10kW) is about $0.14 to $0.18/kWh (9 pt. to 12 pt./kWh). Power from larger diesel generators and pumps cost about $0.10 to $0.12/kWh (6.7 pt. to 8 pt./kWh) with current fuel prices, but can be expected to rise with the cost of fossil fuel, so that these prices can be considered the bottom line for future installations. For very large systems in the MW range (used in some larger towns) the cost of power reduces to about $0.8 or $0.9/kWh (5.3 pt. or 6 pt./kWh). Other considerations associated with fuel-fired engine generators is their high emission levels, noise, and high maintenance requirements.

It should be noted that the power costs of figure 57 are relatively optimistic. Significantly higher costs than those indicated are often experienced in remote areas where maintenance of systems is poor and skilled repair personnel are not readily available.

The power cost of figure 57 is considerably higher than those projected for the solar/wind options discussed in Section 3.0 if the expected improvements in solar/wind technology materialize.

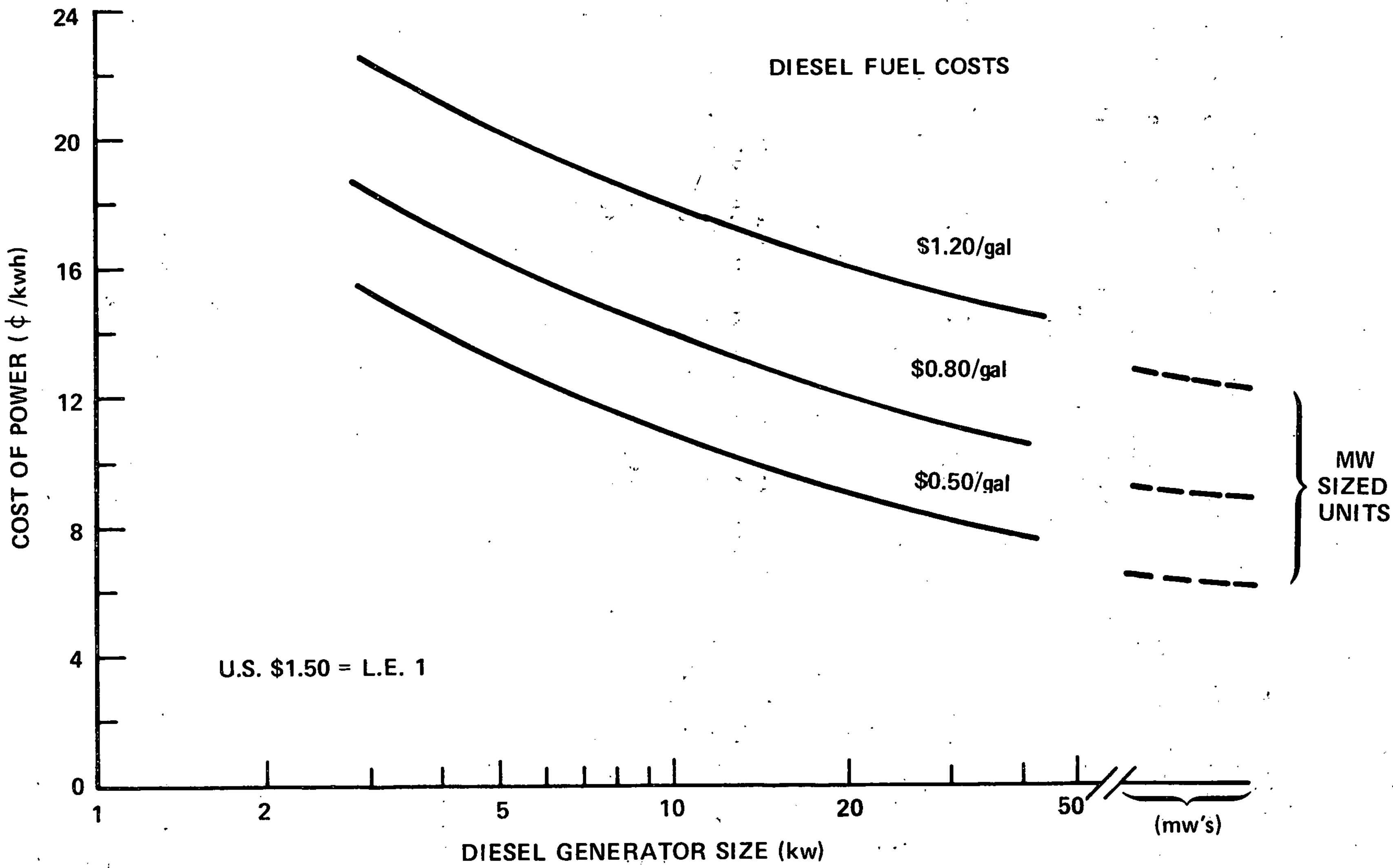

Fig. 57 Cost of power from diesel generators

4.3 Impact on Solar Options

In the implementation scenarios of Section 3.0 it was assumed that in the 1980's solar power units would be used either to replace or supplement power normally produced by diesel engines and to provide power in remote areas where no power would otherwise be made available.

Diesel engines are used extensively in Egypt both for water pumping functions and to provide power in towns (such as along the Red Sea Coast) not connected with the utility grid. It is, however, difficult to estimate the installed capacity of diesel pumps and generators in Egypt due to the range of applications, size, and ownership of such systems.

Information obtained from the Ministry of Irrigation indicates that the installed capacity of large diesel power pumps operating under their control is about 25 MW and that there are roughly 40,000 smaller diesel pumps (7 to 15 hp) in operating condition under private ownership (capacity roughly 280 MW).

Little information is available on diesel electric generating capacity, however, it is known that substantial amounts of power are generated by diesel engines in areas other than the Nile Valley, where the grid is quite extensive. For example, the public electric power systems in the towns along the Mediterranean Coast (Mersa Matruh, Salum, etc.) have an installed diesel generator capacity of over 5 MW.*

Based on the above, it is apparent that there is a substantial near-term market potential for solar/wind power generation even if the market is restricted to those applications now serviced by diesel generators and pumps.

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*This cost level is in agreement with those experienced on the towns of the Mediterranean Coast as reported in "Regional Plan for the Coastal Zone of the Western Desert," August, 1976.

ANNEX-9

GEOTHERMAL ENERGY TECHNOLOGY PROJECTIONS
IN EGYPT

BY

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U.S.-EGYPT COOPERATIVE ENERGY ASSESSMENT

September, 1978

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1.0 RESOURCES

1.1 Resouces with Temperatures above 180°C

The heat from these waters can generate electricity. Such resources can be used to drive steam turbines directly, and the steam can, if necessary, be separated at the wellhead. Costs are competitive with the current average world prices of coal, and electricity produced with this geothermal resource is less expensive than power produced from gas and oil. There are two principal problems, however, with such geothermal waters:

- Because of their concentrations of dissolved solids, high-temperature waters often cause scaling problems. Experience in areas with particularly "dirty" waters, such as the Salton Sea in California, has not been encouraging. Steam heat exchangers appear to be one part of a solution. The wells must also be cleaned periodically to remove scale accumulation if flashing and/or cooling occurs in the well bore.

- The high-temperature brines also seem to contain a great deal of dissolved non-condensable H_2S. Controls developed and used at the geysers in California should be applicable at many other locations.

Because of environmental concerns about discharging the used fluid, the injection of cooling-tower blow-down and other used geothermal fluids appears to be a necessity for long-term applications.

1.2 Resources of from 150°to 180°C

These waters also have the potential for economically producing electricity. With waters in this range, however, the binary organic-fluid cycle is generally required. The process has yet to be proven in long-term pilot tests. Under certain conditions, the steam cycle may be used with a double flash. The second flash would lower the steam to atmospheric pressure. This system must flash the steam at the power plant, however, and a great deal of water must be pumped. In either case, in order to maintain reservoir pressure and minimize environmental impacts, the used water should be injected back into the ground.

1.3 Resources of from 100° to 150°C

In the foreseeable future, it does not seem that waters in this range can economically generate electric power, except where few alternatives are available. There is potential, however, for using waters of this temperature for process heat, primarily for food processing. New plants would be located near such geothermal resources; this type of development might well fit Egypt's plans.

1.4 Resources with Temperatures Below 100°C

Because it lacks the disadvantages associated with high pressures, water below the boiling point can be used with greater safety. Its use also presents fewer technological problems, and wells can be drilled inexpensively. Standard tube-and-shell heat exchangers are suitable if a pump pressure head is maintained. A number of industrial operations (such as food processing, again) could make good use of the heat.

The most important worldwide potential for this geothermal energy is for space heating. However, because Egypt's climate would not require heating during most of the year, local economics may not favor the use of geothermal space heating.

Studies in the United States have indicated that if geothermal energy is to compete with conventional fuels, the space heating system must be utilized at approximately 3000°C per day per year in order to amortize the large capital investment. This rule of thumb depends quite heavily on the proximity and depth of hot water and on the cost of utilizing the energy at the building location. These low-temperature hot waters can often be beneficially disposed of on the surface, in agricultural applications, with minimum environmental impact.

2.0 SUMMARY

At present, it appears that geothermal resources in Egypt will generally not exist near present population centers. However, if productive resources are found, these could be considered as locations for new energy complexes, and therefore new population centers. The contribution that geothermally-generated electricity might make to Egypt's future needs is not likely to be of major national significance but could have local importance, especially if coupled with industrial applications that could use geothermal heat directly.

TABLE 1

STEAM SYSTEM FOR ELECTRIC POWER GENERATION

FROM GEOTHERMAL RESERVOIR

RESOURCE AND WELL COMBINATIONS	GENERATION	DISPOSAL
1. Pure steam wells Geysers in California, USA Lardarello, Italy	A) Non-Condensing Turbines	1. Only "Blow-down" accumulation from bottom of cooling tower is required
2. Wells that flash in well bore, steam separator at wellhead Cerro Prieto, Mexico Wairakei, New Zealand	B) Condensing Turbines (not practical if high concentration of non-condensible gases) I) Single entry turbine II) Dual entry turbine (best adapted to No. 3 at left)	2. Surface discharge Mexico Injection Japan
3. Wells that are maintained in liquid state, delivered as liquid to power plant, and there flashed.		3. Full water flow to plant will require injection in most applications.

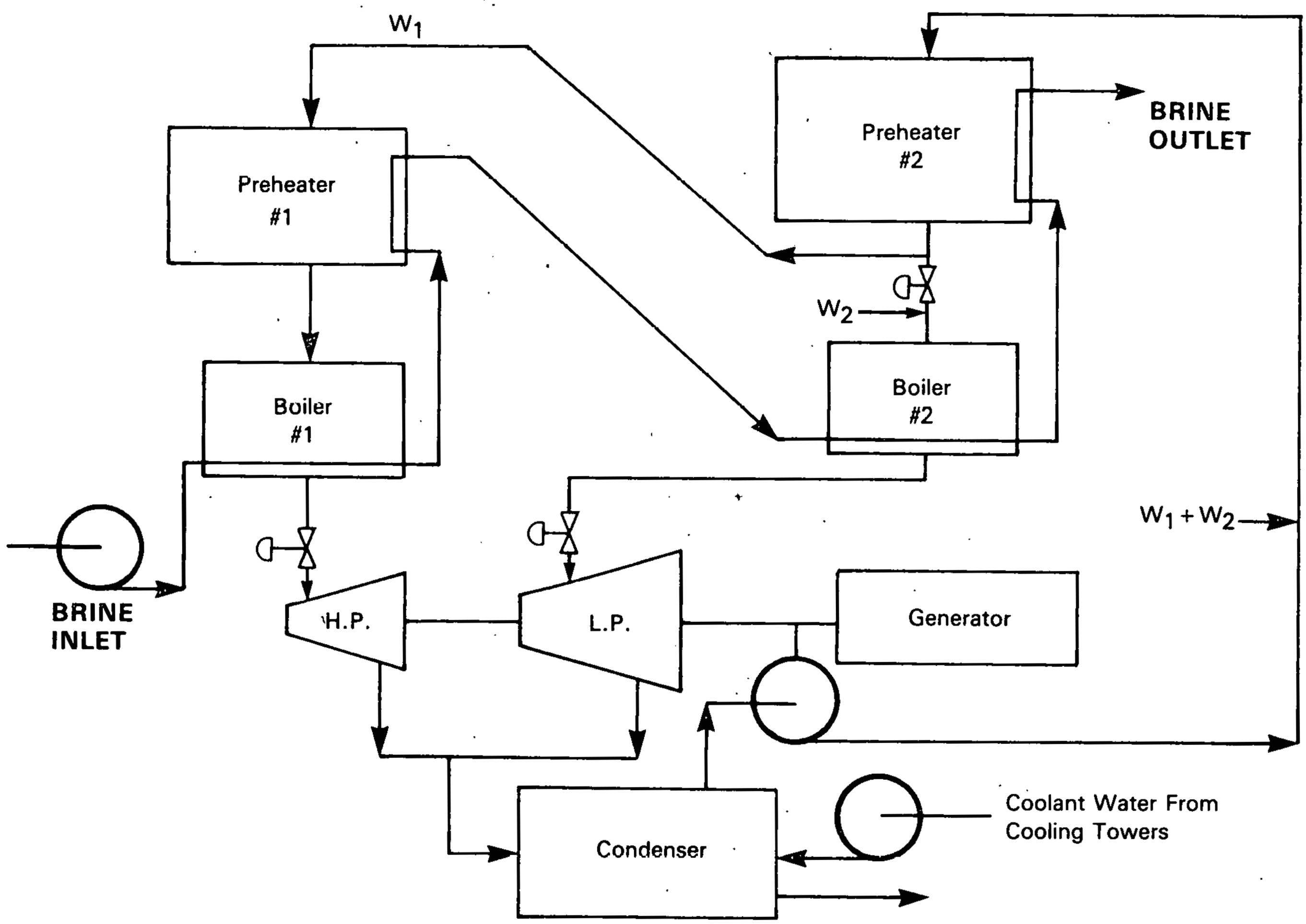

Fig. 1. Binary Cycle Geothermal Power Plant

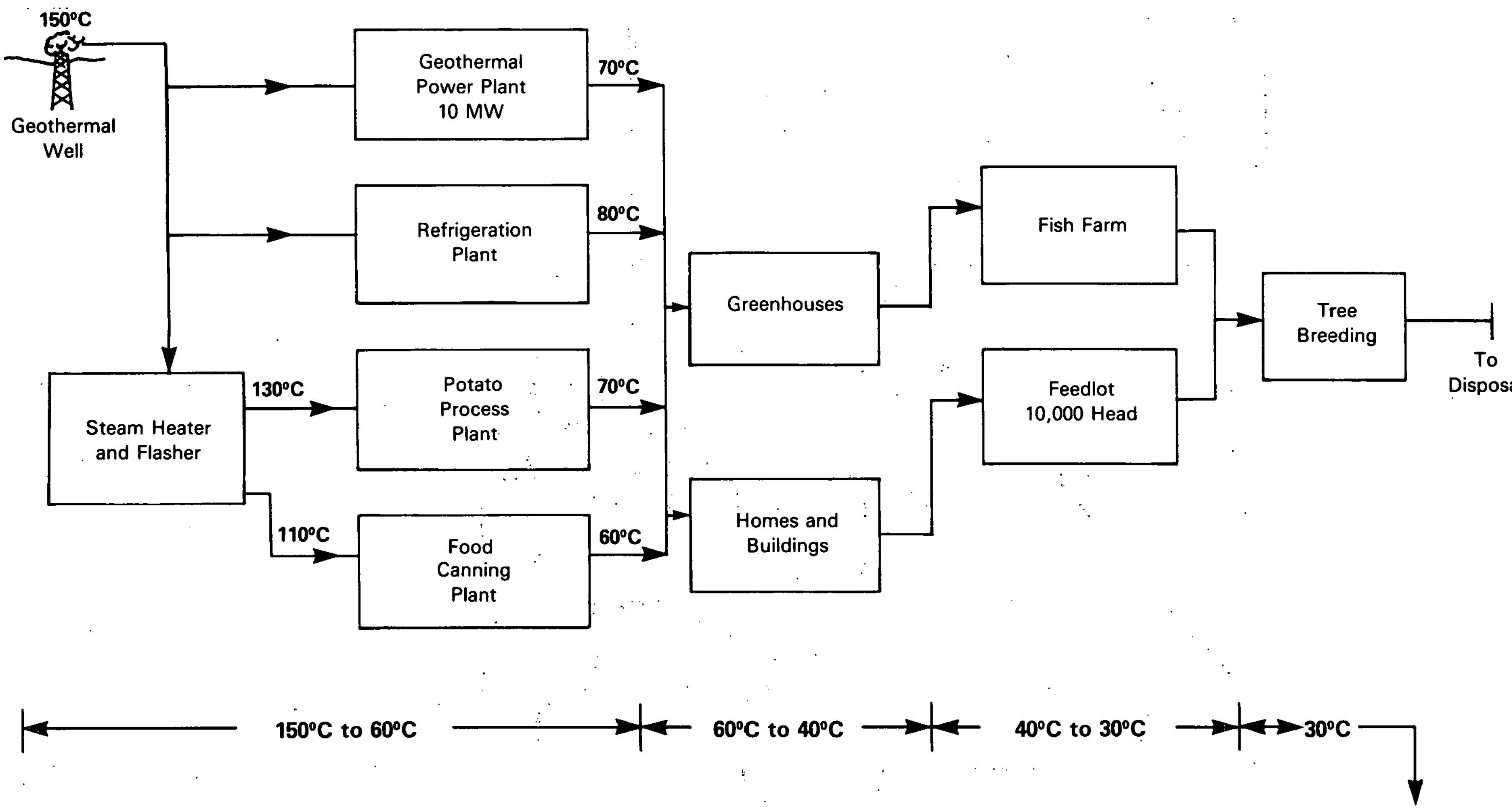

Fig. 2. Typical Multiple Purpose Application for Moderate Temperature Geothermal Wells

ELECTRICAL POWER SYSTEMS

BY
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U.S.-EGYPT COOPERATIVE ENERGY ASSESSMENT

September, 1978

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GLOSSARY OF ABBREVIATIONS

Organizations

MEE - Ministry of Electricity and Energy

REA - Rural Electrification Authority

EEA - Egyptian Electricity Authority

GEEC - General Egyptian Electricity Corporation

UPS - Unified Power System

Electrical

MW	megawatt	1,000 kilowatts
MWH	megawatthour	1,000 kilowatthours
GW	gigawatt	1,000,000 kilowatts
GWH	gigawatthour	1,000,000 kilowatthours

1.0 INTRODUCTION

Before 1959 all of the electrical energy was generated at power plants using oil as the primary fuel. At the present time, two-thirds of the electrical energy is supplied by hydroelectric generating stations located in Upper Egypt. The remaining one-third of the electrical energy is generated by steam electric and gas turbine generating plants. The primary fuel for these plants is heavy and light oil. Some of the future fossil thermal power plants and combustion turbine generators will be designed to burn either oil or natural gas. Most of the natural gas presently available is associated with production of oil from wells located in Egypt.

Beyond 1985, and up to year 2000, generation planning and transmission system planning studies have not been done or completed to the same extent as planning done up to 1985. The Egyptian Electricity Authority (EEA) supplied a copy of a preliminary schedule of generation expansion up to year 2000. The projection for capacity and energy was used in the preparation of drawings to roughly show the expanded power system to 2000. The information was used to prepare order-of-magnitude cost estimates for power generating stations, transmission lines, substations, and power system control facilities.

The information used in preparing this report on Electrical Power Systems was obtained from people named in Appendix A.

2.0 SUMMARY

Data on the Unified Power System has been collected and documented. Pertinent aspects of the existing electrical power system presented and discussed are: (a) electrical generation; (b) historical, existing, and projected rate of load growth; (c) characteristics of the High Aswan Dam Project and power transfer capability of the 500-kV transmission lines; (d) reliability and operating experiences; and (e) power system control. Information is also presented on transmission lines, distribution facilities, generating stations under construction, EEA's plans for additional transmission lines, new generating stations, and a new power system control center projected for service by 1985.

Studies and plans for a system from 1985 to 2000 have not been completed by EEA and its consultants. However, projections of power system expansion were made and drawings were prepared to show an approximation of how a power system could be developed to year 2000. EEA supplied information for the electrical capacity and energy that would be required for each year to 2000. EEA assumed that the electrical load requirements would be supplied by oil/gas, nuclear, hydro, and hydropump generating plants. The existing 500-kV and 220-kV transmission system would be enlarged to transmit the bulk power from the generating stations to serve the expanded loads in the existing cities and rural areas, new industry, and new cities. Order-of-magnitude cost estimates were compiled for the electrical power, control, and communication facilities required for development from 1985 to 2000.

2.1 Present Electrical Power System

Construction of the High Aswan Dam Project in the late 1960's with the last turbine generating unit placed into service in 1970 provided the EEA with a Unified Power System (UPS). The independent electrical power systems of Cairo, Upper Egypt, the mid-Nile Valley, Alexandria, and Delta became electrically integrated. The system was controlled and power dispatched from a new Power System Control Center equipped with a computer to assist the dispatchers. The Power System Control Center is located at the Cairo 5C -kV Substation.

The existing thermal and hydro generating name plate capacity is as follows:

	Name plate Rating, MWe	Effective Capacity, MWe
High Aswan Dam	2,100	1,750
Aswan Dam	345	225
Subtotal	2,445	1,975
Fossil Thermal	1,265	
Combustion Turbine	137	
Subtotal	1,402	
Total	3,847	

Not all of the capacity is available or effective enough to serve the load in the UPS. For example, the capacity of Aswan Dam, 7 km downstream from the High Dam, has been reduced to 260 MWe due to reduced hydraulic head caused by encroachment of the tail water at the High Dam by the Aswan Dam reservoir. Also, at least one generating unit generally is not available due to maintenance; therefore, the effective capacity is usually 225 MWe. At the High Dam the twelve hydroturbines operate in pairs with one common penstock supplying water to two hydroturbines. When one unit is down for maintenance, two units, or 350 MWe, are not available. At least one unit is down throughout the year. The effective hydroelectric capacity is accepted to be 1,750 MWe + 225 MWe, or 1,975 MWe total. The present load in Upper Egypt is approximately 600 MWe. Not all of the remaining generating capacity of 1,375 MWe (1,975 MWe - 600 MWe) can be delivered north (transmission distance of 788 km) because of the limited power transfer capability of the two 500-kV transmission lines. The lines have been loaded in the past to deliver a peak load of 950 MWe to the Cairo 500 Substation.

In the early years (1968-1973) of operating the 500-kV system, numerous "flashovers" or line tripouts occurred due to contaminated insulators. At times, these required shedding of load. Since then, the insulation level of the 500-kV transmission lines has been increased and the number of outages due to insulator flashovers has decreased.

Peak loads occur during the winter months. During the months of December and January the water released at the High Aswan Dam is held to a minimum. Irrigation requirements are less during this period, which is also the time that work on the canals takes place. EEA is apprehensive about its ability to meet the load for the winter of 1978-79. The usual practice for the winter of 1977-78 was to reduce the voltage and frequency.

The Ministry of Electricity and Energy has experienced unprecedented system load growth during recent years. During the last four years the annual growth in load has varied from between 12 to 19 percent. The lowest has been during the war of 1973. The per capita annual energy consumption is approximately 300 kWh. This includes total national energy used---industry, commercial, and domestic. The domestic annual consumption per person has been less than 20 percent of 300 or less than 60 kWh. The Rural Electricity Authority (REA) plans to extend distribution systems during the next five years to 6,000,000 people living in villages. The electricity would be used primarily for lighting and radio, and possibly for cooking.

2.2 Electrical Power System - Year 1985

The generating power plants now under construction will provide 1,420 MWe of additional capacity; oil/gas steam electric generating stations will provide 1,120 MWe of the new capacity and gas turbine generators will provide 300 MWe. These power plants are scheduled to be completed by 1985. Approximately 630 km of 220-kV transmission lines are under construction and an additional 220-km are planned for construction by 1985.

A new Power System Control Center, estimated to cost approximately $48 million, will be designed, constructed, and placed into operation before 1985.

This is being funded by USAID and will provide for a Power System Control Center with an advanced computer, a new powerline carrier communications system between Cairo and Aswan, and a microwave communication system in Lower Egypt. REA's distribution system will be reconstructed and expanded in four cities and in nine provinces.

By 1985 the system daily load cycle on the UPS will have changed and power flows on the two 500-kV transmission lines between Cairo and Upper Egypt probably will reverse, particularly during the months of December and January. This assumes that the loads in Upper Egypt increase as predicted. Figures 1 and 2 illustrate peak power flows for 1985 based on the assumption.

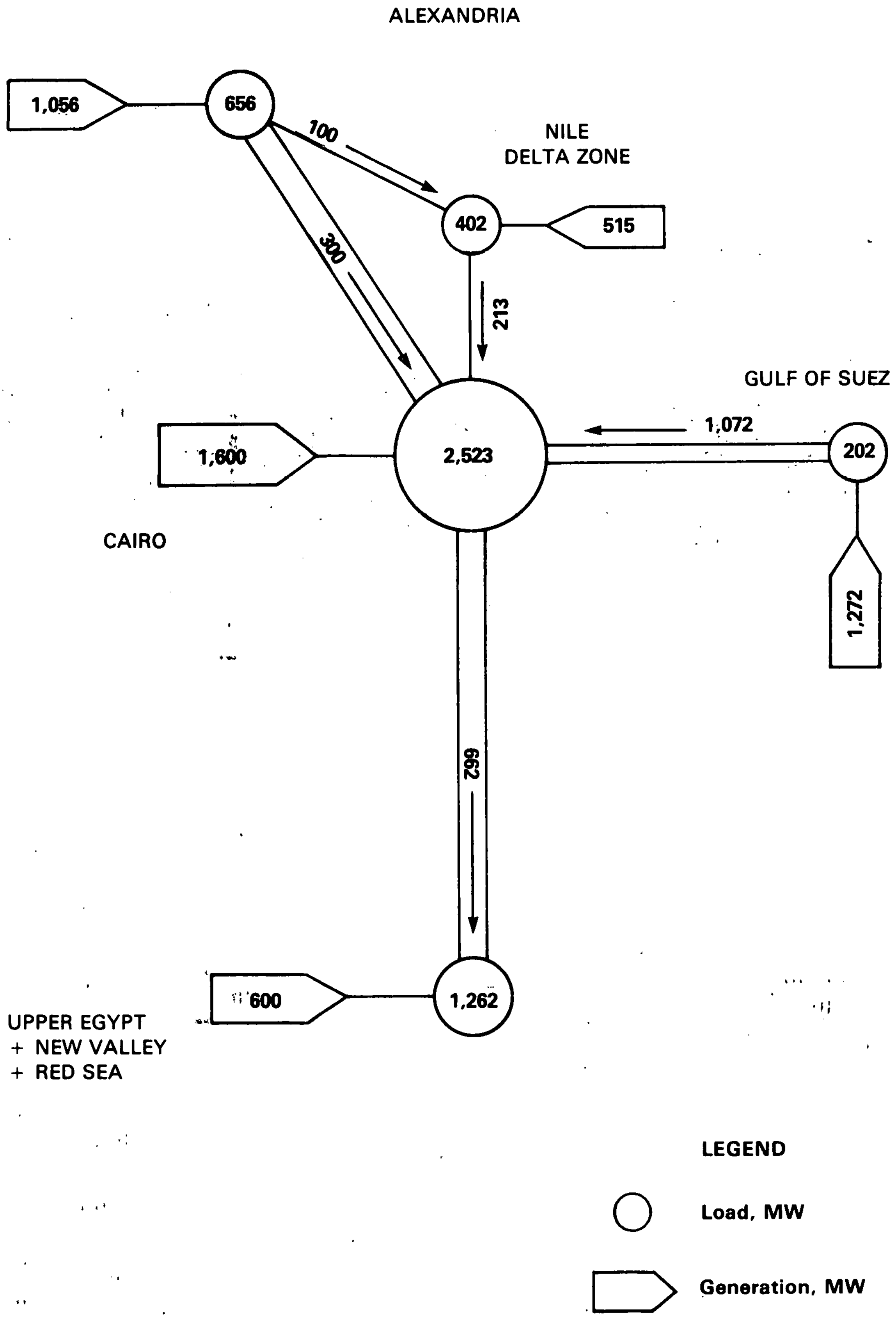


Fig. 1 Peak load power flows-December and January, 1985-86

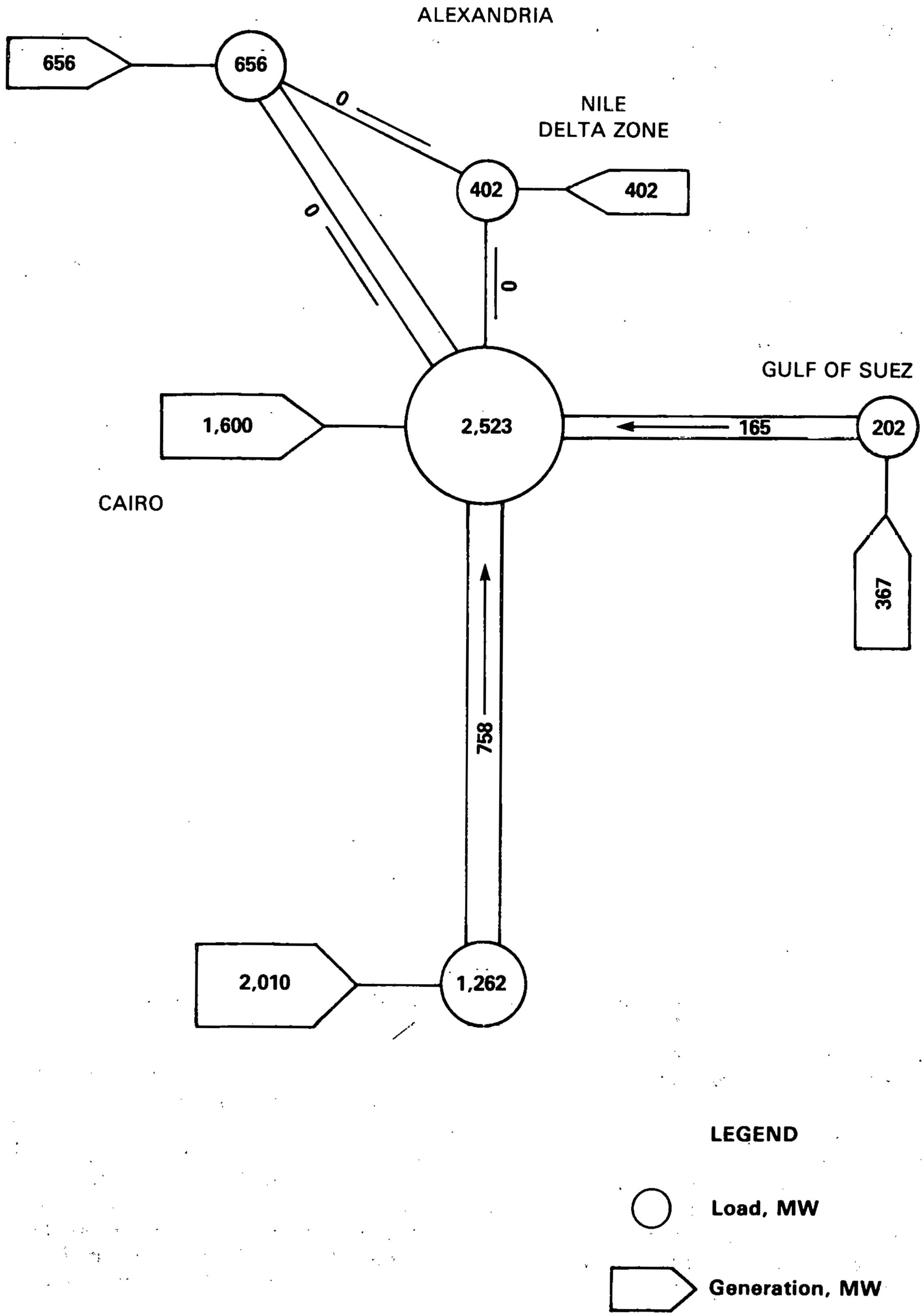


Fig. 2 Peak load power flows-Irrigation season, 1985-86

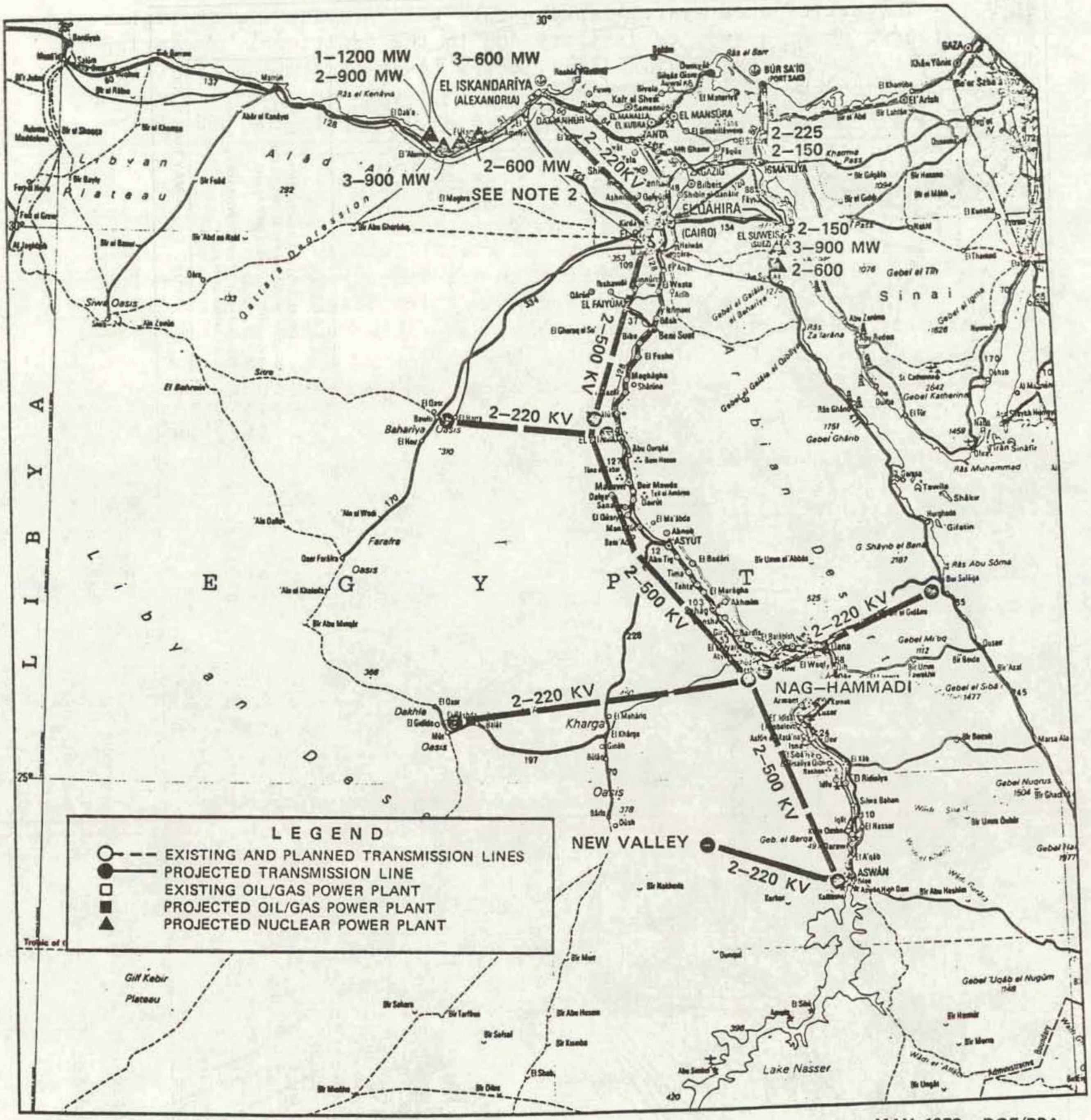
The anticipated system improvements will provide a much higher degree of power system reliability due to the additional generating capacity, more transmission lines, a new Power System Control Center and an upgraded communication system. Industry will then have no need for on-site power generating units to serve as backup to the UPS power supply.

2.3 Electrical Power System - Year 2000

The annual growth in electrical energy in Egypt has been forecasted by the Ministry of Electricity and Energy to be approximately 8 to 9 percent. Based on this assumption a projected schedule to 2000 for capacity and energy was prepared to by EEA. The added new capacity between 1985 and 2000 is indicated below:

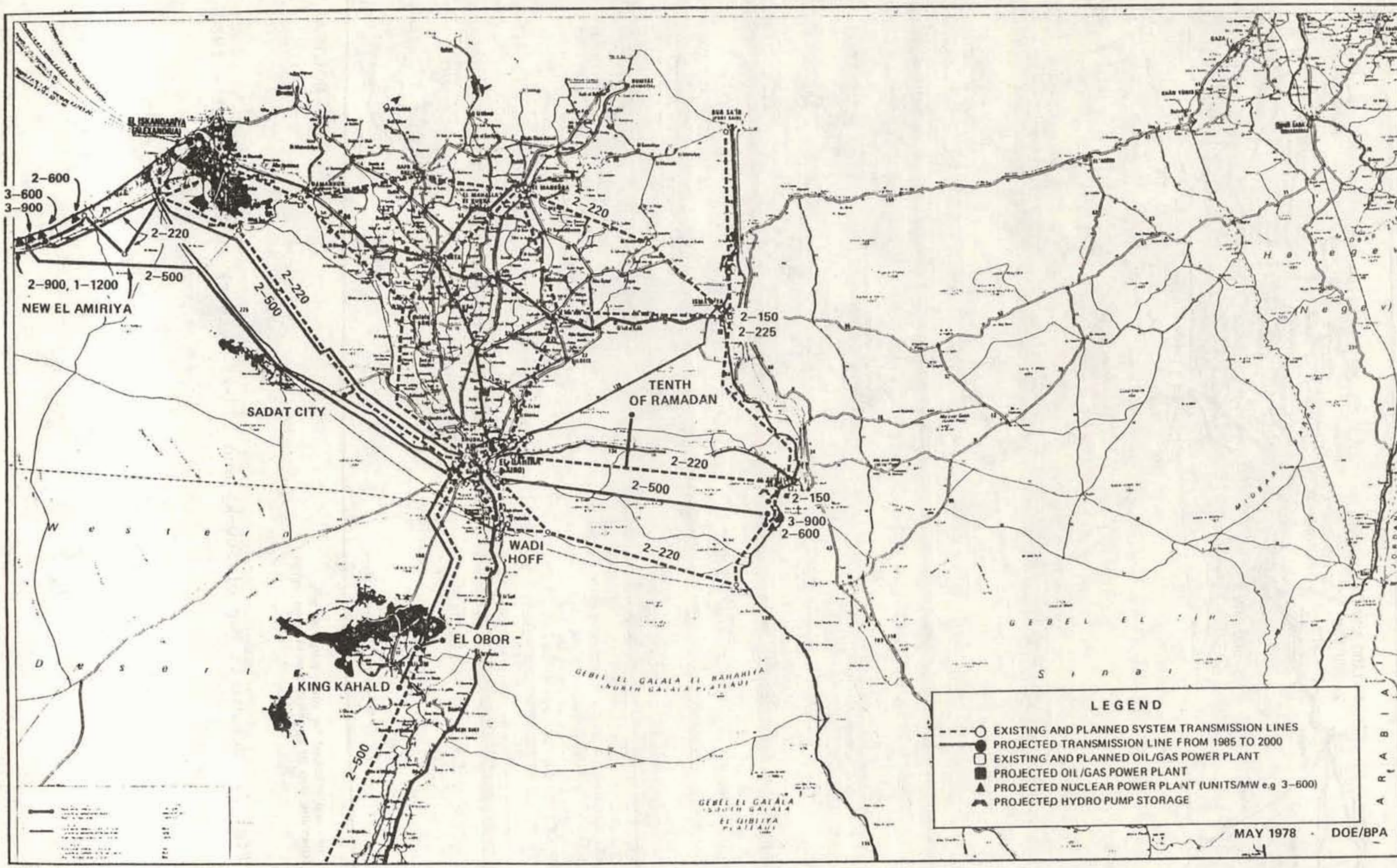
	Capacity MWe
Fossil Thermal, MWe	3,385
Hydroelectric, MWe	347
Nuclear, MWe	12,600
Hydro Pump Storage, MWe	2,900
Total	19,232

The transmission lines to serve new loads (including five new cities) and transmit the bulk power from the power generating stations are shown in figures 3 and 4. The two nuclear power generating complexes are assumed to be located on salt water coast lines, one along the Mediterranean Sea and another along the Gulf of Suez. Detailed planning studies will need to be prepared to determine the optimum system. One way of reducing the investment in transmission lines by some increment and also reduce transmission losses would be to site some of the generating stations near the new cities located in the desert. This would need to be evaluated along with higher plant construction costs, higher cooling water costs, lower thermal plant operating efficiency, and other technical and non-technical factors. If the loads in Upper Egypt increase to approximately 3,500 MWe by 2000, then the increased load in Upper Egypt could support one or more two-unit thermal power generating plants which could be located there. If one of the plants were to be sited on Lake Nasser, it could employ a once-through cooling system which would obviate the need for cooling towers; as a result, plant operating efficiency would be higher. If one of the plants was sited near Nag Hammadi, and integrated electrically at 500 kV to the existing 500 kV/230 kV substation, there could be some benefits to the 500 kV transmission system. Power flow and transient stability studies will need to be made and periodically updated to determine the optimum system as it is expanded out to year 2000. Figures 5 and 6 illustrate peak power flows based on the assumed conditions for 2000.



NOTES:
1. This schematic map was prepared for study purposes only.
2. See fig. 2 for schematic map of power system in lower Egypt.

Fig. 3. Schematic Map of 500-kV and 220-kV network in Upper Egypt - 1980



NOTE: This schematic map was prepared for study purposes only.

Fig. 4 Schematic map of unified power system in lower Egypt planned for 1980 and projected to the year 2000

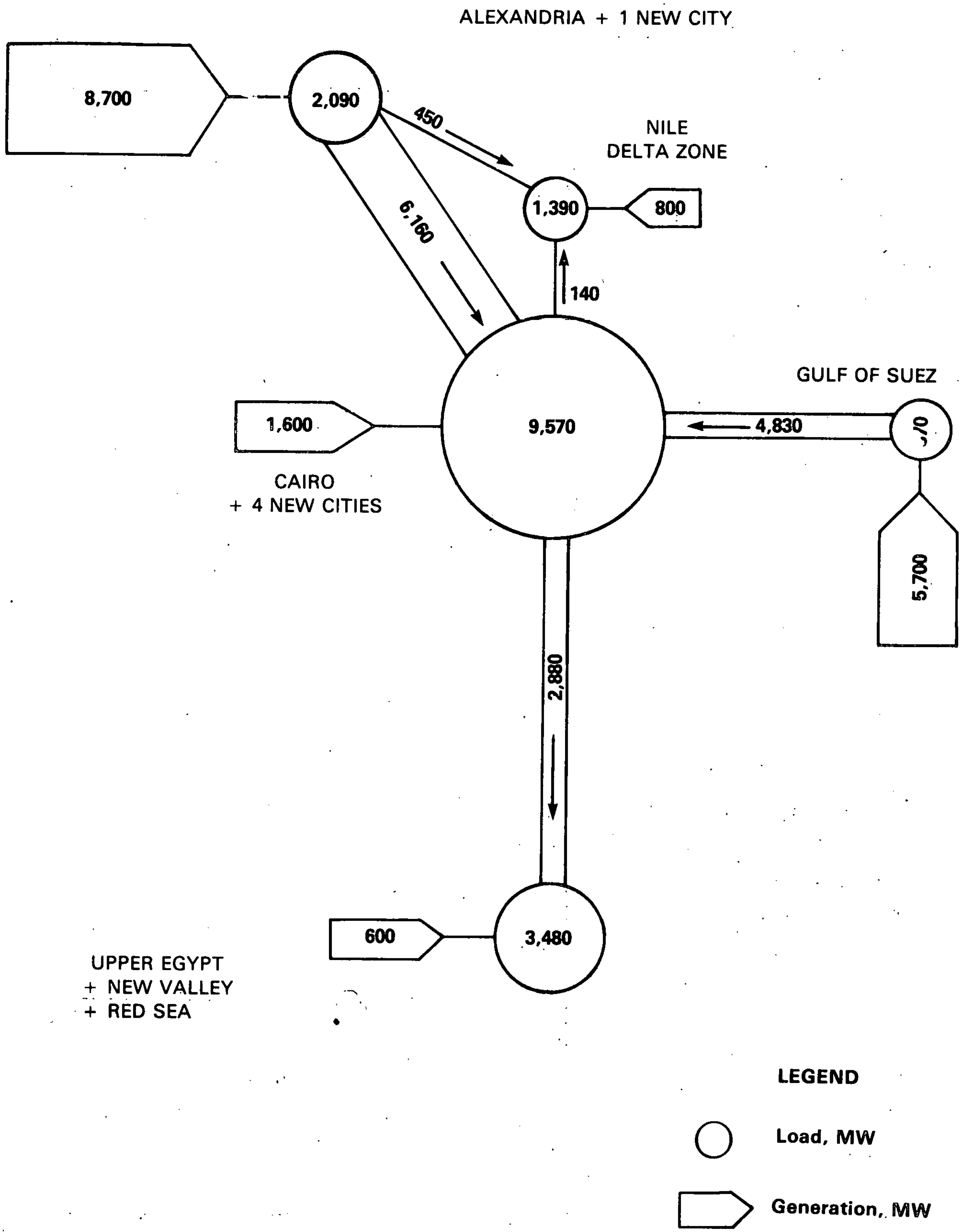


Fig. 5. Peak Load Power Flows, December and January - 1985-86

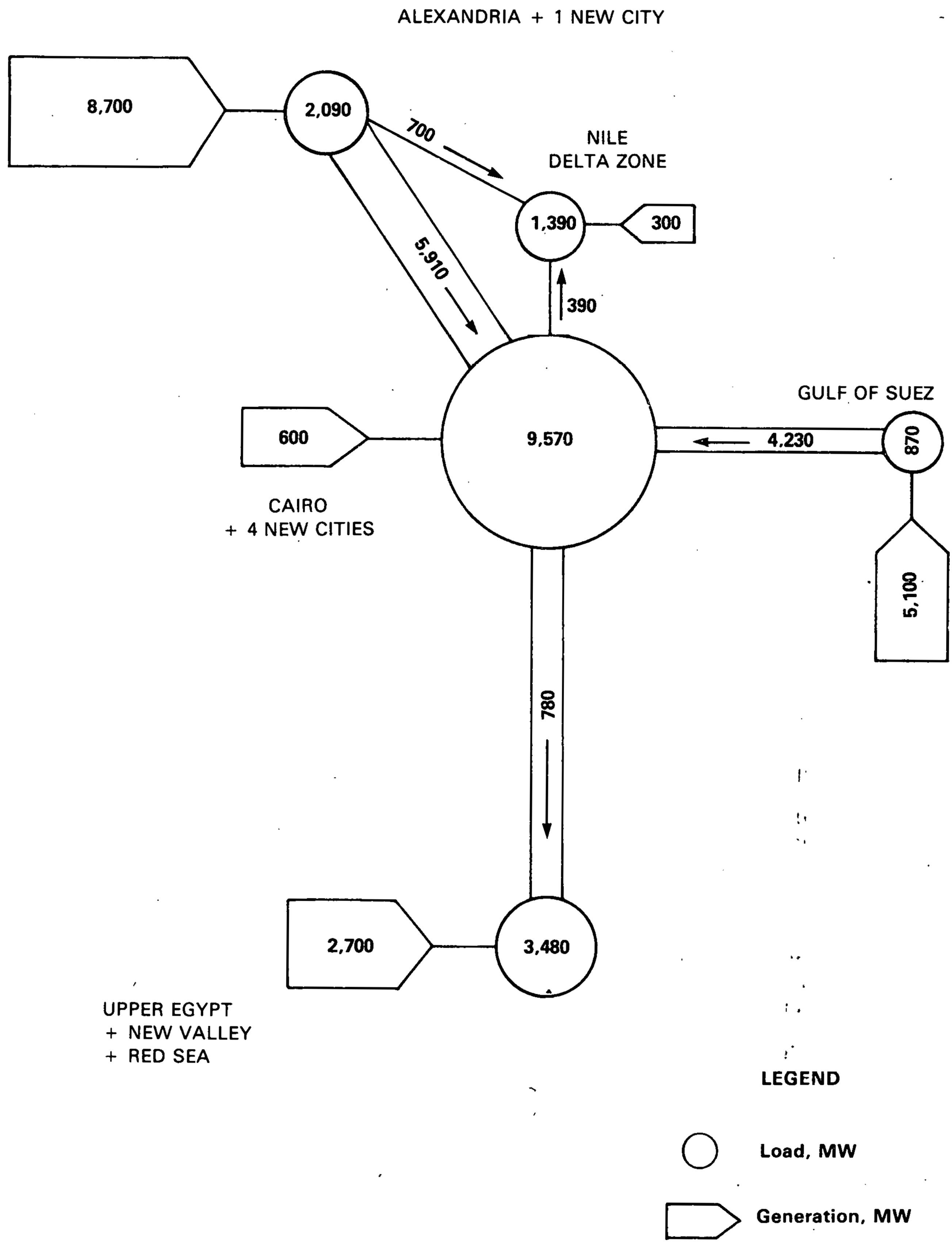


Fig. 6 Peak load power flows-irrigation seasons, year 2000

The Power System Control Center planned for completion by 1985 could be replaced before 2000 because of partial or complete obsolescence. The communication system will be enlarged as the power system expands further. The communication circuits will be needed for control and protection of power facilities, data transmission, and telecommunication for power dispatching, operations, and maintenance.

The order-of-magnitude estimated cost for the electrical power facilities constructed during the period of 1985 to 2000, based on 1978 dollars, is approximately $34 billion, as follows:

Facility	Amount $ Million
500-kV and 220-kV Transmission Systems	1,588
Distribution Systems	1,000
Control and Communication	150
Thermal and Hydro Generation	30,915
TOTAL	$33,653

The equivalent in Egyptian pounds is L.E. 22.7 billion.

3.0 EXISTING ELECTRICAL POWER SYSTEM

3.1 Independent Power Systems in Upper and Lower Egypt

As of 1962, and prior to the completion of the High Aswan Dam Project on the Nile, the power system of Egypt was characterized by the existence of a number of independent power districts with networks of 66 kV, 33 kV, 11 kV, and low voltage distribution lines. The main transmission lines at Aswan were 132 kV. These were in service in 1960 upon completion of the Aswan hydroelectric project, which consisted of seven units with a capacity of 46 MWe each, and two units with a capacity of 11.5 MWe, or a total nameplate capacity of 345 MWe. Most of the power is used by the Kima Company fertilizer manufacturing plant in Aswan.

The fertilizer manufacturing process begins with the electrolysis of water into hydrogen and oxygen. The fertilizer product contains 30 percent nitrogen in the form of calcium ammonium nitrate. Ferrosilicon steel is also manufactured at the Kima plant. The power consumption is 200 MWe for fertilizer and 20 MWe for ferrosilicon steel, or 220 MWe total for the plant. The High Aswan Dam, completed in 1970, is located 7 km south of Aswan. The effective capacity of Aswan has been reduced to 260 MWe because of reduced head upon completion of the High Aswan Dam.

3.2 Unified Power System - UPS

Many independent power districts and low voltage networks were electrically interconnected and operated as one main power system upon completion of the High Aswan Dam Project. The Unified Power System is planned, maintained, and operated by the EEA. Power is dispatched and the power system is controlled from the Power System Control Center located at the Cairo 500 Substation.

3.3 High Aswan Dam Project

The High Aswan Dam increased the hydroelectric generating capacity by 2,100 MWe. The power house consists of twelve hydroelectric turbine generator units each rated at 175 MWe. The turbine design head is 57.5 meters with a water discharge flow rate of 346 m^3/sec. The first 175 MWe unit was placed into service on October 15, 1967, and the twelfth unit was placed into service on July 7, 1970. Appendix B contains further details on that High Aswan Dam Project, including principal design data and operating experiences of the 500-kV transmission lines.

The major electrical facilities that were constructed as part of the High Aswan Dam Project include:

- 500-kV T. L. to Cairo, 2 circuits 788 km each;
- 220-kV T. L. Cairo-Alexandria, 2 circuits, 241 km total;
- 132-kV T. L. Upper Egypt, 508 km total;
- 500-kV Sectionalizing Stations at Nag Hammadi and Samalut with 165 MVA shunt reactor connected to the 500-kV bus by 500-kV air-blast power circuit breakers; and
- three 80 MVA synchronous condensers at Cairo 500 Substation.

3.4 Existing Generating Capacity

The existing generating stations, both hydro and thermal electric, are listed in table 1. The total installed thermal capacity is 1,402 MWe and hydro capacity is 2,445 MWe, or 3,847 MWe total for the Unified Power System.

For various reasons, not all this capacity, however, is available or effective for supplying load requirements in Lower Egypt. All of the thermal power generating units are from foreign manufacturers; some have efficient boilers with good control of combustion and others are poor, requiring frequent shutdowns for maintenance. The oldest units were installed about 30 years ago and the newest units went into service approximately 9 years ago. Replacement parts have been difficult to obtain for some of the units, resulting in long shutdown periods.

TABLE 1

EXISTING GENERATING STATIONS[2]

Plants	Type	Units & Size (MWe)	Total Name Plate Capacity (MWe)
Upper Egypt			
High Dam	H	12 x 175	2,100
Aswan Dam	H	7 x 49.5	345
Assiut	T	3 x 30	90
Cairo			
Cairo North	T	2 x 10	
		1 x 20	
		2 x 30	100
Cairo South	T	4 x 60	240
Cairo West	T	3 x 87	261
Tebbin	T	3 x 15	45
Cairo North	GT	1 x 17	17
Delta			
Talka	T	3 x 12.5	
		3 x 30	127
Damanhour	T	2 x 15	
		3 x 65	225
Alexandria			
Siouf	T	2 x 26.5	
		2 x 30	113
Max	GT	2 x 14	28
Karmouz	T	4 x 16	64
Canal Area			
Suez	GT	1 x 23	23
Ismailia	GT	1 x 23	23
Port Said	GT	2 x 23	46
Suez*	T	4 x 25	100

Total Thermal Units		37
Total Gas Turbine Units		7
Total Name Plate Rating - Thermal Plant	(T)	1,265 MW
Total Name Plate Rating - Gas Turbine Plant	(GT)	137 MW
Total Name Plate Rating - Hydro Plant	(H)	2,445 MW

* In the process of being restored to operation after having been seriously damaged during the wars.

[2] Egyptian Electricity Authority, Studies and Research Sector. Report on Review and Analysis of the United Power System Network and Expected Energy and Load Requirements up to 1985. December, 1976.

All of the installed hydroelectric capacity of 2,445 MWe (Aswan 345 MWe and High Dam 2,100 MWe) is not effective or available. Historically, since the High Dam went into full service in 1970, not more than 10 out of the 12 units have been available for service. Each of the six penstocks supplies water to two 175 MWe units. When one unit is down for maintenance the other unit is also shut down. The generating capacity at the Aswan Dam was reduced from 345 MWe to 260 MWe when the High Dam went into service. Because at least one of the units is down for maintenance, the available dependable capacity is about 225 MWe. Therefore, 1,975 MWe of generating capacity is about the maximum. Because of power system stability limits under steady state or transient conditions, the power transfer capability from the High Dam to the Cairo 500-kV Substation is less than 1,975 MWe. Studies by the Russians and others have shown that the maximum through power transfer capability under steady state conditions is of the order of 1,700 to 1,800 MWe.

Studies prepared by Sanderson and Porter [1], consultants for the World Bank, have indicated that under normal operation the limit of power transfer capability would be in the order of 1,420 to 1,500 MWe.

Peak load in Upper Egypt now is approximately 600 MWe. With ten units carrying full load at the High Dam, and assuming 225 MWe at Aswan, the power received at Cairo 500-kV Substation would be 1,975 MWe minus 600 MWe, or 1,375 MWe. By 1983, the EEA forecasts the load in Upper Egypt to be approximately 1,240 MWe. Hydro power available at Cairo 500-kV Substation in 1983, assuming these conditions develop, would be 1,975 MWe less 1,240 MWe, or 735 MWe. This, of course, is within the safe normal operating dynamic stability limit of the 500-kV T.L. For the 1980's, EEA and others feel that the upgrading of the 500-kV transmission system, by adding series compensation or a third 500-kV T.L. to Nag-Hammadi or all the way to Cairo, is not necessary.

The Surge Impedance Loading (SIL) of the three bundle conductor 400-kV T.L. operating at 50 H_z is 900 MWe, or 1,800 MWe for both lines. Each line could handle 200 MVA with 90° C maximum conductor temperature in 50° C ambient, or 4,000 MVA for both 500-kV lines. According to the Director at the High Dam, the maximum power generated as of April 1978 at the High Dam was 1,400 MWe.

3.5 Operating Experience

The number of "trip outs" or "flashovers" on the 500-kV transmission lines has decreased since the system was energized eight years ago. The EEA experienced flashover problems on lower voltage lines before the High Aswan Project was started. Based on EEA's past experience with 33-kV and 66-kV lines, cleaning or washing of insulators once or twice a year was envisioned.

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[1] Sanderson and Porter, Inc. Power Sector Survey, Arab Republic of Egypt System Planning Diagnostic Report Section I, Cairo, April, 1977.

Russian design for the 500-kV transmission lines provided for a minimum length of insulation leakage path of not less than 1.7 cm/kV (525 kV maximum working voltage), which was 30 percent higher than the insulation level for 500-kV transmission lines in the U.S.S.R. The operating experience of the 500-kV, 220-kV, and 132-kV transmission lines showed that the insulation level at some transmission line sections was not sufficient because of high concentration of salts in the soils and intensive contamination and moistening of insulators with dew.

During the period of November 1967 to February 1969, a group of Soviet specialists on insulation, with the help of Arab specialists, conducted research including studies on the process of insulation contamination and effectiveness of cleaning, analysis of salt concentration in soils, measurement of salt content and specific surface conductivity of contamination on the surface of insulators, measurement of discharge voltages of insulators dismantled from a large number of towers, and investigation of vibration of 3-bundled conductors at 10 to 20 percent increased average tension.

More insulators were added at different locations; insulators were washed twice a year between Samalut to Cairo, once a year between Nag-Hammadi to Samalut, and once every two years between Aswan to Nag-Hammadi. The number of insulators between Samalut and Cairo on some towers was increased to 40 bells or units in a string. The minimum number of insulator units in all of the strings was increased from 23 to 27 units.

During the five-year period from 1971 to 1975, Upper Egypt became separated from Lower Egypt 16 times. Load shedding is initiated automatically by under-frequency relays. The first set of underfrequency relays is set to trip at 49.2 H_z, which removes 65 percent of the load on the power system. A complete collapse of the system has occurred once during the last six years because all the zones did not properly shed load.

Table 2 shows the number of these separations and the accumulated total times for the year in hours and minutes.

TABLE 2
SYSTEM DISTURBANCES RESULTING IN SEPARATION OF LOWER AND UPPER EGYPT

Year	Number	Hour/Min.
1971	6	2/35
1972	3	0/49
1973	4	5/29
1974	3	2/35
1975	0	0/0

4.0 ELECTRICAL POWER FACILITIES UNDER CONSTRUCTION OR PLANNED FOR CONSTRUCTION BY 1985

4.1 Thermal Power Generating Stations

Table 3 is a list of thermal power generating stations under construction.

TABLE 3
THERMAL POWER GENERATING STATIONS UNDER CONSTRUCTION

Station Name	Type	Units/MWe	MWe	Financed By
Kafr El Dauwar	FT	2x110	220	EEA
Abu Qir	FT	2x150	300	EEA
Suez I	FT	2x150	300	West Germany
Ismailia	FT	2x150	300	USAID
Helwan	GT	4x30	120	USAID
Talkaha	GT	6x30	180	USAID

FT - Fossil Thermal Steam Electric Powerplant
GT - Gas Turbine Powerplant

Not included in the above list is a proposed large (± 600 MWe) plant presently being studied by Sanderson and Porter for EEA. The generation planning studies will determine the plant capacity, number of units, and location of the plant site. Earlier studies indicated that a 600 MWe plant (2 x 300 MWe) would be needed by 1984. It now appears that a 1984 schedule cannot be met and that a large plant will be needed by 1984 or 1985. The new plant will probably be designed to burn either oil or gas because of short time schedule and for other reasons. The S&P study is scheduled to be completed by October 1978.

4.2 Transmission Lines

Table 4 lists the 220-kV lines under construction and lines planned for construction within the next year. The estimated length of line is also tabulated.

TABLE 4

220-kV TRANSMISSION LINES UNDER CONSTRUCTION

Line	Distance/km	Remarks
Nag Hammadi-Abutartur UC	250	New Western Desert Phosphate mine
Cairo-Ain Sukhna UC	100	On Gulf of Suez
Cairo-Suez UC	120	On Gulf of Suez
Cairo-Ismailia UC	100	
Ismailia-Suez UC	60	
Suez-Ain Sukhna PC	40	This line will close a loop
Nag Hammadi-Safafa PC	180	Alumina and aluminum shipping port on the Red Sea

UC - Transmission line under construction
PC - Planned for construction to start within one year

Figures 3 and 4 are maps showing the existing, under construction, and projected generating stations and 500-kV, 220-kV, and 132-kV transmission lines.

4.3 Hydroelectric Power Generating Stations

Additional potential hydroelectric capacity in Upper Egypt is in various stages of planning. A second power house at Aswan would increase the capacity by 160 MWe with the addition of four units rated 40 MWe. Power houses added to the three existing barrages downstream from Aswan would provide some additional energy. The potential additional hydroelectric capacity is listed in table 5. It is possible some of this capacity could be built and available for service by 1985.

TABLE 5

POTENTIAL ADDITIONAL HYDROELECTRIC CAPACITY IN UPPER EGYPT ON THE NILE

Project	Units/MWe	Capacity/MWe
Aswan, 2nd P.H.	4 x 40.0	160.0
Esna	6 x 14.9	89.4
Nag Hammadi	5 x 10.5	52.5
Assiut	4 x 12.0	48.0

Information on hydroelectric potential, including Qattara Depression, and pump storage is covered by the Supply Team for Hydro Power. Two 500-kV transmission lines would probably be extended from the Unified Power System to Qattara Depression for the first phase, which would have a hydroelectric generating capacity of 640 MWe during the first ten years while the depression is being filled. After the level in the depression reaches minus 60 m below sea level from minus 131 m, the generating capacity would be reduced to 340 MWe.

4.4 Power System Control Center

The existing Power System Control Center is located at the Cairo 500-kV Substation; it was built as part of the High Aswan Dam Project. Under a USAID grant of $48 million, a new Power System Control Center will be constructed. The Computer Data Corporation (CDC) was awarded the contract to supply and install the latest automated computer-assist power dispatching system. The present multi-channel power line carrier communication system between the Cairo 500-kV Substation and the High Dam will be replaced. The General Electric Company will replace the power line carrier system and provide a microwave radio communications system for control and protection of power facilities in Cairo, Alexandria, and in the Delta. Gilbert Associates of Reading, Pennsylvania, have been engaged as architect-engineers for the project.

5.0 PAST AND PROJECTED GROWTH OF ELECTRICAL ENERGY

It is well recognized that making long-range electrical load forecasts with reasonable accuracy out to year 2000 is difficult. The EEA has undertaken several load forecasts to year 1985 and projections out to year 2000. Accurate forecasts are particularly difficult in Egypt because of past and present economic conditions. A sudden high rate of load growth has occurred during the last 5 years since the war of 1973.

5.1 Historical Data

Table 6 shows the installed capacity and energy generated by thermal and hydro from 1952 to 1976. Information for Table 6 was taken from the EEA "Annual Report of Electrical Statistics - 1976".[3]

TABLE 6

HYDRO AND THERMAL CAPACITY AND ENERGY 1952 - 1976

Year	Thermal		Hydro		Total	
	MWe	$kWh \times 10^6$	MWe	$kWh \times 10^6$	MWe	$kWh \times 10^6$
1952	150	400	0	0	150	400
1959	550	1,400	0	0	150	1,400
1965	650	2,800	350	1,700	1,000	3,500
1970	1,335	2,000	2,445	4,900	3,780	6,900
1975	1,335	3,000	2,445	6,800	3,780	9,800
1976	1,344	3,640	2,445	8,000	3,789	11,640

5.2 Forecasted Growth to 1985

Table 7 is a tabulation of the installed effective capacity, maximum demand, and generated energy and the annual load factor.[4] The annual rate of load growth from 1970 to 1976 varied over a wide range. The annual load factor, higher than for most electrical power systems throughout the world, is expected to decrease after 1983.

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[3] Ministry of Electricity and Energy, EEA. Annual Report of Electric Statistics, 1976.

[4] Egyptian Electricity Authority. Report on Review and Analysis of the United Power System Network and Expected Energy and Load Requirements up to 1985. December, 1976.

TABLE 7

PROJECTED GROWTH OF TOTAL INSTALLED EFFECTIVE GENERATING CAPACITY, MAXIMUM DEMAND, AND GENERATED ENERGY[5], 1970 - 1985

Year	Installed effective generating capacity[a]	Maximum Demand MWe	Maximum Demand Annual increase (%)	Generated Energy GWH	Generated Energy Annual increase (%)	Annual load factor (%)
1970[b]		1,091		6,800		71.2
1971[b]		1,121	2.7	7,300	7.4	74.3
1972[b]		1,176	4.9	7,400	1.4	71.6
1973[b]		1,248	6.1	7,400	0	67.6
1974[b]		1,433	14.8	8,500	14.9	67.7
1975[b]		1,733	20.9	9,800	15.3	64.6
1976[b]	2,477	1,909	10.2	11,640	18.8	69.4
1977	2,711	2,192	14.8	13,500	16.0	70.3
1978	3,271	2,470	12.7	15,150	12.2	70.0
1979	3,568	2,678	8.4	16,750	10.6	71.4
1980	4,075	2,924	9.2	18,520	10.6	72.1
1981	4,643	3,192	9.2	20,470	10.5	73.2
1982	5,550	3,578	12.1	22,630	10.6	72.2
1983	5,811	4,028	12.6	25,020	10.6	70.9
1984	6,111	4,518	12.2	27,660	10.6	69.7
1985	6,675	5,045	11.7	30,580	10.6	69.2

Maximum Demand Compound Rate %		Generated Energy Compound Rate %	
(1952-76)	12.6[b]	(1952-76)	11.1[b]
(1970-76)	9.8[b]	(1970-76)	9.4[b]
(1976-80)	11.2	(1976-80)	12.3
(1981-85)	12.1	(1981-85)	10.6
(1976-85)	11.4	(1976-85)	11.3

a Total installed effective generating capacity = combined contributions of Aswan Dam and High Dam towards meeting annual maximum demand + installed and projected effective capacity of all other plants. (Does not account for scheduled or unscheduled equipment outages.)

b Historical data.

5 EEA, December, 1976

A study prepared by EEA[6] dated December 1976 shows the forecasted peak load and energy demand for the period of 1980 to 1985. The information is reproduced in table 8.

TABLE 8

PEAK LOAD AND ENERGY DEMAND 1980 TO 1985[6]

Year	Peak Load MWe	Annual Energy Billion kWh
1980	2,950	19.95
1981	3,130	21.94
1982	3,430	24.13
1983	3,790	26.55
1984	4,100	29.2
1985	4,500	32.12

In order to meet the energy requirements in the period from 1981 to 1985, the EEA planned to have the thermal power generating stations added to UPS as shown in table 9.

TABLE 9

PROPOSED THERMAL POWER GENERATING STATIONS FOR PERIOD 1981 to 1985[6]

Station	Units/MWe	Total MWe	Scheduled to Operate
Abu-Kir	2 x 150	300	1981
Ismailia	2 x 150	300	1981-82
Suez I	2 x 150	300	1981-82
Suez II	2 x 150	300	1982
Nuc (Sidi Krir)	1 x 600	600	1983
Nuclear	1 x 600	600	1985

The EEA study of December 1976 also showed additional 220-kV transmission lines that would be needed by 1985 (no 500-kV T. L. additions). Figures 3 and 4 are maps showing the existing, proposed 1985, and projected Unified Power System as it might develop out to year 2000.

[6]Ministry of Electricity and Energy, Egypt. Oattara Depression.

5.3 Projected Growth from 1985 to 2000

Future plans for power system expansion from 1985 to 2000 were not as far along as those up to 1985. EEA indicated plans for 1985 to 2000 would be completed by October 1978. However, EEA did supply a tabulation prepared for a system reserve analysis to year 2000 and indicated the information could be used for study purposes in the interim. The projected added capacity, available system capacity, peak demand, and reserve percentages are shown in table 10.

TABLE 10

PROJECTED SYSTEM CAPACITY AND RESERVES TO YEAR 2000

Year	Added Capacity MWe	Retired Cap. MWe	Total Avail. Cap. MWe	Peak Demand MWe	Reserves MWe	Reserves %
1983	0	0	5,786	4,028	1758	43.6
1984	450T+59ES		6,236	4,518	1718	38.0
1985	450T+30SS	36	6,716	5,045	1671	33.1
1986	600N+59ES	34	7,341	5,527	1814	32.8
1987	600T+33NH		7,974	6,066	1908	31.4
1988	600N+66AS	40	8,564	6,629	1935	29.2
1989	600N+150PS		9,314	7,221	2093	30.0
1990	600N+150PS	26	10,038	7,834	2204	28.1
1991	600N+150PS		10,741	8,510	2231	26.2
1992	600N+150PS		11,491	9,208	2283	24.8
1993	600N+300PS		12,231	10,032	2359	23.5
1994	900N+300PS	100	13,491	10,884	2607	24.0
1995	900N+300PS	240	14,451	11,826	2625	22.2
1996	900N+300PS	24	15,627	12,794	2833	22.1
1997	2 x 900N	172	17,255	13,941	3314	23.8
1998	2 x 900N	623	18,432	15,015	3417	21.1
1999	900N+300PS	166	19,466	16,197	3269	20.2
2000	1,200N+450PS	330	20,785	17,395	3391	19.5

Notes: The projected energy requirement for 2000 is 97.79 kWh x 10^9

Abbreviations:

AS - Aswan (Lower Aswan Dam)
ES - Esna (An Existing Barrage)
PS - Hydro Pump Storage
N - Nuclear Power Generating Station
SS - Assiut (An Existing Barrage)
NH - Nag Hammadi (An Existing Barrage)
T - Thermal Power Generating Station

Most of the electrical loads and people are concentrated in the cities of Cairo and Alexandria and in the immediate suburban area. The population of Egypt is about 40 million and approximately 10 million are in Cairo. The population is rapidly expanding in Cairo and Alexandria. Most of the country of Egypt with an area of about 1 million km^2 is desert and less than 4 percent of the land is used for farming.

Egypt has been preparing plans to improve the economic social well being of its people. The plans include development of five new cities in the desert, with industry to reduce the population pressure on the large cities and to provide more and better employment. The cities would provide facilities and amenities for 500,000 people in each city. The power requirements for industry, commercial, and domestic loads have been estimated at about 250 MWe for each of the five cities. Table 11 lists the new cities and their approximate locations.

TABLE 11

LIST OF FIVE NEW PROPOSED DESERT CITIES

City		Location
1.	Sadat City	Approximately 75 km NW of Cairo
2.	New Amiriya	Approximately 75 km SW of Alexandria
3.	Tenth of Ramadan	Between Cairo and Ismailia
4.	El Obor	See Note
5.	King Kahald	See Note

Note: The sites for El Obor and King Kahald are near El Faiyum, which is approximately 110 km south of Cairo. El Faiyum is located near an oasis which is west of the Nile River, approximately 37 km by an existing highway.

The per capita electrical energy consumption after the population in the cities has grown to 500,000 people in 25 years is expected to be about 1,160 kWh per year. This is based on, for example, 583.7 GWH (or 583.7×10^6 kWh) total use of electrical energy for all services--industry, commercial, and domestic. Alexandria used about twice this much in 1976.

Alexandria's population of 2,300,000 used 1.162×10^9 kWh in 1976 or 505 kWh/year/capita. It has been estimated that domestic consumption is about 17 percent of the total or 86 kWh/year/person. National usage by 38 million people was 11.64×10^9 kWh in 1976 or approximately 305 kWh/year/capita.

Table 12 data is based on information provided by EEA and as tabulated in table 10. The annual growth in peak demand is projected at about 8 to 9 percent. Table 12 assumes this electrical energy and capacity requirements will be served primarily by conventional sources.

TABLE 12*

PROJECTED LOADS AND RESOURCES WITH OPTIONS TO YEAR 2000

	1976	1985	2000			
			Option 1	Option 2	Option 3	Option 4
Capability, MWe	3,789	3,789	20,785	20,785	20,785	20,785
Hydro	1,500	2,130	2,200	2,200	2,200	2,200
P. S.	0	0	2,900	4,300	2,900	4,300
F. Thermal	2,289	4,540	3,385	3,985	4,415	8,015
Nuclear	0	0	12,600	10,600	10,600	5,600
Qattara Depr.	0	0	0	0	640	640
Peak Demand, MWe	1,909	5,045	17,395	17,395	17,395	17,395
Energy, B kWh:						
Generated	11.64	30.58	103.29	105.89	103.29	105.89
Load	11.63	30.58	97.79	97.79	97.79	97.79
Pumping	0	0	5.50	8.10	5.50	8.10

*Prepared in collaboration with the Supply Team during the debriefing on April 25 and 26, 1978, in Washington, D.C.

By year 2000 it is expected that solar energy will be used, particularly for supplying some of the energy needs, such as for heating hot water and for central air conditioning. Space heating requirements are minor. There may also be other new renewable types of resources employed for generation of electrical energy, such as wind, geothermal, and photovoltaic. If these sources become available for generation of electrical energy, they will make contributions to supplying some part of electrical energy needs by year 2000.

The use of direct solar heating of water, of course, would reduce the consumption of butagas. Cooking and lighting with electricity in the villages would reduce consumption of kerosene and increase use of electricity.

6.0. DISTRIBUTION

Distribution facilities in most of Egypt are run-down and overloaded. The subtransmission network at 66 kV (2600 km) and 33 kV (1600 km) supplies 11 kV, 6.6 kV, and 3 kV distribution facilities. Low voltage distribution is 380/220 volts, patterned after European practices. System frequency is 50 H_z.

Two major efforts are in progress to rehabilitate and expand the distribution facilities. One under EEA is a distribution project for Cairo, Alxandria, Beni Suef, and Shibin-El-Kom by Harza Overseas Engineering Company and Sabbour Associates.[7] This work is funded by USAID, $50 million. The other by the Rural Electrification Authority (REA) covers a regional population of 6 million people in about 32 zones. The World Bank is financing work for about 18 percent of REA's National Rural Electrificiation Plan which was started in 1971 with the help of Soviet consultants.[8] The World Bank loan is in the amount of $48 million.

The total cost of the REA portion of the distribution rehabilitation and expansion project (1978-80) in 32 REA zones is estimated at $70.6 million (a portion, $48 million, was loaned by the World Bank). The project consists of approximately 3,400 km of 11-kV and 380/220 V overhead and underground distribution lines and related equipment, 230 MVA of substation and distribution transformer capacity, and 100 km of 66-kV and 33-kV subtransmission lines and related facilities, training, and consulting services.

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[7] Harza Overseas Engineering Company and Sabbour Associates. Electrical Distribution System Rehabilitation and Expansion for Cairo, Alexandria, Beni Suef, and Shibin El Kom. Phase I Report. February, 1978. (Funded by A.I.D.)

[8] Harza Overseas Engineering Company and Sabbour Associates. Electrical Distribution System Rehabilitation for Expansion for Nine Provincial Cities: Assiut, Aswan, Damietta, El Minya, Fayoum, Fuwa, Mahalla, Mansoura and Tata. Phase I-A Report. February, 1978. (Funded by IBRD.)

7.0 ELECTRICAL POWER SYSTEM PROJECTED FROM 1985 TO 2000

7.1 Thermal Power Generating Stations

Generation planning and transmission system planning out to year 2000 have not been completed by EEA and its consultants. The location of future conventional thermal power generating stations (oil, gas, and nuclear) are based on typical criteria for plant siting factors and system loads. Siting studies for nuclear plants are being conducted by French consulting engineers.

Figures 3 and 4, which show a projected layout of generating stations, transmission lines, and substations were prepared for making order-of-magnitude estimates. The figures do not represent results of load flow or transient stability studies.

Table 13 is a list of thermal power generating stations projected for the period from 1985 to 2000.

7.2 Hydroelectric Power Generating Station

Table 12 shows the hydroelectric capability or effective capacity for the years 1976, 1985, and 2000. The capability of the installed hydroelectric capacity which is located in Upper Egypt to supply load in Cairo depends on water supply available for generation of power, the load in Upper Egypt, power transfer capability of the two 500-kV transmission lines to Cairo, and the availability of the hydroturbine generator units. Table 14 lists the existing and proposed additional hydro capacity that could be installed in Upper Egypt.

Table 15 lists the potential hydro pump storage projects along the Gulf of Suez and the Qattara Depression.

7.3 Transmission Lines and Substations

During the period between 1985 to 2000 the 500-kV transmission system would be extended from Cairo to Alexandria and to the large thermal power generating stations located along the Mediterranean Sea. Also, 500-kV transmission lines would be extended from Cairo to the power projects (power plants and pump storage) located south of Suez on the Red Sea.

Table 16 is an order-of-magnitude type of projection for additional 500-kV and 220-kV transmission lines for the 1985-2000 period.

7.4 Power System Control and Communication

Power system, control, protection, and communication facilities will be expanded with the expanded power facilities for the period of 1985 to 2000. Basically, both microwave and powerline carrier will provide the essential communications for transmission of data, protection of transmission lines, transformers and other electrical apparatus, control, and telecommunications. In Upper Egypt multichannel carriers on the 220-kV transmission lines could provide communication circuits extended to Safaga on the Red Sea. In Lower Egypt the microwave communication system could be extended to the large power generating complexes on the Mediterranean Sea and Gulf of Suez.

The new power system control center and communication systems presently in the design stage and placed in operation before 1983 will be expanded during the next decade. The carrier and microwave system installed in 1983 probably will be in service by 1995 but will be gradually replaced due to obsolescence. The high technology computers, dispatching terminals, and other peripheral facilities in the power system control could be replaced sometime before 1995 due to obsolescence and difficulties in obtaining spare parts.

7.5 Order-of-Magnitude Cost Estimates

A summary of the order-of-magnitude cost estimates for electrical power system facilities built for and during the period of 1985 to 2000 is indicated in table 17. The costs are based on 1978 price levels including escalation and interest during the construction period.

TABLE 13

THERMAL GENERATING STATIONS PROJECTED FOR PERIOD 1985 - 2000

Type	No.	Size MWe	Total Cap. MWe
Oil/Gas	2	450	900
Oil/Gas	1	600	600
Nuclear	7	600	4,200
Nuclear	8	900	7,200
Nuclear	1	1,200	1,200
			14,100

TABLE 14

EXISTING AND PROPOSED ADDITIONAL HYDROELECTRIC CAPACITY AND ENERGY IN UPPER EGYPT

Power House	Max. Cap. MWe	Conventional Annual Gen. GWH	Capacity Factor %
Existing:			
High Dam	2,100	5.01	27
Aswan[1]	260	1.78	59
Subtotal	2,360	6.79	
Proposed:			
Aswan 2nd P.H.	160.0	.59	42
Esna[2]	89.4	.55	70
Nag Hammadi[2]	50.2	.29	66
Assiut[2]	48.0	.26	62
Subtotal	347.6	1.69	
Total	2,707.6	8.48	

[1] The installed capacity at the Aswan Hydroelectric Power House is 345 MWe. After completion of the High Aswan Dam the capability was reduced to 260 MWe because of lower hydraulic head.

[2] Existing Barrages. Potential hydro capacity at four other Barrages further down stream have been studied but these projects do not appear to be economically feasible at this time unless a large share of the construction costs is offset and allocated for benefits to irrigation.

TABLE 15

POTENTIAL HYDRO PUMP STORAGE PROJECTS AND QATTARA DEPRESSION

Power House	Max. Cap. MWe	Conventional Annual Gen. GWH
Suez #1 (El Bahariya)	1,000	
Suez #2 (El Bahariya)	1,900	
Suez #3 (Atiga)	1,400	
Qattara:[1]		
Phase I	670	5.69
Phase II	530	3.12
Phase III[2]	1,200[2]	4.64[2]

1 Qattara Depression with an open canal.

2 Combined conventional hydrogenerator and pumped storage.

TABLE 16

ADDITIONAL 500-kV AND 220-kV TRANSMISSION LINES PROJECTED FOR PERIOD 1985 to 2000

500-kV Transmission Line		No. of Circuits	Total Length,km	No. of Terminals
Cairo 500 - El Amiriya[7]		2	430	4
Cairo 500 - Cairo SW[7]		1	20	2
Cairo 500 - Cairo S[7]		1	20	2
Cairo SW - El Faiyum		1	120	2
Cairo SW - Cairo S[7]		2	40	4
Cairo SW - Med 500 #2[7]		2	520	4
Med 500 #1 - El Amiriya[7]		2	100	4
Cairo S - Suez[7]		2	240	4
El Faiyum[1]		2	40	2
Suez Hydro P.S.[2]		2	50	4
GOS Plant #1 P.H. Lines[3]		2	4	2
GOS Plant #2 P.H. Lines[3]		3	6	3
	Total		1,590	37
200 kV				
Med 500 #1 - Sidi Krir		2	10	4
GOS 500 kV/220 kV Sub. Sta.[4]		4	40	4
Suez Hydro P.S.[2]		4	100	8
Sadat City[5]		4	40	4
Tenth of Ramadan[6]		4	80	4
Cairo 500 - Cairo N		2	40	4
El Faiyum - El Obor		2	50	4
El Faiyum - King Kahald		2	50	4
Aswan - New Valley		2	200	4
Hydro P.S. P.H. Lines		4	4	4
	Total		614	44

[1] One of the existing Cairo-Aswan High Dam 500-kV lines looped into new El Faiyum 500-kV Substation.

[2] Hydro pump storage plant near Suez integrated with 500-kV and 220-kV transmission lines.

[3] Gulf of Suez Nuclear Power Plant Number 1 and 2 x 600 MW power house line to Gulf of Suez 500-kV/220-kV Substation.

[4] Two existing Ain Suknna-Suez 220-kV transmission lines looped into Gulf of Suez 500-kV/220-kV Substation.

[5] Two existing Cairo-Tohrir II (Abon El Matamir) 220-kV lines looped into new Sadat City.

[6] Two existing 220-kV transmission lines looped into new Tenth of Ramaden City.

[7] High capacity 500-kV transmission lines (4000 MW per circuit).

TABLE 17

A SUMMARY OF ORDER-OF-MAGNITUDE ESTIMATED COSTS OF ELECTRICAL POWER FACILITIES 1985 - 2000

Facility	Unit Cost $ Million	Quantity	Amount $ Million
500 kV T.L., $\$10^6$/mi	.50	220	110
500 kV T.L. High Cap. $\$10^6$/mi	.60	1,370	822
500 kV Terminal $\$10^6$ each	8	37	296
220 kV T.L., $\$10^6$/mi	.3	614	184
220 kV Terminal $\$10^6$ each	4	44	176
Distribution Lump Sum	1000	Lump	1,000
Power System Control + Comm $\$10^6$/Lump		Lump	150
Oil/Gas Power Units, $\$10^6$/450 MW	200	2	400
Oil/Gas Power Plant, $\$10^6$/600 MW	270	1	270
Nuclear Power Units, $\$10^6$/600 MW	850	7	5,950
Nuclear Power Plant, $\$10^6$/900 MW	1,206	8	9,648
Nuclear Power Plant, $\$10^6$/1,200 MW	1,400	1	1,400
Subtotal			17,668
Hydro Pump Storage $\$10^6$/MW	1.0	2,900	2,900
Hydroelectric Plants $\$10^6$/MW	1.0	347	347
Total Generation			30,915

Summary:

Facility	Amount $ Million
Transmission	1,588
Distribution	1,000
Control and Communication	150
Generation	30,915
Total	$33,653

Or approximately $34 Billion, or L.E. 22.7 Billion Egyptian Pounds

8.0 OBSERVATIONS AND OPTIONS

The reliability of the UPS transmission system has improved significantly since 1970. The reliability and quality of service is expected to further increase by 1985 with the addition of sufficient generating capacity, transmission lines, the new Power System Control Center, and with adequate numbers of appropriately trained operating and maintenance personnel.

The planned expansion and upgrading of the distribution facilities combined with a systematized maintenance program (procedures and stock control of replacement parts and material) and adequately trained and equipped crews will improve the availability of higher quality electric service to all sectors of consumers.

Generation planning studies are being prepared for the near-term generation requirement. It would be appropriate to include studies to determine the cost and benefits of increasing the power transmission capability of the existing two 500-kV transmission lines between Cairo 500 and the High Dam. It is possible that the increase in transmission capacity from 1,000 MWe to 2,000 MWe would be of significant benefit not only from south to north but also power transfers from north to south.

Preparation of an accurate, comprehensive study of future load growth for each year to 2000 is a difficult task. The information with respect to projected capacity and energy requirements, load duration, daily load cycle, and location of loads is needed for generation and transmission system planning studies. The load growth studies are also needed for planning for distribution facilities.

An option with respect to the existing oil-fired power generating stations would be to establish a vigorous power plant operating efficiency improvement program. The other options are to shut down the small, old, inefficient plants and maintain them on a cold standby basis or dismantle the power plants and use the site for a new plant or for other purposes.

9.0 APPENDICES

9.1 Appendix A - Contact List

Discussions with Egyptian officials in Egypt were held from March 23 to April 19, 1978.

March 25: Harza Engineering Company, Vaugh J. Andres, P.E., Resident Manager; Thomas E. Horkay, P.E., Resident Manager; Herbert Barton, Senior Electrical Engineer; Lawrence E. Rodewald, P.E., Senior Utilities Engineer; and Dr. Zahedani, Economist. Harza has prepared studies of existing distribution facilities and requirements for rehabilitation and expansion of electrical distribution facilities financed by the U.S. Agency for International Development (USAID) and the

International Bank for Reconstruction and Development (IBRD). The Phase I study, financed by USAID, was for Cairo, Alexandria, Beni Suef, and Shibin El-Kom. Phase I-A study, financed by IBRD, was prepared for nine provincial cities with a combined population of 6 million.

March 29, April 1 and 15: Engineer Adly Kamel Yakan, Principal Executive Chairman, and Undersecretary of State Ministry of Electricity, Engineer Naguib Ibrahim Rizk and Mohamed Caha El-Safty, Undersecretary of State Ministry of Electricity. All are with the Qattara Depression Project Authority. The Qattara Authority also is responsible for planning and engineering work for hydroelectric and pump storage projects as well as for the Qattara Depression Project. Tel. 28621.

April 2: Egyptian Iron and Steel Company located in Helwan. Engineeer Tawakol El Maghrabi, Vice Chairman. Tel. 38523.

April 4 and 17: Dr. Mostafa Swidan, Director, Power System Planning, Egyptian Electricity Authority (EEA). Tel. 831-525.

April 6: Dr. Eng. Hamdy M. El-Shaer, General Director of Operating Conditions and Computing Center Dispatching Inspectorate EEA, and Yehia Abu-Alam, Project Control Manager, National Energy Control Center. The Power Control Center is located near the West Cairo Steam-Electric Generating Station on the Nile River near Embaba, a suburb of Cairo. Tel. 971260 and 91252.

April 8: Mohamed A. Elnefely, General Director, High Aswan Dam and Sayed Grad, Head of Public Relations, Kima Co. at Aswan. The Kima Co. produces hydrogen and oxygen by electrolysis of water. The hydrogen is combined with nitrogen, three parts of hydrogen to one part nitrogen, to make ammonia as part of the fertilizer manufacturing process. The fertilizer is in solid form as calcium ammonium nitrate. The Kima fertilizer plant, which was built before High Aswan was constructed, uses 220 MWe of power, of which 20 MWe is used for the manufacture of ferrosilicon. Most of the oxygen which is produced as a by-product (300 tons per day) is wasted by venting to the atmosphere.

April 9: Aluminum plant in Nag Hammadi. Design capacity is 100,000 tons per year. Electrical power required is 240 MWe. The energy consumed for reduction of aluminum is 16,500 kWh per ton. The total energy consumed by the aluminum plant including for casting and for the rod mill is 18,000 kWh per ton of aluminum. Construction is underway to increase the capacity to 166,000 tons per year which will require an increase in power requirements from 240 MWe to 400 MWe total.

April 11: NASR Oil Refinery in El Ameriya which is near Alexandria.

April 12: El Siouf Electric Generating Station, Abdel Aziz, Power Plant Superintendent; MISR Rayon Co., Shoku Elkalya, Deputy Director, located in Kafr Ed Dauwar.

April 18: John W. Callahan, P.E., Power Engineer, U.S. Agency for International Development (USAID), American Embassy, Cairo, Egypt. Tel. 28219.

Discussions were also held in Washington, D.C. on Monday and Tuesday, April 24 and 25 with the following people from the World Bank and USAID on Electrical Power Systems:

April 24: Mr. Auturo Roa, the World Bank.

April 25: Mr. Thomas Sterner, USAID.

9.2 Appendix B - High Aswan Dam Project

9.2.1 History: The construction of the High Aswan Dam on the Nile in Upper Egypt was a fulfilled goal of President Nasser and the people of Egypt to control the devastating floods of the Nile, provide irrigation water during periods of drought, and generate a relatively large block of power. Planning and negotiations for this project were conducted during the 1950's and 1960's. President Nasser successfully concluded agreements with Russia for financial loans to design and construct the High Aswan Project. The project was a major undertaking and included design and construction of (a) the earth-filled high dam, (b) 500-kV transmission lines to Cairo, (c) 220-kV transmission lines from Cairo to Alexandria, (d) two 500-kV sectionalizing stations with 500-kV/132-kV transformation, (e) 132-kV transmission lines and substations in Upper Egypt, and (f) 500-kV substation at Cairo with 500-kV/220-kV transformation and three 80 MVA synchronous condensers.

In 1959 an agreement was concluded with the Sudanese Republic which stipulates that:

1. The net live storage of the Aswan High Dam is calculated on the basis of the average Nile annual discharge at Aswan. After ensuring the prior rights of both countries amounting to 48 billion m^3 to the Sudan, the net benefit of 22 billion m^3 resulting from the High Dam is to be divided between both countries at the proportion of 7.5 billion m^3 for the U.A.R. and 14.5 billion m^3 for the Sudanese Republic.

2. The U.A.R. Government pays 15 million Sterlings to the Sudanese Government as an indemnity for the properties which will be inundated by the storage water within the Sundanese Boundaries, and the Sudanese Government takes the necessary measures for transferring the inhabitants of that region before the end of July 1963.

The length of the Nasser reservoir is 500 km with an average width of 10 km and the surface area is 5,000 km^2. The maximum storage level above sea level is 182 m, reservoir capacity is 157 billion m^3, dead storage is 30 billion m^3, flood central storage capacity is 37 billion m^3, operational capacity is 90 billion m^3, and guaranteed live storage is 84 billion m^3. The annual evaporation and seepage losses are 10 billion m^3 with a net live storage of 10 billion m^3.

The estimated cost of the project amounted to 415 million Egyptian pounds.

<u>9.2.2 Power house</u>: The first 175 MWe hydroelectric generating unit was placed into service on October 15, 1967. The twelfth and last unit was energized on July 7, 1970. The total installed nameplate capacity at the High Dam is 2,100 MWe. Each unit has a generator step-up transformer. The 500-kV side of three step-up transformers are connected together to form a group of 2 x 175 MWe units. Each group is connected to two separate 500-kV buses by means of two 500-kV air-blast power circuit breakers. There are four groups of three units connected to the two separate 500-kV buses. This is an economical and a flexible arrangement. A 500-kV PCB can be taken out of service for maintenance without the loss of generation from the group of three units.

Six penstocks supply water to the twelve hydraulic turbines. If maintenance is required on a unit the common unit also must be shut down, which can result in a restriction on available generation during periods of maximum water flow.

The design head is 57.5 m with a turbine discharge of 346 m^3/sec. Turbine capacity at design head is 180 MWe. The head variation is 77-35 M and speed is 100 rpm.

<u>9.2.3 Transmission</u>: The protocol of agreement for the construction of 500, 220, and 132-kV transmission lines, the design of which was by the Soviets and agreed to by the U.A.R., was completed on June 8, 1969.

The major electrical facilities that were constructed included the following:

1. Two 500-kV lines from High Dam to Cairo; total length of both circuits: 1,576 km (788 km each).

2. A two-circuit 220-kV line from Cairo to Alexandria and in the Cairo region, total length 241 km.

3. A two-circuit 132-kV line from Quena substation through Nag-Hammadi-Assiut-Samalut up to Beni-Suef, total length 508 km.

4. Three 500-kV substations, Nag-Hammadi, Samalut, and Cairo 500. Nag-Hammadi and Samalut served as 500-kV sectionalizing switching stations with two main 500-kV buses. The 500-kV lines are terminated with two 500-kV air-blast power circuit breakers permitting each line to be connected to both buses or to either bus.

5. Six 220-kV substations, Helwan, Heliopolis, Tahrir-II, Alexandria-II, Zagazig, and Tana.

6. Five 132-kV substations, Sohag, Mallawi, El-Minia, Naghagha, and Beni-Sueff.

7. Central dispatcher office, computer, carrier communication, and telemetry.

8. Three 80 MVA synchronous condensers at the Cairo 500 Substation.

9. Shunt reactors at High Dam, Nag-Hammadi, and Samalut, six reactors each rated 165 MVA. Figure 3 shows the 500-kV, 220-kV, and 132-kV transmission lines of the Unified Electrical Power System. Figure 4 is electrical one line diagram of the 500-kV, 220-kV, and 132-kV transmission lines and substations. Continuous overhead single static generator provides discharge path for lightning strokes and is installed on the 500-kV. The static wire or ground wire also serves to reduce the tower ground resistance. Single pole switching is employed for clearing line faults. These subconductors are used in each base and the two 550-kV lines are built on separate towers. (Double circuit 500-kV towers are not employed.)

Data on the 500-kV conductors and characteristics of the transmission line are as follows:

1. ASO-500 type conductors, ACSR 3 conductors
2. 1,450 mm^2 total cross sectional area
3. 2,000 MVA for 90°C max conductor temp. (50^{o} C ambient)
4. 40 cm spacing between the three conductors in a bundle.
5. 24.8 kV/cm (peak) electric field intensity on the conductors
6. 0.3 ohm/km inductive reactance
7. 280 ohms characteristic impedance
8. 900 MW surge impedance loading

The adopted line insulation design has the following characteristics:

1. The minimum length of leakage path equalled not less than 1.7 cm/kV (525 kV maximum working voltage) which was 30 percent higher than the insulation level for 500-kV transmission lines in the U.S.S.R.

2. Special PFE-type porcelain insulators with increased leakage path were recommended.

3. In areas with higher contamination near cement factories and near the Mediterranean Sea, the 220-kV lines had leakage paths of 2.5 kV/cm and 3.5 kV/cm respectively.

4. The insulators and leakage path distance for the 500-kV lines initially were as follows:

Line Section	Suspension No. & Type	Leakage kV/cm
Samalut-Cairo, angle 5	32xPFE-11	2.45
angle 11	36xPF-11	2.75
Other lines	23xOF-11	1.75

Based on past experience with 33-kV and 66-kV lines, cleaning or washing of insulators once or twice a year was envisioned.

9.2.4 Operating experience: The operating experience of the 500-kV, 220-kV, and 132-kV transmission lines showed that the insulation level at some transmission line sections was not sufficient due to high concentration of salts in the soils and intensive contamination and moistening of insulators with dew.

During the period of November 1967 to February 1969, a group of Soviet specialists on insulation with the help of Arab specialists conducted research including: process of insulation pollution and effectiveness of cleaning, salt concentration in soils, measuring salt content and specific surface conductivity of contamination of surface of insulators, measuring discharge voltages of insulators dismantled from a large number of towers, and investigation of vibration of 3-bundled conductors at 10 to 20 percent increased average tension.

More insulators were added at different locations and insulators were washed twice a year between Samalut to Cairo, once a year between Nag-Hammadi to Salalut, and once every two years between Aswan to Nag-Hammadi. The number of insulators between Samalut and Cairo on some towers was increased to 40 bells or units in a string. The minimum number of insulator units in a string was increased from 23 to 27.

9.2.5 Hydro generation and 500-kV transmission line transfer capability: The 500-kV transmission line cannot at the present time deliver the output of all twelve units (2,100 MWe) that could be generated at the High Aswan Dam. The maximum water flows occur during the irrigation season, primarily during the spring, summer, and fall seasons. During December and January the controlled outflow is generally reduced, resulting in total output from both of the Aswan and High Aswan Dam powerhouses of 600 MWe.

The operation of the High Dam is limited by water discharge requirements for irrigation which is determined by the Ministry of Irrigation. During the irrigation seasons in the spring, summer, and fall seasons of the year, the discharge is 100,000,000 m^3/day. The permissible fluctuation of water released from the High Dam is limited to no more than $\pm$1M at the forebay of Aswan Dam. Aswan Dam is located 7 km downstream from the High Dam. The limit on permissible water fluctuation is because of possible structural damage to Aswan Dam due to temperature variation and hydraulic effects.

The annual average discharge of the Nile is 84 billion m^3 which is presently sufficient to meet the irrigation requirements of both the U.A.R. and Sudan, amounting to 52 billion m^3. The annual discharge can vary from a low drought of 45 billion m^3 to a disastrous flood of 150 billiom m^3.

The following discussion with respect to the power transfer capability of the two 500-kV transmission lines is reported by Sanderson and Porter.[9]

Previous studies by the Russians and other have shown that the maximum through transfer capability governed by steady state stability considerations of the two 500-kV transmission lines between the High Dam and Cairo is of the order of 1,700-1,800 MWe. This assumes no intermediate loads between the High Dam 500-kV bus and the Cairo 500-kV bus, and is the maximum capable stable power transmission limit between the High Dam source and the Lower Egypt load when the system is subjected to small disturbances. At this point the internal angle between the hydro generators in Upper Egypt and generators in Lower Egypt would be the maximum possible with the system on the verge of instability.

A cursory check of such steady state stability limit utilizing a power circle diagram with ten of the High Dam hydro units and all of the Aswan hydro units in operation has indicated a maximum limit of the order of 1,540 MWe. This analysis, however, disregarded line capacitance, synchronous condensers, etc., so the 1,700-1,800 MWe maximum transfer capability is believed to be a realistic value.

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[9] Sanderson and Porter, 1977.

The philosophy of the EEA in operating the 500-kV transmission system is to allow a reasonable safety margin. The safety factor normally considered is expressed as follows:

$$Ks = \frac{Pmax - Ptr}{Ptr} \times 100$$

where: Pmax = maximum power transmitted
Ptr = normal transmitted power

Ks must be equal or greater than:
20% for normal operation
8% for short-term condition after fault clearance

Normal utility practice is to operate within a "safe area" where system stability is assured. A usual practice is to allow a 20 percent safety margin with the limit extended by the use of automatic voltage regulators particularly when fast acting regulators such as those of the electronic type are used. When applied to the UPS, this can be interpreted to mean that for normal operation the through transfer power limit between the High Dam 500-kV switchyard and the Cairo 500-kV switchyard would be of the order of 1,420-1,500 MWe.

Such limiting values were considered in determining the usable peak hydro generation capability on a yearly basis to employ in the generation expansion study. The other limitation was that of limiting the Aswan hydro dam to a capability of 260 MWe because of the reduction in head experienced by the Aswan Dam after the construction of the High Dam.

By the year 1983, the following large industrial loads are expected to be operating in Upper Egypt:

<u>INDUSTRY</u>

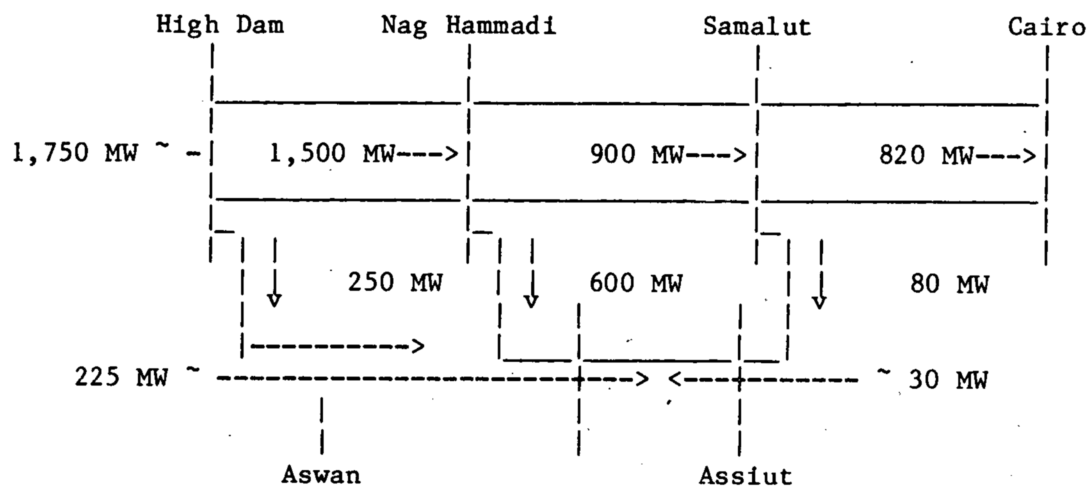
1.	Ras Gharib Nitrates	50 MWe
2.	Kima Fertilizer	250 MWe
3.	Ferro Silicon at Edfu	120 MWe
4.	Mining at Esna	10 MWe
5.	Mine Fertilizer at Abu Tartur	90 MWe
6.	Aluminium Smelter at Nag Hammadi	400 MWe
7.	Cement Plant at Assiut	35 MWe
	Total	955 MWe

These loads coupled with the normal growth of the other sectors of Upper Egypt brings the forecasted load in that area to approximately 1,240 MWe for the year 1983.

Assuming ten of the twelve 175 MWe hydro units at the High Dam in operation (two units out because of maintenance work) and all but one of the Aswan Dam hydro units in operation, the expected approximate maximum power flow in the two circuit 500-kV transmission lines as shown in figure 7 "Load Flow Diagram - Upper Egypt" would be:

FIGURE 7

LOAD FLOW DIAGRAM - UPPER EGYPT (1983)



Note: All 500-kV transmission line losses (normally 5 to 6 percent of transmitted power) have been neglected.

It can be seen from the above load flow diagram that the system is operating well outside the 20 percent safety margin that the EEA requires for normal operation. An AC Network analyzer study has verified the above load flow normal stability safety limit transfer capability of the 500-kV transmission lines.

It is on this basis that the full operating capability of the High and Aswan Dams complex of 1,975 MWe (1,750 MWe H.D. and 225 MWe Aswan Dam) was considered as being easily within the safe transmission capability limit in the 1980's. It is also for this reason that any series capacitor line compensation or the building of a third 500-kV transmission line is believed unnecessary under the presently anticipated future load conditions. However, improvement in reliability of the two existing 500-kV transmission lines is necessary if the full capability of such lines is to be available on an adequately dependable basis.

The capability of the hydro complex for the years preceding 1983 has been roughly determined considering both transmission line stability and system dynamic stability as restraints limiting the hydro output at peak time.

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