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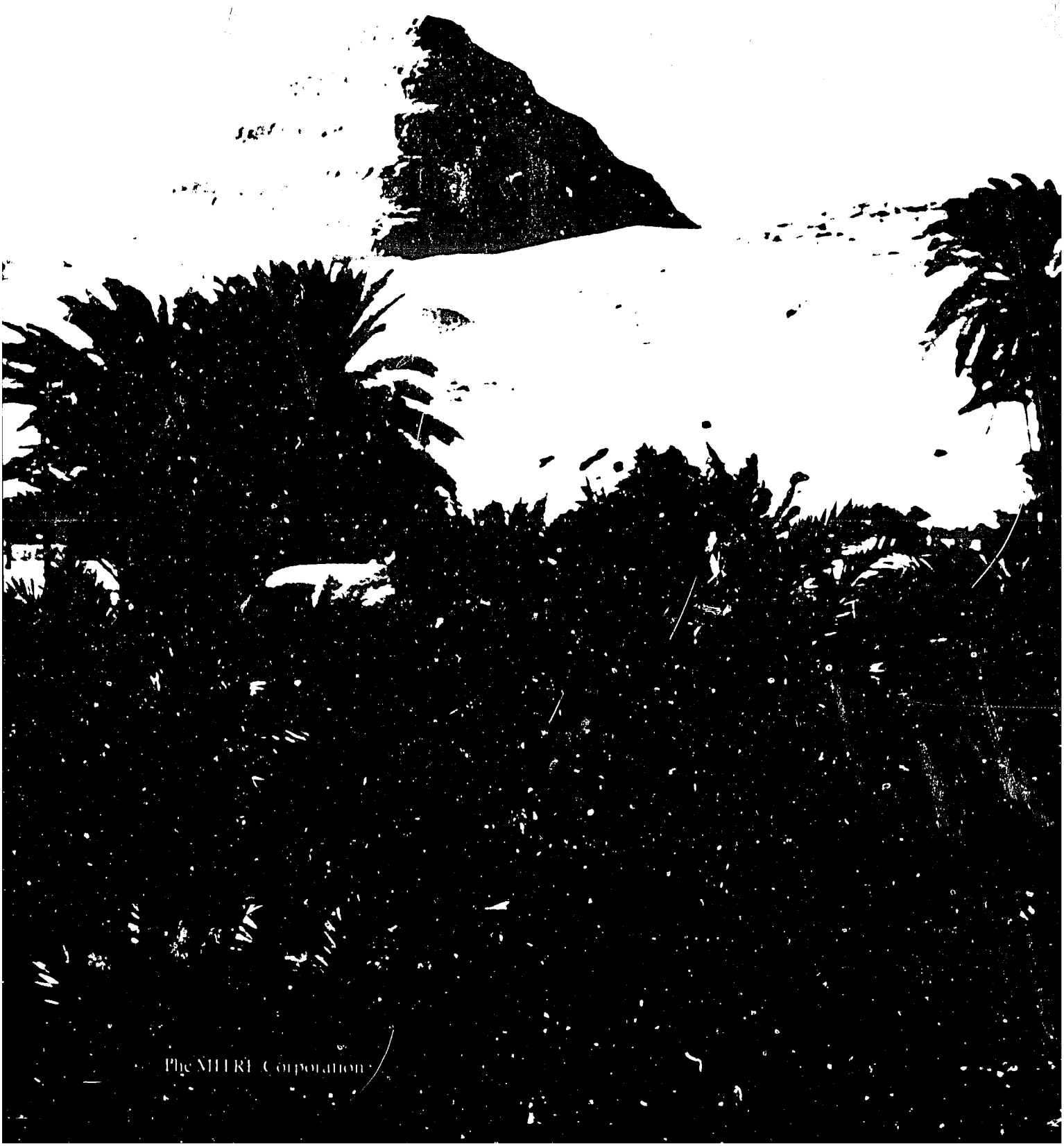
An Analysis of Options



Renewable Energy in Egypt

An Analysis of Options

A Joint Study by an American and Government of Egypt Team

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ABSTRACT

This report contains an analysis of various renewable energy options from the standpoint of Egypt's energy needs and its social and economic development. The report presents recommendations for USAID assistance in renewable energy development. This study was undertaken jointly by a U.S. team and a counterpart team provided by the Government of Egypt.

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EXECUTIVE SUMMARY

This study has been conducted for the United States Agency for International Development (USAID). The objective is to analyze all reasonable options for the use of renewable energy resources in Egypt and to develop recommendations for USAID assistance programs. A major portion of the work was conducted in Egypt jointly by American and Egyptian teams. MITRE provided technical leadership and support for the American team which included USAID experts. The Egyptian team was appointed by the Government of Egypt (GOE).

In conducting the analysis, the development of renewable energy applications was regarded as being a component part of the development of the Egyptian economy as a whole, rather than as an end in itself. Therefore, care was taken to ensure that the options recommended could be fully integrated into Egyptian economic, social and physical realities.

The major characteristics of Egypt are briefly described here. Egypt lies at the North-East corner of Africa. The country is roughly 700 miles (1100 km) from North to South and about the same from East to West. Egypt is mostly desert except for the Nile River, running from South to North. There are no other significant sources of surface water in Egypt. The population numbers about 40 million growing at a rate of 2.3% per year, and ninety-five percent of all Egyptians are crowded into the Nile Valley and the Nile Delta regions (which comprise some 4% of the surface area of the country).

The economy is predominantly agricultural with 47% of the labor force involved in farming, although a significant industrial sector totalling 28% of the GNP exists. The per capita GNP was about $300 in 1975. Egyptian industry has good technical capabilities and a relatively well-educated work force. The major industries are textiles, iron and steel, and food processing. Egypt produces about six hundred thousand barrels of oil per day, although some petroleum products such as butane are imported, due to the characteristics of Egyptian crude oil and refinery capabilities. Net petroleum exports are about 350,000 barrels per day.

This study was conducted in two phases. The objective of Phase I was to identify and examine all reasonable combinations of resource, technology and end-use which seemed likely to be fruitful in Egypt, and to categorize these combinations in terms of their attractiveness as potential areas for USAID assistance and cooperation with the GOE. Twenty-two combinations were identified and analyzed for compatibility with the Egyptian context, for technical and economic feasibility and suitability for potential USAID assistance.

Six areas were selected by the American and Egyptian teams in consultation with USAID/Cairo as having the greatest promise. The objective of Phase II was to develop recommendations for USAID program elements in these six areas. These areas were analyzed in detail by the joint team with each region of the country being visited. Attention was focused on delineating potential major USAID support

activities consistent with overall USAID policies and objectives, and Egyptian needs and priorities.

The selected resources and technologies are, with one exception (photovoltaics), economically competitive at world prices with conventional energy sources. However, none of these renewable resources can compete on equal terms unless the GOE takes some actions to counterbalance the high subsidies currently given to fossil fuels in Egypt.

These six program areas can be undertaken as one logical set of USAID assistance activities in renewable energy. We believe that the USAID and the GOE can undertake such a program now, and that this program can make a substantial impact on Egypt's economic and social development in the near term (5 to 10 years). This impact will be substantial notwithstanding that the social acceptability of biogas digesters in Egypt needs to be fully determined and that projected reductions in the present high costs of photovoltaic cells may not occur.

The six areas with outstanding potential are:

- solar water heating for industrial process heat and agricultural, institutional, and domestic applications
- solar crop and food drying
- rural biogas digesters
- wind machines for irrigation, electric generation and perhaps desalination
- solar refrigeration and cooling

- photovoltaic remote applications

A description and summary of the analysis and recommendations in each area follow.

(1) Solar Collectors for Industrial and Domestic Applications

Prospects for solar water heating in Egypt are excellent, since Egypt has high solar insolation (in an American context, 12% to 70% higher than the American South-West), and Egypt has significant energy needs which can be satisfied by solar hot water. About 2/3 of Egyptian industrial production comes from industries such as food processing and textiles which use low-temperature water, and nearly 20% of Egypt's fossil fuels are used for domestic and institutional water heating.

There is wide interest in and support for use of this technology in Egypt, and manufacture and maintenance of the systems is mostly within the capability of Egyptian industry. Limited manufacture of solar collectors for domestic applications has started at one plant and six new manufacturing ventures are planned.

Industrial applications could substitute for up to 14 QJ of fossil fuel per year (2.3 x 10^6 bbl oil/year, or about 20% of Egypt's industrial energy consumption at present) by 1990. Domestic applications could substitute for 2 to 6 QJ of fossil fuel per year (0.3 to 1.0 x 10^6 bbl oil/year), or 7 to 20% of present urban residential fuel consumption) by 1990, with greater savings possible in the longer term.

The major recommended objectives and support activities necessary to achieve them are:

- Objective: To demonstrate the potential of solar water heating in industrial applications.

  Recommended activities: A strong demonstration program of 10-15 industrial applications in the food processing and textile industries. These plants should be mainly located in the Delta Region where industry is concentrated. Examples of possible applications are bottle washing and milk pasteurization (Egyptian Dairy Co.), soap manufacture (Wadi El Natrun), bread baking (Biscomisr Co.). R&D should be undertaken to determine suitable methods for drying phosphate slurry at El Hamrawain mine using solar energy, and a development and demonstration program undertaken there.

- Objective: To develop a strong supporting infrastructure for solar water heating systems.

  Recommended activities: Work with National Research Center (NRC) to extend courses in training for installation and maintenance of domestic-type systems, assess direct or indirect provision of systems to prospective users who lack capital, work with NRC, users and manufacturers to assist in setting performance standards and assist in quality control improvement and production development.

- Objective: To provide solar water heaters to selected target groups.

  Recommended Activities: USAID can directly or indirectly provide water heaters to selected target groups such as the urban poor, health clinics and hospitals, and schools.

(2) Solar Crop and Food Drying

Crops and food are dried on both commercial and domestic/farm scales in Egypt. About 100,000 tonnes of dried foodstuffs are produced commercially each year mostly by plants of 0.5-10 tonnes/day output capacity. Use of solar drying can reduce fossil fuel consumption (up to 160,000 bbl/year, or 25% of current usage in commercial

drying), and will raise farm incomes by improvement of quality and reduction of losses in domestic/farm drying. Considerable expansion of commercial drying activities is possible (e.g., drying fish for animal feed or human consumption). Major recommendations for potential program elements are divided into two areas, commercial and domestic/farm.

The recommended objectives and support activities for the commercial area are:

- Objective: to transfer existing dryer technology.

  Recommended activities: Joint R&D programs with the National Research Center (NRC) and Universities (e.g., Cairo).

- Objective: To demonstrate the potential of commercial solar crop drying.

  Recommended activities: Construction of 10-15 demonstration drying plants (e.g., the Kaha Company has expressed interest in such a venture). These plants should be spread through the farming regions of the Delta, the Nile Valley and Fayoum.

- Objective: To develop a strong supporting infrastructure.

  Recommended activities: Assist development of local manufacturing and maintenance capacity by training, technical assistance and perhaps financial assistance.

The recommended objectives and support activities for the domestic area are:

- Objective: To transfer existing solar crop and food drying technology.

  Recommended activities: Joint R&D programs with NRC and universities.

- To demonstrate potential of domestic solar crop drying.

Recommended activities: Distribution of up to 500 domestic crop dryers throughout the farming regions (primarily Delta, Nile Valley and Fayoum). Major emphasis and costs in this program will be associated with personnel rather than capital goods.

- Objective: To develop a strong supporting infrastructure.

  Recommended activities: Train local craftsmen in dryer construction, assist in making credit available to prospective purchasers (perhaps in conjunction with local co-operative movements), assist in developing local markets for dried crops.

This program must be co-ordinated closely with USAID and GOE agricultural programs and services, such as the Agricultural Extension Service.

(3) Rural Biogas Digesters

Nearly sixty percent of Egypt's population lives in rural areas and approximately 30% of Egypt's energy consumption takes the form of combustion of animal and crop wastes in rural areas, for cooking and water heating. This material is therefore unavailable for soil conditioning and fertilization, and soil quality in Egypt has been steadily deteriorating since the completion of the Aswan High Dam stopped replenishment of the soil by silt from the annual Nile floods. The use of biogas digesters could capture most of the fuel value of animal and human wastes, and some of the crop residues, while leaving a slurry with high soil nutrient value.

Any program in this area must be closely coordinated with USAID and GOE agricultural services, such as the Agricultural Extension Service.

The major recommended objectives and supporting activities are:

- Objective: To develop suitable designs.

  Recommended activities: Continued assistance to R&D efforts at the University of Cairo campus in Fayoum and the NRC to select and adapt the best from Indian and Chinese designs, bearing in mind Egyptian conditions and capabilities.

- Objectives: To demonstrate the viability of rural biogas digesters.

  Recommended activities: limited demonstration program (about 100 to 200 units) in the farming regions of the Delta , Nile Valley and Fayoum to prove economic feasibility and social acceptability. Units should include family-scale designs of various types, and communal units, the latter at large government or private dairy or poultry farms, or other suitable institutions. The main emphasis and costs of this program will be associated with personnel rather than capital goods.

(4) Wind Machines

Suitable wind regimes for the use of wind machines exist along Egypt's North-West and Red Sea Coasts. Up to 1000 small wind-powered irrigation pumps (with 2 to 3m diameter blades) are operating along the North-West Coast where non-saline ground water exists and there are no sources of fresh surface water. Machines of this type were produced in Egypt in the 1960's, but institutional mechanisms to tap the potential market were inadequate and production ceased. Considerable potential also exists for the use of wind machines to generate electricity, especially in areas where the national grid does not run. Wind machines may also be used to drive desalination or refrigeration plants.

Recommended objectives and supporting activities for wind machines are:

- Objective: To determine potential markets.

  Recommended activities: Detailed short-term studies of wind conditions, underground and surface water availability, population, soil conditions, current electrical systems, costs of alternative fresh water supplies, and other factors determining markets for wind-powered irrigation and electric generation.

- Objective: To re-establish manufacturing capability.

  Recommended activities: Consider direct involvement in establishment of wind-machine manufacturing using modern designs and technology if demand justifies and private enterprise is unable or unwilling.

- Objective: To evaluate potential of large wind-electric machines.

  Recommended activities: Deployment of a U.S.-made wind generator (of about 1/2 megawatt) at a suitable site in Egypt, and monitoring and evaluation of its operation.

- Objective: To develop a strong supporting infrastructure.

  Recommended activities: Assistance in training and marketing and maintenance; financial aid to potential users who lack capital.

(5) Solar and Wind Refrigeration and Cooling

Several different technologies using solar collectors or wind machines appear to be feasible for refrigeration and cooling applications, primarily food preservation. Egypt now has about 250,000 tonnes of cold storage capacity, which is inadequate to meet demand. Recommended USAID objectives and supporting activities include:

- Objective: to enhance Egyptian R&D capability in solar refrigeration and cooling.

  Recommended activities: Technical assistance and joint R&D with the NRC; development of pilot models.

- Objective: To demonstrate viability of solar refrigeration.

  Recommended activities: Construction of demonstration plants for food preservation using selected technologies. Plants may be located near fishing areas (North-West Coast, Aswan, Red Sea Coast) as well as in farming areas (Delta, Nile Valley, Fayoum).

- Objective: To develop supporting infrastructure.

  Recommended activities: Aid and assistance in development of production and maintenance capabilities as appropriate.

(6) Photovoltaic Remote Applications

Potential applications exist for photovoltaic cells in refrigeration and lighting for remote rural health clinics, in telecommunications and perhaps in water pumping. The main obstacle at present is the cost of the cells. However, the United States Department of Energy projects large cost reductions for photovoltaic cells in the near future.

- It is recommended that developments in the United States be monitored for applications in Egypt.

- Initially, a small program of electrification of remote health clinics should be started because of the health benefits. (Several hundred unelectrified clinics exist in Egypt.) The size of this program should be dependent upon continuing major reductions in photovoltaic cell costs.

- Infrastructure development and establishment of Egyptian R&D and production expertise should be evaluated later when the technology is more mature.

1.0 INTRODUCTION

In connection with its development assistance and cooperation program in Egypt, The United States Agency for International Development (USAID) has asked The MITRE Corporation to provide technical leadership and support for a study of renewable energy resources in Egypt. This team worked in close cooperation with an Egyptian counterpart team appointed by the Government of Egypt (GOE). The MITRE team included experts in renewable energy technologies (solar, wind, hydro, biomass and geothermal) as well as a development economist, sociologists, and an expert in Egyptian industrial and institutional infrastructure. The counterpart team assembled by the Government of Egypt included experts with a similar mix of skills. The bulk of the work was carried out in Egypt during a 2-month period, and involved field trips to villages and factories, meetings with central government and local officials and experts, and a detailed survey of published and unpublished sources.

The study identified and delineated potential areas for cooperative programs between the GOE and USAID for development of renewable energy resources in Egypt. The conclusions and recommendations of the study are described in this report.

The development of indigenous Egyptian renewable energy resources is desirable for the following major reasons:

(1) use of renewable energy resources will free up additional Egyptian petroleum for export, thus alleviating the Egyptian balance of payments deficit.

(2) development of local manufacturing facilities for renewable energy resources will help the Egyptian economy and provide employment.

(3) changes in the manner of use of renewable resources such as dung and agricultural residues which are now burned as fuel will make more fertilizing and soil conditioning material available, improving agricultural production, and providing significant social benefits.

This study considers combinations of renewable energy sources, conversion technologies and end-uses which are relevant in the Egyptian situation. Renewable resources in this context include solar, wind, biomass, hydro and geothermal. The analysis leads to a selection of renewable resource applications which can contribute to Egypt's development and which present major programmatic opportunities for USAID. Attention is focused on the near and mid-term time frame, i.e., up to the mid-1980's or 1990.

In considering the recommendations of this report, it is important to understand the scope of the analysis within which they have been developed. First, only renewable energy development was considered. Secondly, within the area of renewable energy development, the analysis concentrates on formulating recommendations for USAID assistance initiatives. The active cooperation of the GOE will be essential to the success of these initiatives, and the GOE, with broader perspectives and prerogatives, may develop additional programs.

In conducting the analysis, it was assumed that the development of energy resources was not to be regarded as an end in and of

itself, but was rather to be regarded as an integral part of a process of economic development. Thus, those resources or technologies which would have a greater positive impact on overall development (by provision of employment, stimulation of the local economy, etc.) were regarded as preferable. Equally, resources or technologies relying on expensive imported equipment were regarded negatively.

The analysis was conducted in two phases shown diagrammatically in Figure 1. In Phase I, 22 combinations of resource, end-use and technology which seemed likely to be fruitful in the Egyptian context were identified and subjected to analysis. The starting point for this process was an assessment of Egypt's renewable energy resources and energy needs. Specific technologies were then introduced as ways of applying the resources to the end-uses desired. Each combination of resource, technology and end use was analyzed under 11 criteria, including economic viability, potential market size, and economic and social impacts. Six resource/technology areas which offer excellent opportunities for USAID assistance were selected in consultation with USAID and the Egyptian counterpart team. In Phase II, the most promising areas were then subjected to further detailed analysis, and program recommendations were developed for consideration by USAID.

Chapter 2 comprises a detailed description of the approach and methodology employed. The total list of renewable energy areas investigated is given in terms of resource/technology/end-use combinations, and the reasons for adopting this approach are explained.

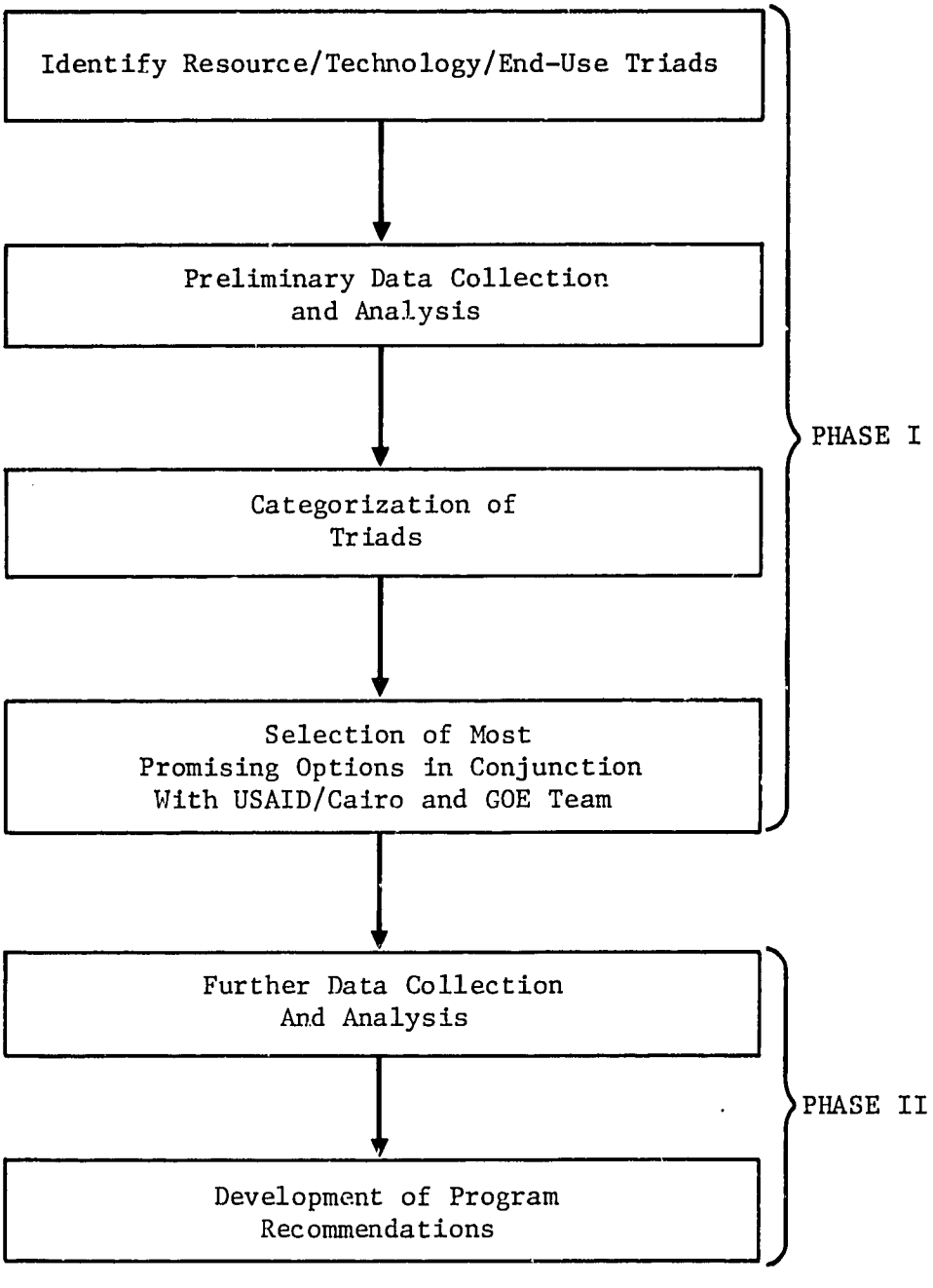

FIGURE 1
LOGIC DIAGRAM OF APPROACH

The criteria which were used to select the most promising areas are listed and described in detail.

Chapter 3 contains an overview of the Egyptian context within which the analysis and selection processes were carried out. Aspects covered include geography, demography, economic structure, agriculture, energy supply and demand, and institutional and industrial infrastructure.

Chapters 4 through 10 of this report introduce the renewable energy areas recommended for USAID assistance projects. The recommended assistance elements which have been developed for each of these areas are described in detail.

There are four appendices. Appendix A contains details of the resource/technology areas; Appendix B describes the economic analysis methodology and assumptions used to compute life-cycle costs; Appendix C describes the criteria used in the selection process, and Appendix D discusses the potential roles of several Egyptian organizations in implementation, and possible institutional development needs.

Metric units are used in this report. Hence, the energy units used are Joules. There are 1054 Joules per Btu, so that 1 quadrillion Joules (1 QJ) is a little less than 0.001 quadrillion Btu (Q), or about 164,000 barrels of oil equivalent. Costs and prices are reported in Egyptian pounds (L.E.); the present exchange rate is L.E.1 = $1.40.

2.0 APPROACH AND METHODOLOGY

It was apparent from the beginning of the study that the analysis had to be driven by the renewable energy resources available in Egypt and by Egypt's needs. Technologies were regarded as means of applying specific resources to specific needs or end-uses. Thus, the most meaningful basic unit for study in this context was a combination of resource, technology and end-use. These combinations have been called "triads" for ease of reference.

An example of a particular triad is irrigation windmills. The resource area in this case is wind, the technology is a windmill driving a pump, and the end use is irrigation. This triad is then distinct, for example, from the use of windmills for electric generation, or the use of photovoltaic-powered electric pumps for irrigation, and therefore represents a basic element for analysis.

The inclusion of all three elements (namely resource, technology and end-use) is necessary to define a meaningful entity. In particular, the inclusion of resource is necessary to define the available resource base which may be a limiting factor on the eventual utilization. The definition of the technology is necessary to allow computation of costs (either current or projected), to define the manufacturing and support structures needed and to project environmental impacts. The inclusion of the end-use is essential to the estimation of the potential for utilization, the economics of

competing energy sources, and, in conjunction with technology, the likely social impacts.

Of course, the definition of a triad is not completely clear-cut and self evident, particularly with regard to different technologies. In the above example, it could be argued that different types of windmills (e.g., vertical-axis rotors as distinct from horizontal-axis rotors) represent different technologies. Thus, it is theoretically possible to divide up any triad into sub-elements with differing technologies and/or end-uses. The triads defined in this study are at a level of aggregation appropriate to the analysis being undertaken, that is appropriate to a broad, fairly high-level survey. In particular, the level of aggregation of the triads varies from one area to another depending upon the perceived potential and availability of data. Thus the wind triads are quite specific, while the geothermal triad is quite aggregated, reflecting the limited information available regarding this resource in Egypt.

Clearly, triads may be grouped on the basis of similarities of resource, technology or end-use, or on some other basis such as infrastructure compatibility, and this has been done in developing the potential program elements.

Starting with a knowledge of Egypt's basic energy needs and renewable energy resources, 22 triads were identified as having some potential for applications in Egypt. These triads are listed in Table I.

TABLE I

TRIADS HAVING POTENTIAL FOR APPLICATIONS IN EGYPT

RESOURCE	TECHNOLOGY	END-USE
Solar	Flat-Plate Collectors	Domestic and Institutional Hot Water
Solar	Flat-Plate or Concentrating Collectors	Agricultural and Industrial Process Heat
Solar	Flat-Plate or Concentrating Collectors	Refrigeration and Cooling
Solar	Concentrating Collectors	Cooking
Solar	Flat-Plate Type	Crop and Food Drying
Solar	Solar Still	Desalination
Solar	Photovoltaics	Electric Generation (Off-Grid)
Solar	Passive Design	Building Heating and Cooling
Solar	Concentrating Collectors	Electric Generation (Off or On-Grid)
Wind	Small Windmills (Up to 100 kw)	Water Pumping
Wind	Small Windmills (Up to 100 kw)	Electric Generation (Off Grid)

TABLE I (CONCLUDED)

TRIADS HAVING POTENTIAL FOR APPLICATIONS IN EGYPT

RESOURCE	TECHNOLOGY	END-USE
Wind	Large Windmills	Electric Generation (Off or On-Grid)
Biomass	Improved Rural Stoves	Rural Domestic Cooking and Water Heating
Biomass	Anaerobic Digestion (Biogas)	Rural Domestic Cooking, Lighting and Water Heating
Biomass	Direct Combustion of Municipal Solid Waste	Electricity Generation (On-Grid)
Biomass	Composting of Municipal Solid Waste	Fertilizer and Soil Conditioner Production
Biomass	Anaerobic Digestion of Municipal Solid Waste (Biogas)	Urban Domestic, Institutional and Industrial Uses
Biomass	Anaerobic Digestion of Sewage (Biogas)	Electricity Generation (In-Plant Use)
Biomass	Biomass Plantations	Direct Combustion or Other Energy Use
Hydro	Small-Scale Decentralized Plants	Electric Generation (Off-Grid)
Hydro	Large-Scale Plants	Electric Generation (On-Grid)
Geothermal	Various	Electric Generation (On-Grid) or Direct Use

The relationships of the various triads listed is illustrated in Figure 2, which relates end-uses and technologies within the different resource areas (solar, biomass, wind, hydro and geothermal).

To facilitate inter-comparison and selection among the triads, they were subjected to analysis under 11 assessment criteria. These comprise:

- real costs
- apparent user costs
- costs of competing energy sources
- potential market
- market penetration
- social impacts
- infrastructure
- critical resources
- environmental impacts
- Balance of Payments effects
- other donor activity

The factors included under each of these criteria were as follows:

Real Costs

The estimated levelized* cost per unit of energy produced by the type of systems under consideration. This cost is calculated using real, unsubsidized costs to the extent possible. Real costs are assumed to be reflected by U.S. prices or world market prices.** The cost includes both capital costs and operating and maintenance costs.

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*Appendix B contains a description of the levelized cost calculation method.

**This is not true for certain commodities, e.g., petroleum, but was felt to be the best overall assumption available.

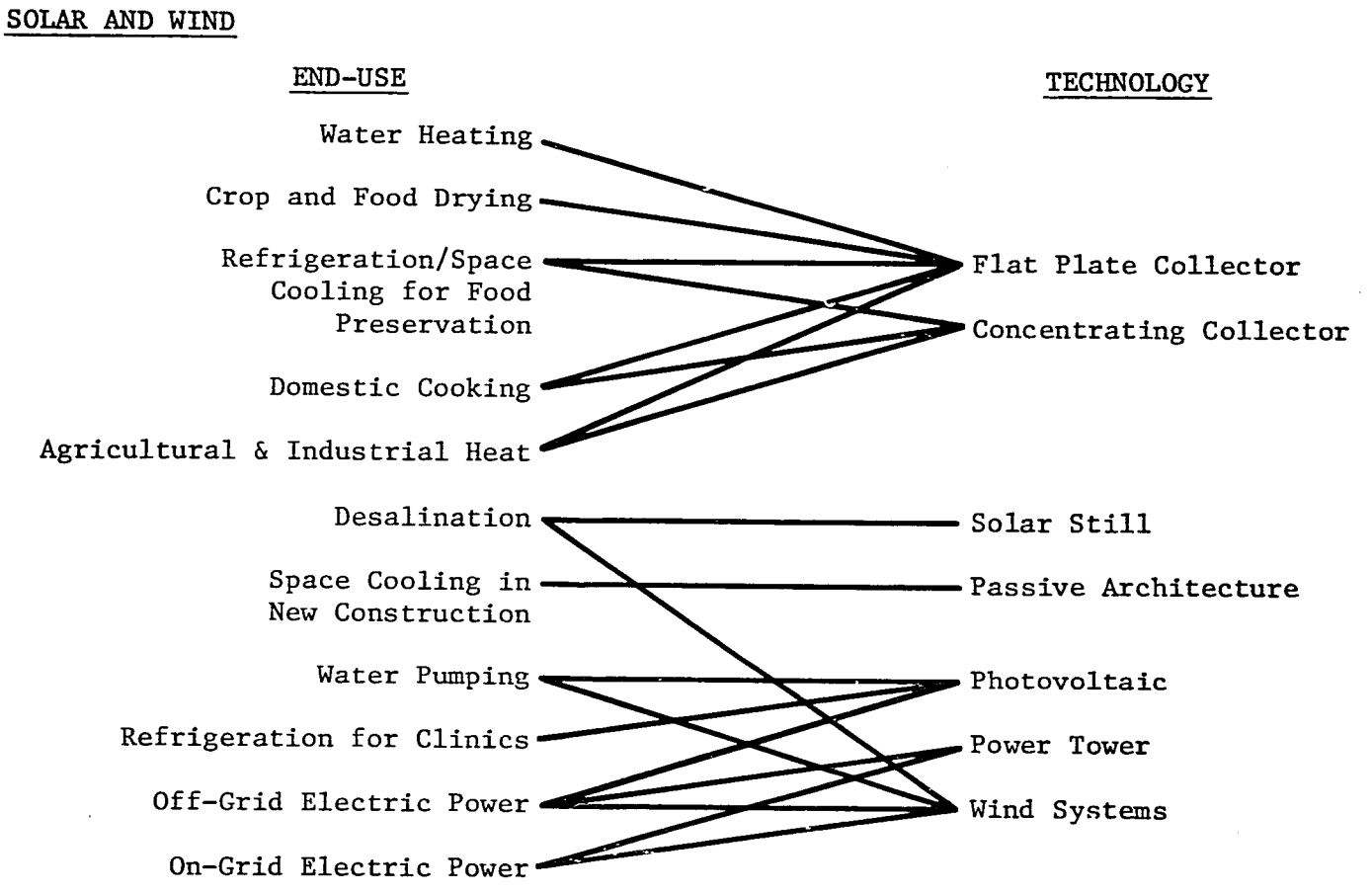

FIGURE 2
RELATIONSHIPS OF POTENTIAL END-USES AND TECHNOLOGIES

BIOMASS

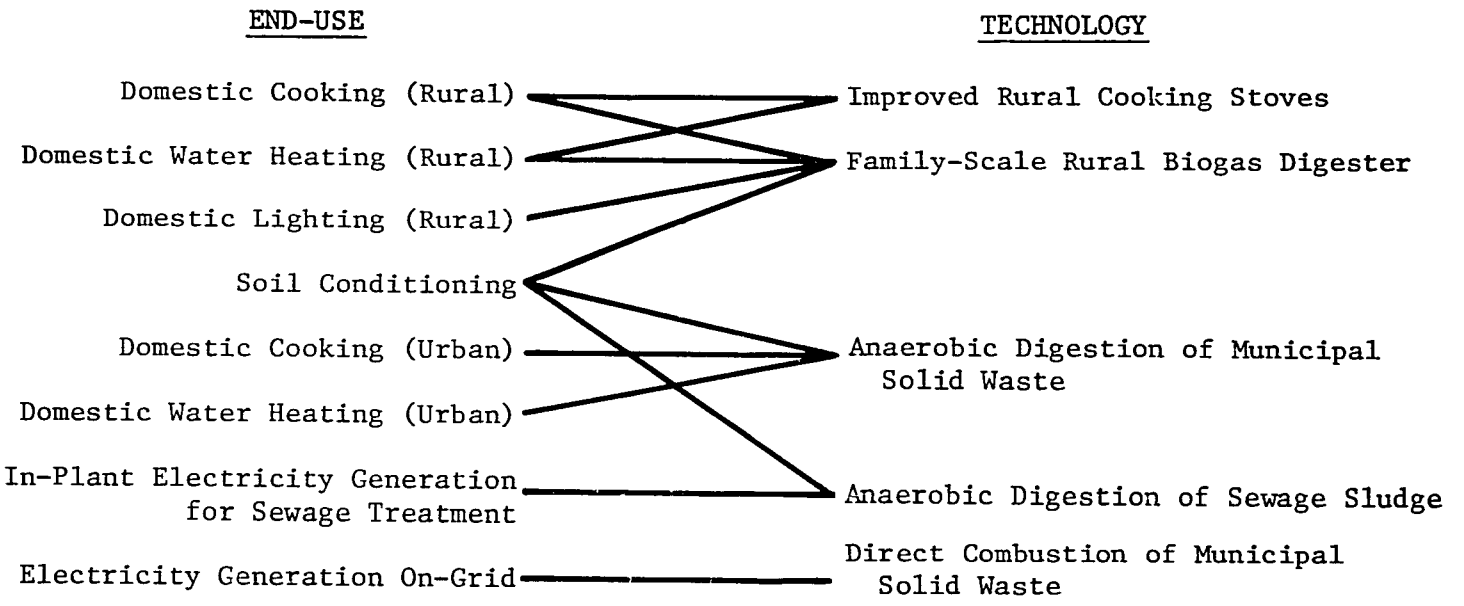

FIGURE 2
RELATIONSHIPS OF POTENTIAL END-USES AND TECHNOLOGIES (CONTINUED)

HYDRO-ELECTRIC AND GEOTHERMAL

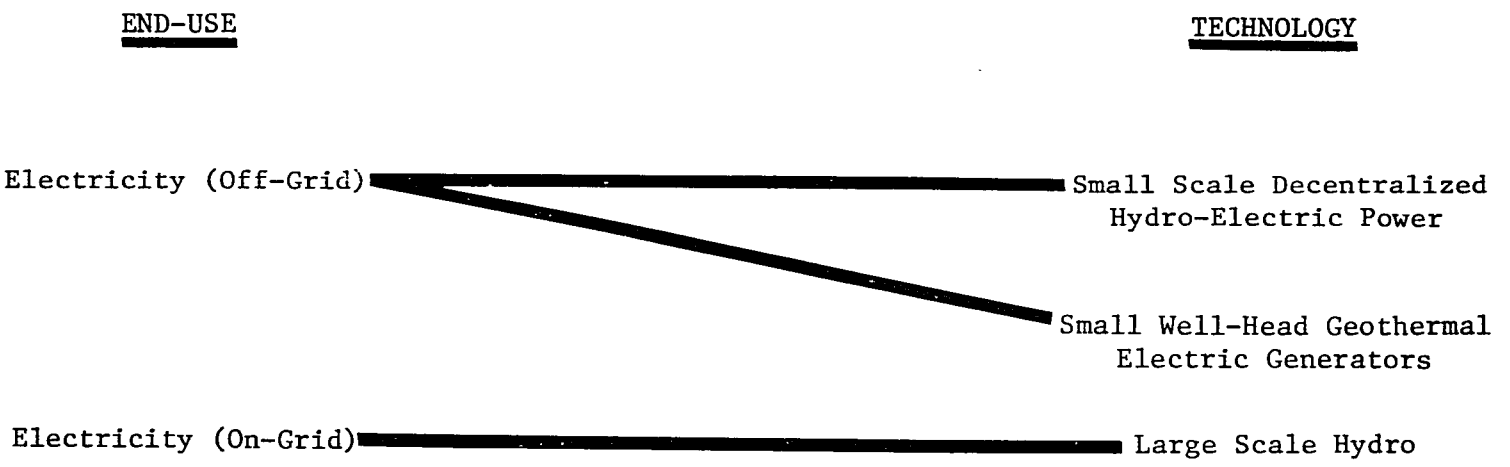

FIGURE 2
RELATIONSHIPS OF POTENTIAL END-USES AND TECHNOLOGIES (CONCLUDED)

Apparent User Costs

These costs reflect the effects of Egypt's widespread commodity subsidies and, hence, represent the estimated levelized cost to the end-user. The comparison of this cost with the apparent costs of competing energy sources determines the economic attractiveness of the system as seen by the user.

Costs of Competing Energy Sources

In Egypt the competing energy sources are petroleum fuels,* grid-provided electricity, or diesel-electric systems. The real and subsidized costs of selected petroleum fuels and marginal electricity generation costs in Egypt are discussed in Chapter 3.

Potential Market

Due to data limitations, potential markets have been usually specified in broad terms. Basically, the potential market represents all the energy usage which could technically be replaced by the triad under consideration.

Market Penetration

This represents the estimated market penetration potential taking into account all factors (e.g., economic competitiveness, speed of technology development, resource base, availability of infrastructure support, geographic restrictions, social impacts, etc.).

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*Coal is used only for metallurgical processes in Egypt.

Social Impacts

Evaluation of social impacts has occupied an important part of the analysis. Under the social impacts criterion are included characteristics of the energy source considered which would either help or hinder its acceptance. Generally, social impacts have been considered to be most significant at the village and domestic levels, where the life-style and habits of the people are intimately bound up with their methods of obtaining and using energy.

As an example, the use of solar cookers might require the main meal of the day to be prepared and eaten in the middle of the day. In an agricultural community where the men customarily, and in many cases the women and children, spend all day working in the fields at some distance from the village, lunching off a cold snack and eating their main meal after sunset, the use of solar cookers would require a major change in social behavior and organization. This would form a significant social impact requiring careful consideration.

Infrastructure

This criterion covers the extent to which existing institutions in Egypt would be capable of supporting the development and implementation of a given renewable energy option. Significant areas of infrastructure may include manufacturing, maintenance, education, management, technical development, financial and legal. This criterion deals with the infrastructure elements relevant to both commercialization/implementation and the management of the option when it

is in place. Possible roles of Egyptian institutions in the development of renewable energy resources, and areas where institutional development in conjunction with USAID may be appropriate, are discussed in Appendix D.

Critical Resources

Requirements for capital, skilled labor, management/personnel, water, land or other scarce resources which may create conflicts with other high-priority uses in Egypt, or which may impose particular constraints on development.

Environmental Impacts

This criterion covers qualitative estimates of environmental impacts compared with competing energy resources. Examples of impact areas include air and water pollution, availability of biomass for soil conditioning and fertilization, and noise levels.

Balance of Payments Effects

These represent qualitative or quantitative estimates of effects on the Balance of Payments (BOP) of implementation of the resource at the projected market penetration rate. A detailed analysis of BOP effects was felt to be outside the scope of this study, but the intent of this criterion is to distinguish between technologies having generally negative or generally positive impacts on Egypt's BOP deficit.

Other Donor Activity

From the point of view of USAID, an important criterion is the extent of activity by other international donors. The feeling of

USAID was expressed as a reluctance to enter areas where significant programs of assistance from other donors were under way.

The assessment criteria were used in a judgemental selection process in which the triads were divided into four categories:

- outstanding options
- good options
- other options
- options needing further study

Both the MITRE team and the Government of Egypt counterpart team provided inputs to this selection process.

In this assignment emphasis was placed on identifying factors which rendered the option less attractive or downright inadvisable. Those options which lacked disqualifying factors were rated high. Selection among high ranking options was based upon the strengths of their positive qualities.

After each triad had been reviewed and assigned, the results were collated and the process was repeated. The repetition had the effect of correcting some early assignments which, in view of the later assignments, were felt to be erroneous. The selected set of highly-ranked options represents an overall balance between different geographical regions, between different resources, between different end-uses, between high-technology and low-technology, between rural and urban, between industrial and domestic/agricultural, etc.

The list of triads, as categorized, was presented with backup material to USAID. USAID then selected, in conjunction with the MITRE and GOE teams, the six areas that are most promising from their

standpoint. The selected areas in some cases comprised more than one triad each, especially in those areas where technological or other similarities make it feasible to conceive of a unified program.

This selection terminated Phase I of the analysis and opened Phase II. In Phase II, the selected areas were subjected to investigation in greater depth, using essentially the same range of data sources as before. However, the data collection and analysis was now directed towards the identification and definition of potential programmatic areas which USAID could consider in its program development process. The six selected areas and the associated recommendations are described in Chapters 6 through 9. Further details on all areas (whether selected or not) are given in Appendix A.

3.0 OVERVIEW OF EGYPTIAN CONTEXT

Analysis of the potential applications of renewable energy technologies in Egypt should be viewed in the broader context of Egypt's geography, demography, economic structure, agriculture, social structure, physical, industrial and institutional infrastructure and energy system as discussed below.

3.1 Geography

Egypt is located in the northern hemisphere between 22° and 32° latitude, with a mean longitude of 30° (Figure 3), with the Mediterranean Sea bordering on the north and the Red Sea on the east. Due to this location, Egypt has excellent climatic conditions for direct solar energy applications such as water heating, crop drying, and power generation. This is supported by the recorded solar data, Figure 4, which show a good solar regime with sunshine over the whole country.(1) There are over 3400 hours per year of solar availability in the north and 3900 hours in the south. The average annual solar insolation is 800 kj/cm^2.(2)

In addition to a high solar insolation, Egypt has two windy regions along the Mediterranean and the Red Sea coasts. Usable annual electric energy output in these areas is estimated(3) to be

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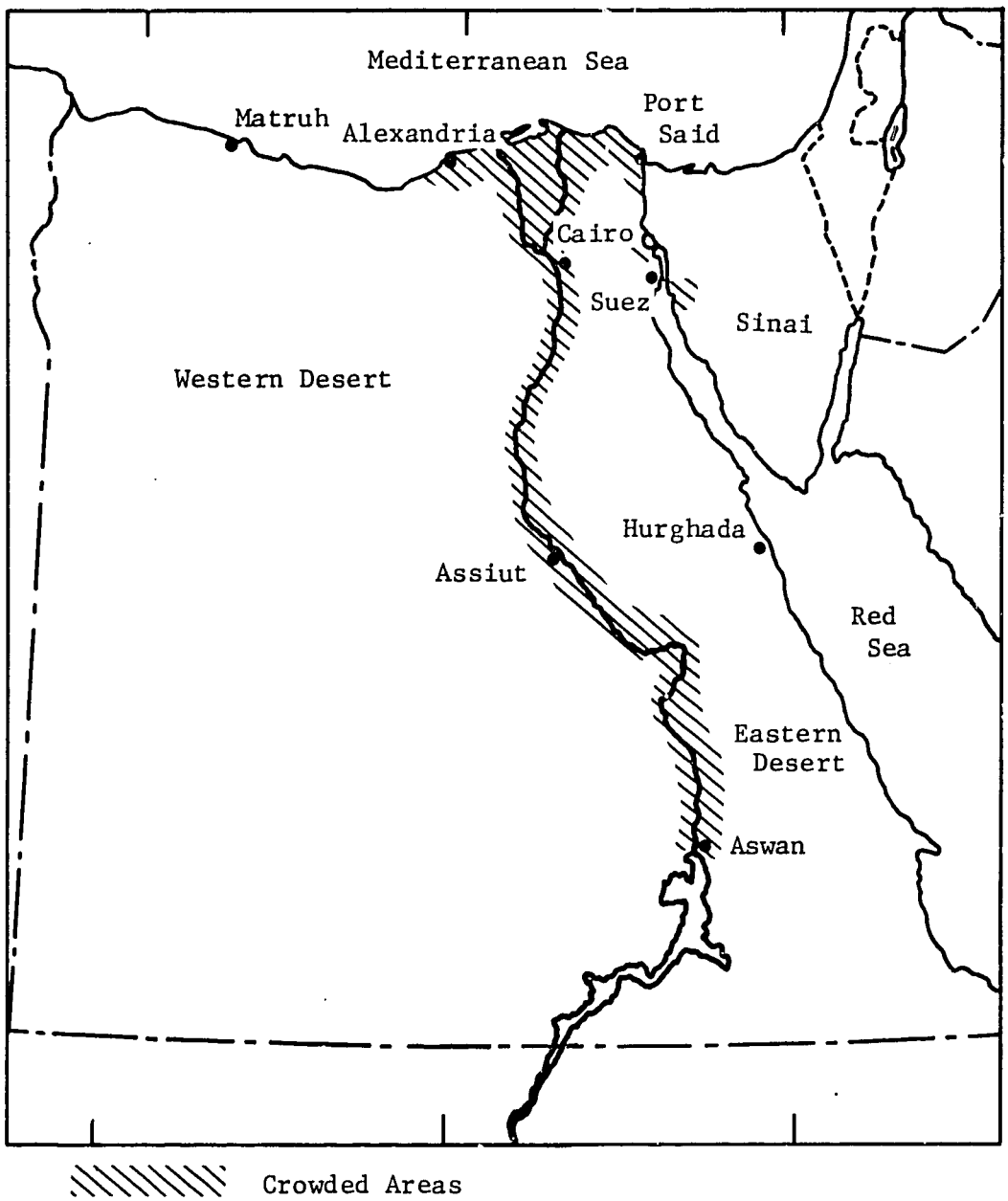
(1) GOE/DOE Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment, Vol. IV, April 1979.

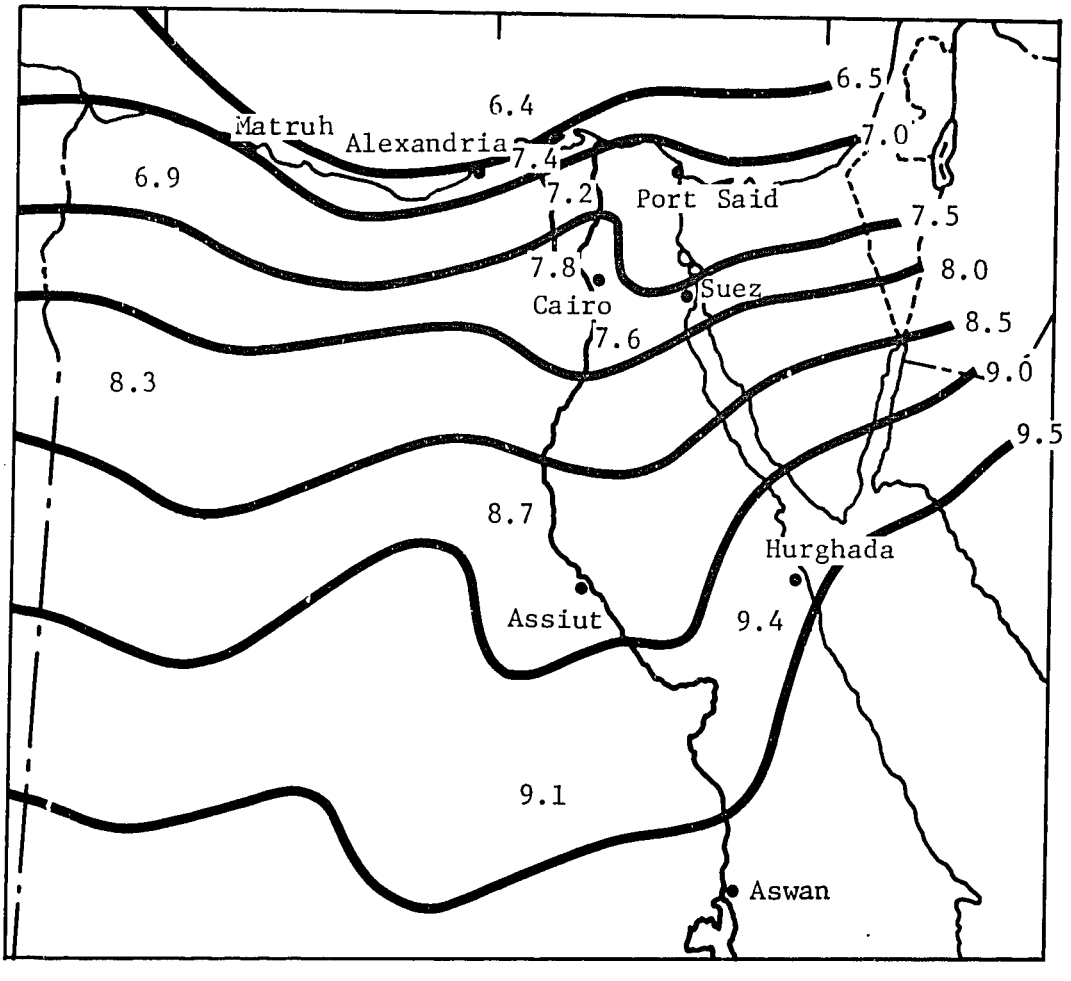
(2) Y. Diffie and W. B. Eckman, Solar Energy Thermal Processes, Wiley and Sons, New York, 1974.

(3) W.L. Hughes, Egyptian Wind Energy Resources Study Final Report, Phase II, Oklahoma State University, 1979.



Source: American University[5]

FIGURE 3
MAP OF EGYPT



Source: GOE/DOE[1]

FIGURE 4
MEAN BRIGHT SUNSHINE DURATION DURING WINTER (JAN) IN EGYPT

about 650 kwh per square meter of windmill swept area. These coastal areas have, therefore, sufficiently high annual average wind velocities to effectively operate wind turbine pumps and generators. The annual diurnal variation of wind speed in some localities in these coastal areas is shown in Figure 5.

Another phenomenon of Egyptian weather is the hot, driving wind blowing through the country in spring, March through May, and called Khamaseen. This sandstorm has been known to raise the temperature 35°F in two hours and have accompanying winds of up to 90 miles per hour.[1] 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 and other equipment will require sandstorm proof design. Also, sand and dust in the atmosphere appear to result in Egypt having a relatively high percentage of diffuse radiation[1] which reduces the output of these solar power options (e.g., concentrating collectors) that utilize only the highly directed portion of the solar radiation.

As shown in Figure 6, Egypt is part of the wide band of desert that stretches from the Atlantic coast of Africa into the Middle East. It has had an extremely disturbed geological history that has produced four distinct physical divisions: the Nile Valley and Nile Delta; the Western Desert; the Eastern Desert and the Red Sea Highlands; and the Sinai Peninsula. Egypt is, thus, geographically

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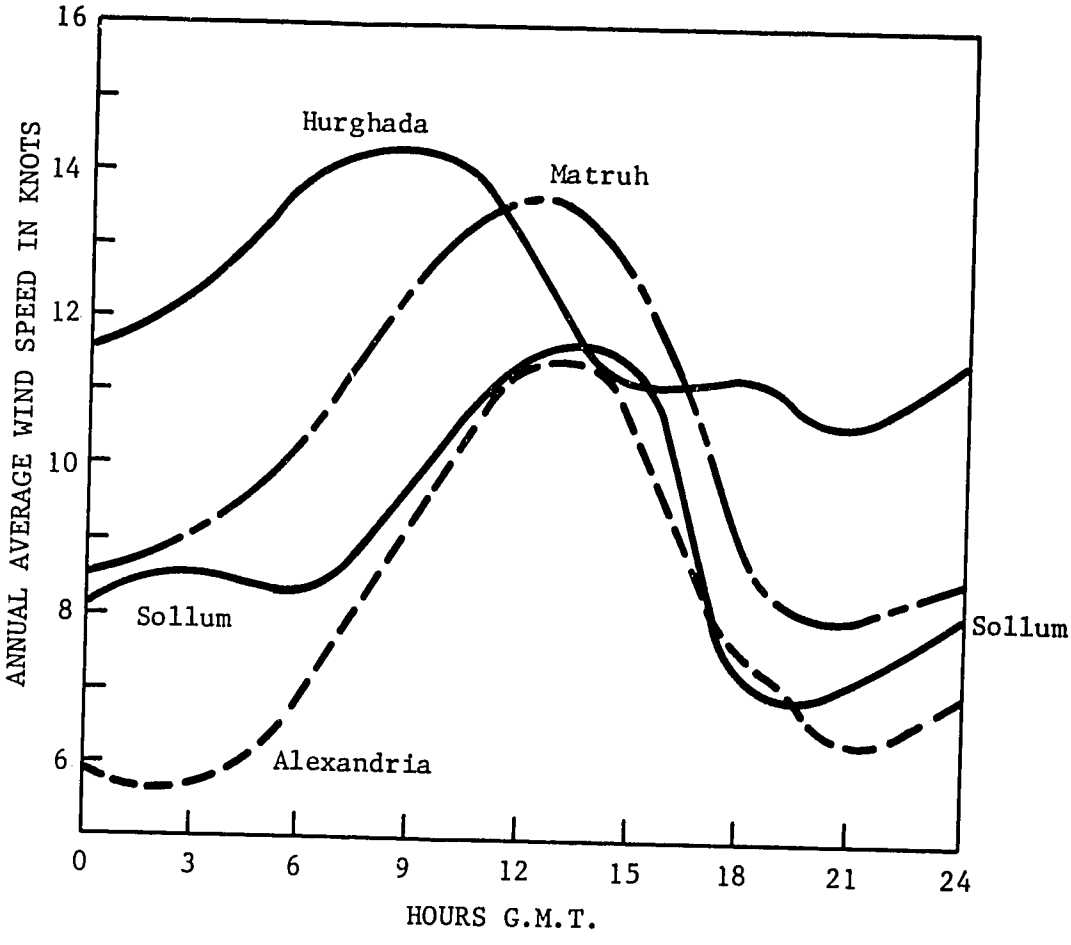
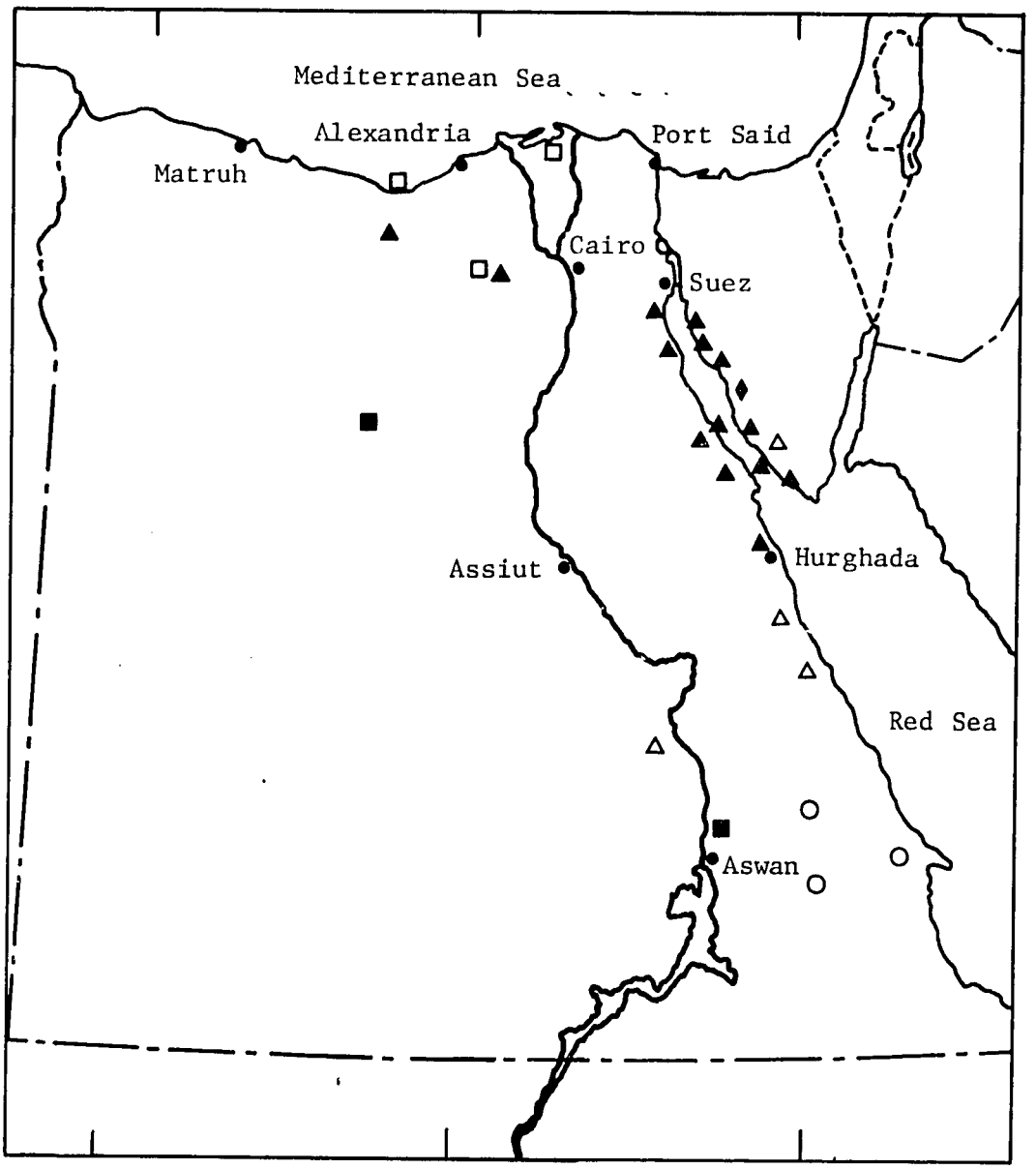
[1]GOE/DOE, op. cit., 1979.



Source: W. L. Hughes[4]

FIGURE 5
ANNUAL DIURNAL VARIATION OF WIND SPEED IN SOME LOCALITIES



Source: American University[5]

▲ Oil
○ Gold
♦ Manganese
△ Phosphate
■ Iron Ore
□ Nat.. al Gas

FIGURE 6
MINERAL RESOURCES OF EGYPT

diverse. Different areas of the country have different resources and needs.

The division that includes the Nile Valley and Delta is most important, since it supports over 95 percent of the people and contains virtually all the country's cultivable land.

The Western Desert accounts for almost three-fourths of Egypt's land area and is considered a frontier region that is divided into two frontier governorates: Mersa Matruh to the North and New Valley to the South. A major feature of this region is its seven depressions. All of these depressions are considered oases except the largest, Qattara, which contains only salt water.(6) Limited agriculture, some natural resources, and permanent habitation characterize the remaining six depressions. As oases these depressions obtain fresh water in sufficient quantities either from the Nile or from local underground sources. The Siwa Oasis, close to the Libyan border, is isolated from the rest of the country but has sustained life since ancient times. The other major oases form a chain extending from Fayoum Oasis (80 km southwest of Cairo) south to Bahariya, Farafra and Dakhla oases before reaching the country's largest oasis, Kharga. The Bahariya Oasis is important for its iron ore deposits and lies 210 miles southwest of Cairo. Farafra Oasis is larger but sparsely populated. The Dakhla and Kharga Oases complete the chain

(6)Argonne National Laboratory, Political, Economic and Energy Profile of Egypt, ANL-PMS-TH-78-6, 1978.

to the south and were the first to be affected by the New Valley project, which proposes the watering of the entire oasis belt of depressions for vast land reclamation.

The Eastern Desert and Red Sea Highlands' most prominent feature is the chain of rugged mountains extending from the Nile Valley eastward to the Gulf of Suez and the Red Sea. This region is isolated from the rest of the country. Without permanent settlements, except for a few villages on the Red Sea Coast, the importance of this region to Egypt lies in its natural resources. The entire Eastern Desert is administered under a single governorate, Red Sea, with its capital at Hurghada on the Red Sea.

Another frontier governorate, Sinai Peninsula, is a triangular-shaped area of 23,600 square miles,[6] situated east of the Gulf of Suez and northeast of the Eastern Desert. Coal, manganese and gypsum deposits are all in this area.

As depicted in Figure 7, Egypt is divided administratively into twenty-five governorates which include four city governorates (Cairo, Alexandria, Port Said and Suez); the eight governorates of lower Egypt along the Nile south from Cairo to Aswan; and four frontier governorates covering Sinai and the desert west and east of the Nile.[6] Recently, (1975) a twenty-sixth governorate, Nubaria, located southwest of Alexandria had been announced. In this analysis, however, Egypt has been divided into nine major regions based on

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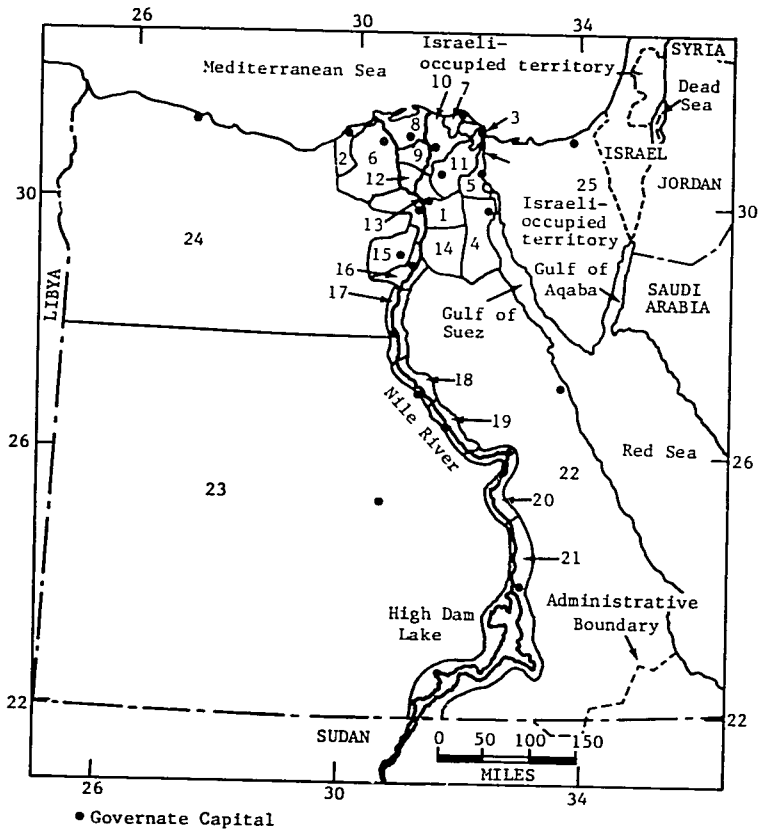
[6]Ibid.



Governorates	Governorate Capital
City Governorates	
1. Cairo (Al Qahirah)	Same
2. Alexandria (Al Iskandariyah)	Same
3. Port Said (Bur Said)	Same
4. Suez (As Suways)	Same
Lower Egypt	
5. Ismailia (Al Ismailiyah)	Same
6. Al Buhayrah	Damanhur
7. Damietta (Dumyat)	Same
8. Kafr ash Shaykh	Same
9. Al Gharbiyah	Tanta
10. Ad Daqahliyah	Mansura (Al Mansurah)
11. Ash Sharquiyah	Zagazig (Az Zaqaziq)
12. Al Minufiyah	Shibin el Kom (Shibin al Kawm)
13. Al Qalyubiyah	Benha (Banha)
Upper Egypt	
14. Giza (Al Jizah)	Same
15. Al Fayoum	Same
16. Bani Suwayf	Same
17. Al Minya	Same
18. Asyut	Smae
19. Suhag (Sawhaj)	Same
20. Qena (Qina)	Same
21. Aswan	Same
Frontier Governorates	
22. Red Sea (Al Bahr al Ahmar)	Hurghada (Al Ghurdaqah)
23. New Valley (Al Wadi al Jadid)	Kharga (Al Kharijah)
24. Marsa Matruh	Matruh
25. Sinai (Sina)	Al Arish

Note — Names in parentheses are the formal names, which are used on many maps and in some of the literature.

FIGURE 7
GOVERNORATES IN EGYPT

population density, primary economic activities and other characteristics as summarized in Table II.

3.2 Demography

Many of Egypt's future needs will stem from its rapid population growth and the resultant stress this places on land use, urban growth, industrialization plans and economic needs, energy resources and other resource requirements. The current population of about 40 million is expected to reach about 60 million by the year 2000.[7] With about 50 percent of the people under 20 years of age, the momentum of sustaining the current 2.3 percent annual population growth rate will be difficult to slow down for a number of years, even with early and effective family planning programs. Creation of enough job opportunities for the young population is yet another impending problem of population explosion.

Egypt is a large country with an area of about 386,000 square miles of which over 90 percent is an uninhabited desert. The country is almost 57 percent rural, but the rapid growth of population as well as rural migration have led to a strong trend towards urbanization. About one-third of the population now lives in the cities of Cairo and Alexandria, and continuing migration is expected to increase urban pressure.[5]

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[7]World Bank, World Development Report, 1978.

[5]American University, op. cit., 1976.

TABLE II

REGIONS OF EGYPT USED IN THE ANALYSIS

REGION	POPULATION (MILLION, 1975)	PRIMARY ECONOMIC ACTIVITIES	COMMENTS	GOVERNORATES INCLUDED
Delta	24	Agriculture, Industry (Textiles, Food Processing, Iron and Steel)	Contains Cities of Cairo, Alexandria, and Ismailia, and Over Half Agricutlural Land. Densely Populated	Cairo, Alexandria, Port Said, Ismailia, Al Buhayrah, Damietta, Kafr Ash Shaykh, Al Garbiyah, Ad Daqahliyah, Ash Sharqiyah, Al Minufiyah, Al Qalyubiyah
Upper Nile	11	Agriculture	500-Mile River Valley: Some Population Centers, Limited Industry (e.g., High Dam at Aswan). Densely Populated	Giza, Bani Suqayf, Al Minya, Asyut Shuhag, Qena, Aswan
Fayoum	1	Agriculture	Oasis 80 km. Southwest of Cairo, Supplied by Canals from Nile. Densely Populated	Fayoum
Northwest Coast	About 0.4	Fishing, Some Agriculture	Sparsely Populated, Irrigation Using Ground Water	Part of Mersa Matruh
Red Sea Coast		Fishing, Mining, Oil and Gas	Sparsely Populated, Arid	Part of Al Bahr Al Ahmar
Eastern Desert		Mining, Semi-Nomadic Herd Raising	Sparsely Populated, Some Limited Grazing Land. Jurisdictional Complications with Sudan	Part of Al Bahr Al Ahmar
Western Desert		Mining, Limited Agriculture and Herd Raising	Arid, Sparsely Populated at Scattered Oases	Al Wadi al Jadid and part of Mersa Matruh
Sinai		Mining, Oil and Gas	Sparsely Populated, Arid, Partly Under Israeli Occupation	Sinai
Suez	0.4	Agriculture, Some Industry, Oil and Gas	Moderate Population Density, Irrigated Agriculture	Suez

The Egyptian Western Desert alone has an estimated potential for housing 14 to 23 million persons, distributed among 84 towns in four regions; the Mediterranean North West Coast, the Qattara Depression, the New Valley and the western bank of Aswan High Dam Lake. The total energy requirement for these new communities in the Western Desert is estimated to exceed 5000 MW (by the year 2025).(8) Both solar and wind energy can be expected to provide a significant part of this energy especially in the Mediterranean Northwest Coast. Along this coast, wind energy has been and will be useful in pumping water for small irrigation efforts (e.g., fig trees, herds of goats, sheep and camels). The water table there is close to the surface, and the quality of water is adequate.(9)

The Red Sea Coast situation is quite different. There is no rain, and no significant known water aquifers. Thus, wind energy, though plentiful, can not be useful for irrigation or water pumping from wells. In these areas, electricity is generated from diesel oil except near Ras Gharib where natural gas is used to fuel gas turbines. In this area hybrid gas-wind electric power generators may be attractive.

New satellite cities, (e.g., Sadat City, New Amiriya, Tenth of Ramadan and El Ohour), outside the existing cities, together with new

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(8)A.I. Ibrahim, A. Fattah, and M.M. Kamel, Energy Forecasts for the Western Desert of Egypt, Cairo Workshop for Desert Development, September 1978.

(9)Egyptian Ministry of Housing and Reconstruction, Regional Plan for Coastal Zone of the Western Desert, Final Report, 1979.

construction in urban and rural areas, will offer an extended market for the nascent local solar water heater industry. With proper government equalization of incentives, at least fifty percent of the expected 6 million dwellings by the year 2000 may find solar water heaters economically attractive.

3.3 Economic Structure

The GNP of Egypt[10] was L.E.4.7 billion in 1975 (about $12 billion at the then-prevailing exchange rates), or roughly L.E.130 per capita ($320). The government occupies a dominant position in the Egyptian economy, and is in a position to dictate internal prices for most goods and services. Agriculture is the major economic activity, although a well-developed industrial sector exists, accounting for about 28 percent of the GNP.

A key element of government economic planning is aimed at decentralization of the urban population and stemming the flow of rural-urban immigrants by creating more productive opportunities and amenities in smaller towns and rural areas.[11] The government's rural electrification project is part of this plan. This rural electrification is conventionally done by extending the utility grid or using on-site generators, usually diesel-electric. Other major aspects of the Egyptian economy are discussed below.

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(10) Arab Republic of Egypt Ministry of Planning, The Five-Year Plan (1978-1982), August 1977.

(11) Harza Engineering Company, National Rural Electrification Plan, 1979.

- Balance of Payments

Given the low export earnings and a negligible level of foreign exchange reserves, Egypt has been suffering a net but fluctuating negative Balance of Payments since 1973. This negative balance rose from $700 million in 1973 to nearly $2500 million in 1975, dropping back to a level of some $1200 million after 1976 due to increased value of Egyptian exports and to significantly more income from services and transfer payments.(6) To decrease the Balance of Payments deficit by over 25 percent by 1980, higher priority is now given to labor-intensive export-oriented projects with fast gestation periods, and to joint venture projects that can attract foreign investment.(10) For a variety of reasons there could be an incentive for Egypt to consider supporting the widespread use of renewable energy technologies in appropriate applications. For the most part, both solar heating devices and windmills could be manufactured in Egypt using indigenous labor and material resources, with the obvious advantages of reducing the foreign exchange component of developing energy sources and making more petroleum available for export. Of equal importance is the building up of an in-country capability in an existing and growing technological field which can help reduce unemployment.

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(6)Argonne National Laboratory, op. cit., 1978.
(10)Arab Republic of Egypt Ministry of Planning, op. cit., 1977.

- Subsidies

There is a wide disparity of income among various classes in Egypt. For example, 321 Egyptian families made more than $1.5 million each last year, and about 2000 families averaged $82,000, while the rest of the people had an average per capita income of $180.[12] The Egyptian government has had a policy of subsidizing basic commodities such as bread and kerosene to reduce the burden on lower income families. The food subsidies alone have now reached more than one billion pounds a year.* Also, both electricity and fossil fuels in Egypt are heavily subsidized. As shown in Table III, the butane gas and kerosene subsidy levels are as high as 88 percent of the world price levels for these household fuels. The economics of solar, wind and other renewable energy applications cannot compete favorably with current subsidized consumer prices for conventional energy. Therefore, the comparative economic analysis of renewable energy options and conventional energy sources in this study is based on real (i.e., unsubsidized) costs for energy delivery. It should be noted, however, that any countervailing subsidies, that would be required to make renewable energy competitive with conventional energy, would generally be a one-time capital subsidy rather than a continuing subsidy on consumption. Clearly, reduction of the disparity between renewable and conventional energy sources (not to mention the

[12] Washington Post, December 9, 1979.
*About 1.4 billion dollars.

TABLE III

FUEL SUBSIDY LEVELS IN EGYPT

FUEL	WORLD PRICE L.E./10^9 J*	LOCAL PRICE L.E./10^9 J	LOCAL PRICE EXPRESSED IN U.S. UNITS
Butagas	9.20	1.10	$1.30/Mcf
Kerosene	3.90	0.48	10¢/Gal
Mazout (Residual Fuel Oil)	2.95	0.17	3¢/Gal

* L.E. 1 = $1.40 U.S.

10^9 J = $0.95 x 10^6 Btu

Source: Egyptian Ministry of Petroleum[12]

disparity between local and world prices) is properly the preserve of the Government of Egypt. This analysis can merely point out the fact that widespread use of renewable energy sources is unlikely if they are uneconomical as seen by the end-users.

3.4 Agriculture

Agriculture is still the largest sector of the economy accounting for 32 percent of the gross national product (GNP), offering employment for 47 percent of the labor force and providing 60 percent of exports (processed and unprocessed). Egypt's agricultural output is dominated by field crops, mainly cotton, maize, rice, wheat and clover, which together occupy about three-quarters of the total arable land (i.e., 4.5 million acres) and account for over half of the value of agricultural productions. The total agricultural production has increased at the rate of 1.6 percent, whereas production per head has declined at about 0.7 percent per year thus leading to a rise in food imports.(10)

The most severe constraints on Egyptian agriculture are the limited cultivable land available and the problems caused by a rise in the groundwater level and increased soil salinity. The general solution which is being considered is the lowering of canal water levels everywhere, and eliminating all gravity irrigation.(13) This will require lifting of water using pumps or water wheels.

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(10)Arab Republic of Egypt Ministry of Planning, op. cit., 1977.
(13)ERA 2000 - Gaithersburg, Maryland, Future Mechanization of Egyptian Agriculture, April 1979.

Residues made available through the harvesting of agricultural crops constitute the major non-commercial energy resource in Egypt. Table IV shows the areas cultivated to produce Egypt's major crops in 1952 and during more recent years. Of particular interest is that since 1952 few significant changes are to be noted except that there has been a slight decline in area cultivated, especially cotton.

Table V is a summary of the 1978 data for crop residues showing, in addition, rural energy usages. It should be noted that cotton, rice, sorghum, maize, sugar cane, peanut and sesame residues are entirely utilized.

Manure from animals, principally cows and buffalo, is used as fertilizer or fuel for rural cooking. Removal of this nutrient-rich resource from the fields often means the use of chemical fertilizers at a high financial and energy cost. In 1977 for example, the equivalent fertilizer value of animal excreta was L.E. 40,000,000.

Table VI lists quantities of manure produced in 1977 from various animal sources. A total of 186 million cubic meters were produced of which approximately one third was left in the fields.

As mentioned, the heat obtained from this resource in 1975 was about 43×10^{15} joules. Since the effective efficiency of combustion is less than 10 percent, only 4.3×10^{15} joules was available in the form of actual heat.

3.5 Social Structure

For the majority of Egyptians, traditional patterns of home, family, and work continue to dominate daily life. Increasing

TABLE IV

AREA CULTIVATED FOR DIFFERENT CROPS (FEDDAN* x 10^6) IN EGYPT

CROP YEAR	1952	1972	1973	1974	1975	1976	1977	1978**
Wheat	1,402	1,239	1,248	1,370	1,394	1,396	1,207	1,374
Barley	137	91	84	77	100	104	88	101
Broad Bean	355	365	302	279	280	298	318	238
Fenugreek	54	29	30	36	32	33	24	21
Chickpea	15	10	8	7	6	8	14	14
Lentila	58	67	74	66	58	64	48	34
Clover (Berseem)	2,202	2,819	2,874	2,797	2,812	2,757	2,854	--
Cotton	1,967	1,552	1,600	1,453	1,346	1,348	1,423	1,177
Rice	374	1,146	997	1,058	1,052	1,079	1,033	1,019
Sorghum	433	484	487	499	489	474	408	435
Maize	1,704	1,531	1,654	1,755	1,830	1,891	1,747	1,877
Sugar Cane	92	202	198	209	217	243	250	--
Peanut	26	34	29	29	32	42	36	31
Sesame	42	42	36	27	33	31	40	23
Vegetables	--	748	798	807	898	931	932	--
Other Crops (Horticulture)	94	253	258	273	285	313	321	--
Flax	13	33	40	46	54	47	59	--
Onion	26	31	25	36	27	28	31	--
Garlic	9	9	14	13	12	12	15	--
Soybean	--	--	4	8	16	32	60	82
TOTAL	9,003	10,685	10,760	10,845	10,773	11,131	10,908	6,426

*1 Feddan = 4200 m^2
**Partial figures

Note: Totals exceed the 6 million feddan of arable land due to double cropping.

Data provided by Dr. Nabil Alaa El-Din, Institute of Soils & Water Res., Agr. Res. Center, Giza, Egypt.

TABLE V

1978 CROP RESIDUE SUMMARY TABLE

CROP	AREA $\times 10^3$	TONS/ FEDDEN	TOTAL RESIDUES TONS $\times 10^3$	VALUE L.E./TON	TOTAL VALUE L.E.	USED FOR ENERGY
Wheat	1,374	2.06	2,830	37.20	105,292	--
Barley	101	1.55	157	28.00	4,383	--
Broad Bean	238	1.19	283	21.80	6,174	--
Fenugreek	21	0.80	17	19.16	322	--
Chickpea	14	0.89	12	28.24	367	--
Lentils	34	0.78	27	34.04	903	--
Clover (Berseem)	233	0.86	201	13.64	1,923	--
Cotton	1,177	1.50	1,766	7.28	12,853	12,853
Rice	1,009	1.60	1,630	5.76	9,391	9,391
Sorghum	435	2.15	935	11.12	10,400	10,400
Maize	1,877	1.85	3,472	7.64	26,530	26,530
Sugar Cane	250	1.00	250	--	1,250	1,250
Peanut	31	1.26	39	--	195	195
Sesame	23	1.29	30	5.04	150	150
Vegetables	932	1.00	932	--	4,660	--
Other Crops (Horticulture)	34	1.06	321	--	1,605	1,605
Flax	59	--	--	--	--	--
Onion	31	--	--	--	--	--
Garlic	15	--	--	--	--	--
Soybean	82	--	82	15.00	1,230	--
TOTAL	8,267		12,986		187,628	62,374

NOTE: Data Provided by Dr. Nabil Alaa El-Din, Inst. of Soils & Water Res., Ag. Res. Center, Giza, Egypt

TABLE VI

ANIMAL MANURE PRODUCTION IN EGYPT FOR 1977

ANIMAL	NUMBER $x10^3$	MANURE PROD., 10^3m^3	LEFT IN FIELD, %	NET PROD. 10^3m^3
Cows	2048	71,680	30	50,176
Buffalo	2266	79,310	30	55,517
Sheep	1821	8,105	35	5,918
Goats	1375	6,875	35	4,468
Camels	97	1,455	80	291
Pigs	15	75	35	49
Horses & Mules	1257	18,855	80	3,221
TOTAL	8879	186,355		120,190

NOTE: Data provided by Dr. Nabil Alaa El-Din, Inst. of Soils & Water Res., Ag. Res. Center, Giza, Egypt

modernization, industrialization and education have, nonetheless, accelerated the trends toward secularization and begun to undermine the strength of traditional institutions, such as the extended family.(6)

The country is 57 percent rural and 40 percent urban. The remaining 3 percent include the nomadic tribes (Beduins) living along the Mediterranean (northwest) coast and the semi-permanent Bashariza settlements in the Eastern Desert; the fishing communities along the Red Sea Coast and around the High Dam Lake south of Aswan; and a few dispersed mining communities around the oil fields and other mining areas in the Eastern Desert and Sinai (Figure 6). The great bulk of the population, therefore, is in the cities or on the rural farms in the Delta, Nile Valley and Fayoum regions.

3.6 Infrastructure

As discussed below, infrastructure refers to all Egyptian supporting capabilities that would be required for the successful introduction and later autonomous growth of a well selected set of renewable energy technologies in Egypt. Thus, the term infrastructure covers physical facilities (e.g., roads and transportation means), manufacturing capabilities, financing institutions, marketing channels and other relevant services (e.g., research and development, training, standardization and control).

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(6)Argonne National Laboratory, op. cit., 1978.

(a) Physical Infrastructure

During the past decade, there has been deterioration in Egypt's physical infrastructure. Transportation, telecommunications and other facets of the infrastructure are inadequate for the desired growth of rural and urban economic activities. The gradual implementation of appropriate renewable energy technology may help improve this situation by reducing the transportation load of conventional fuel to rural and remote areas, and reinforcing village economic independence.

(b) Industrial and Institutional Infrastructure

In general, there is at present no infrastructure that is specifically tailored to support renewable energy applications in Egypt. The existing administrative, manufacturing, financing, marketing and other infrastructural support facilities can, however, be diversified, modified or expanded to take care of the newly emerging renewable energy applications.

For the most part, renewable energy systems using low or intermediate technology could be manufactured in Egypt using indigenous labor and material resources. For example, solar-related energy systems are fabricated primarily from basic construction material such as steel, cement, glass and aluminum, which are produced locally in Egypt. Components such as towers of wind turbine units, collector array support structures, and flat plate thermal collecters are being manufactured in Egypt. More sophisticated subsystems, such

as the blades of large wind turbines and photovoltaic solar cells must be imported.

Many of the renewable energy 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 and other labor skills common to a range of conventional power systems. There will be, however, special training required for many aspects of renewable energy related equipment design, manufacture, installation, operation and maintenance. This will range from training engineers to design and size solar water heaters, to training personnel to maintain wind turbine units. Training facilities in the Solar Energy Laboratory at the National Research Center, and in the Ministry of Industry Vocational Training Centers as well as in higher education institutions (e.g., Cairo University and Helwan Institute of Technology) could all be extended to handle this manpower training load.

Administratively, current responsibilities and organizational structure of the Egyptian Agriculture Extension Service (Figure 8) could be expanded to cover the requirements of all rural agricultural applications of renewable energy technology. The electric service bureau in each rural area can also be entrusted to look after the proper operation and maintenance of some applications in the villages. At all urban levels, the implementation of renewable energy

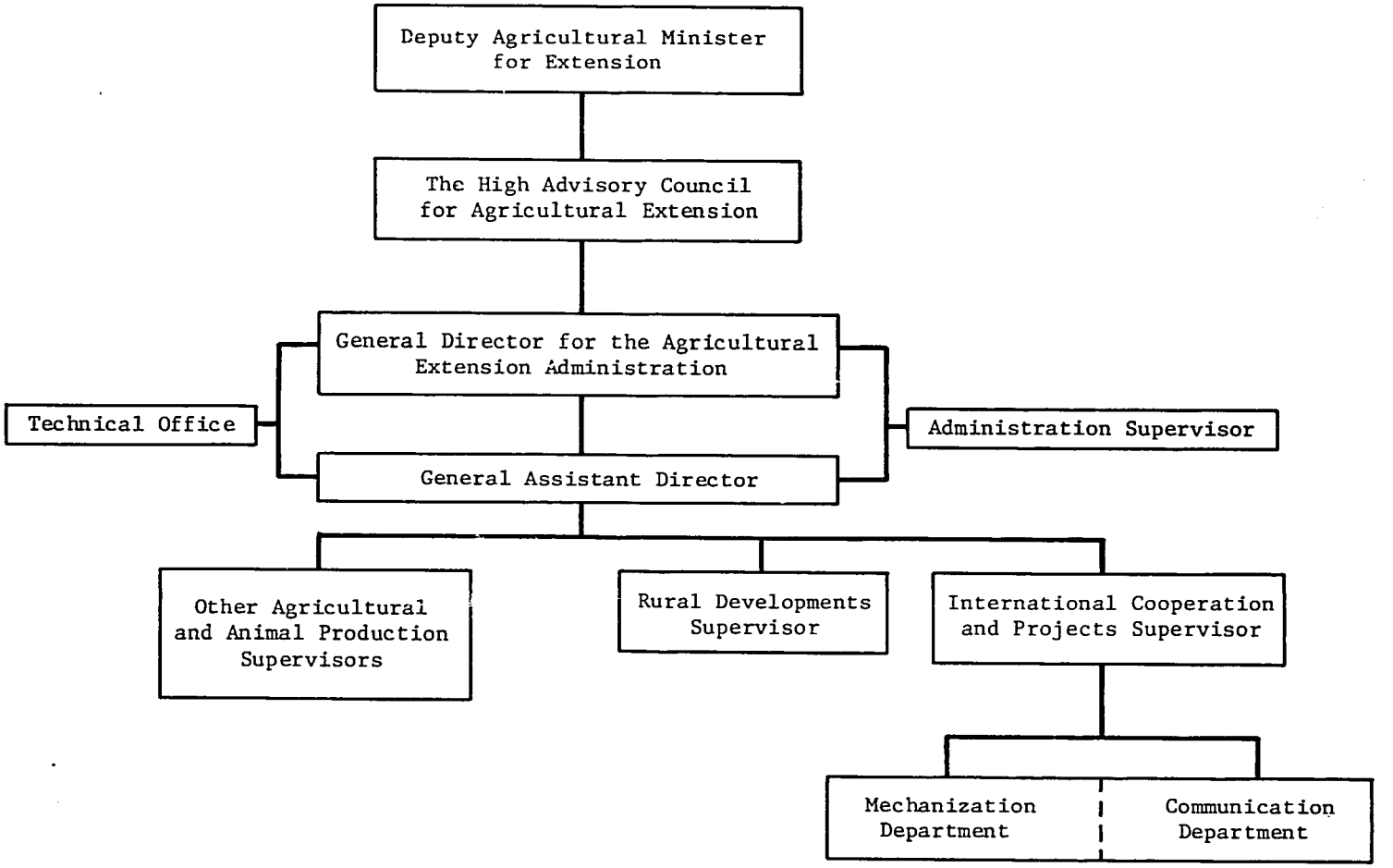

FIGURE 8
ORGANIZATIONAL STRUCTURE OF THE AGRICULTURAL EXTENSION SERVICE

technologies will have to be coordinated between the Egyptian Industrialization Authority, the Supreme Council for Renewable Energy Technologies, the Ministry of Economy and Economic Cooperation, and the end-user involved.

Three cabinet ministries are primarily concerned with energy research and development: the Ministry of Petroleum; the Ministry of Electric Power and Energy; and the Ministry of Atomic Energy and Scientific Research (Figure 9).[6] In addition, three energy research councils are functioning in a consultative role in energy research policy: the Higher Council for Petroleum; the Higher Council for Electricity; and the Higher Council for the Utilization of Nuclear Energy. Recently, a fourth council was formed to handle the utilization of renewable energy technology in Egypt.

Existing rural, industrial and commercial banks can be used to extend loans to potential rural or urban end-users of renewable energy technology. Joint venture projects for technology transfer to and renewable energy manufacturing in Egypt can now be handled by the Ministry of Economy and Economic Cooperation under the provisions embodied in the new foreign investment Law #43 of 1974. This new foreign investment law seems to be stimulating the flow of foreign funds into Egypt, albeit rather slowly. The question is not only whether external funds will be available at the required levels, but will these foreign funds be available on terms that will not accentuate Egypt's debt problem.

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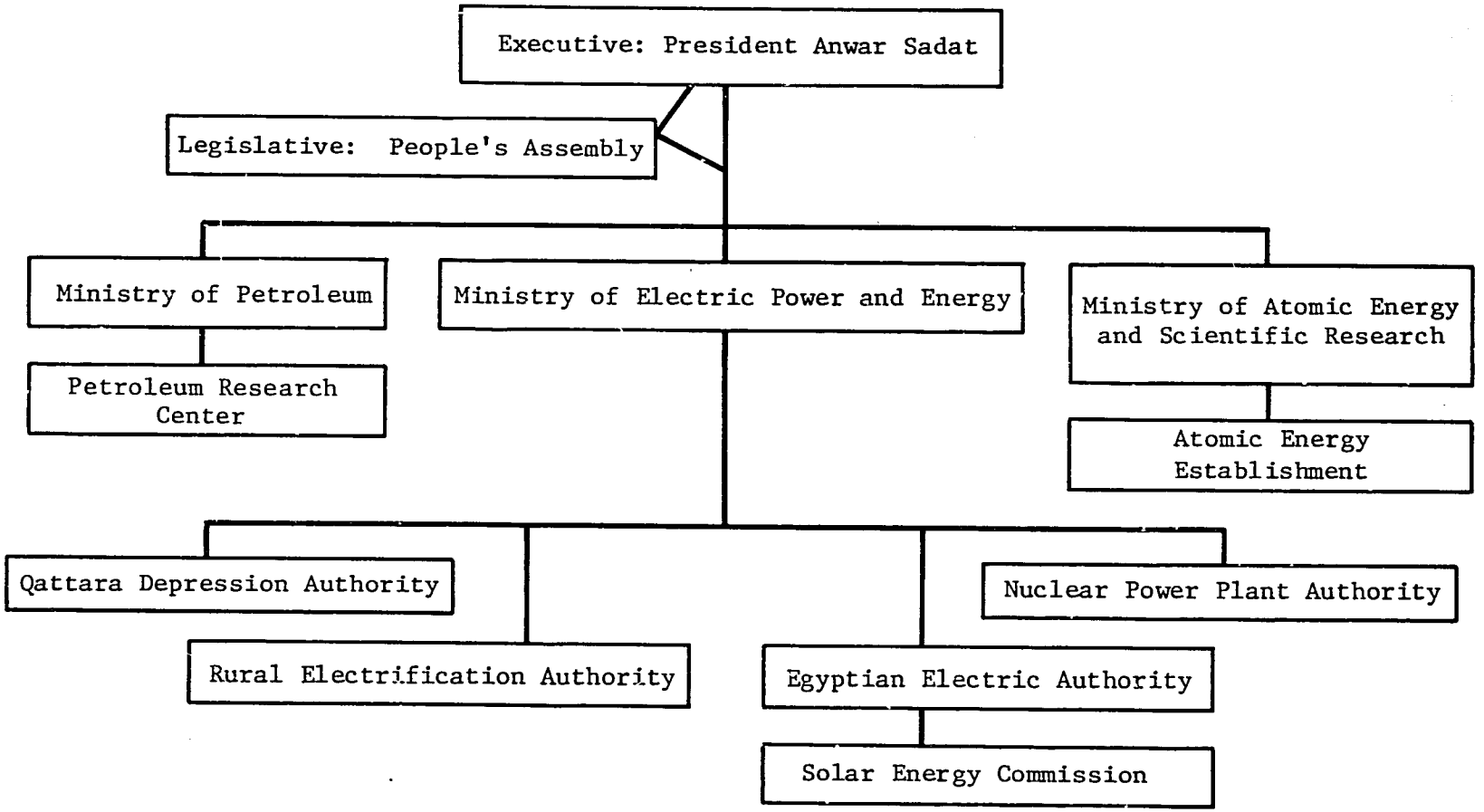
[6]Argonne National Laboratory, op. cit., 1978.



Source: Argonne National Laboratory, Egypt, 1978[2]

FIGURE 9
GOVERNMENT STRUCTURE FOR ENERGY

3.7 Energy System

Egypt consumed about 560 QJ in 1975 (about 0.5 Q), including both commercial and noncommercial energy sources.[14]

As shown in Figure 6 and summarized in Table VII, a variety of primary energy sources are available to Egypt in limited quantities. At present, the main local energy supply sources are oil, natural gas, hydroelectric, and noncommercial fuels (i.e. crop residues, animal dung, and firewood).

During the current Five-Year Plan,[10] Egypt intends to increase oil production to achieve a 1980 crude oil output goal of one million bpd. A more realistic target is estimated to be 700,000 bpd. Current production is over 500,000 bpd.

Egypt's major gas fields are in the Nile Delta at Abu Maadi, in the Western Desert at Abu Elgharadik, and offshore in the Mediterranean at Abu Qir. Each of these three fields has a capacity of 4 million cubic meters per day. Considerable expansion of natural gas production is expected in the near future. Initially, usage is planned to be mainly industrial.

Through the construction of the two Aswan Dams, Egypt has developed the major hydro power resources on the Nile. The dams represent 60 to 70 percent (total installed capacity 2,445 MW) of Egypt's

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(14) GOE/DOE, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment, Vol. I, 1979.

(10) Arab Republic of Egypt Ministry of Planning, op. cit., 1977.

TABLE VII

ENERGY RESOURCE AVAILABILITY IN EGYPT

SOLAR	Excellent. Sun energy incidence minimum 1.7 times U.S. best. High average wind velocities (12 to 18 miles per hour) in certain coastal areas.
BIOMASS	High current noncommercial use. Urban waste is potential new source.
GEOTHERMAL	20 MWE maximum potential based on current information.
HYDRO	Limited additional potential. Nile annual flow: 84 x 109 cubic meters (M^3) (highly variable) Aswan High Dam electrical generating capacity: 2100 MWE; Low Dam: 220 MWE.
OIL	Production increasing. 1977 reserves: 2.1 billion barrels. Current production: 150 million barrels/yr. Resource adequacy to maintain production goals to 2000 highly uncertain.
NATURAL GAS	1976 reserves: 2.0 trillion ft^3. Projected 1978 production: 675 million ft^3. Resource adequacy to maintain production goals uncertain but potentially favorable.
COAL	Limited economically recoverable reserves: 35.6 million tons in Sinai. Best potential use: Blend with imported coking coal.
URANIUM	None currently recoverable economically: Favorable potential.
THORIUM	None currently recoverable economically: 3.7×10^5 tonne reserves (0.62 percent content) in heavy sands but potential for economic recovery small.
PUMPED HYDRO	Adequate sites appear to be available. System needs for storage capacity are increasing but involve significant net consumption of high quality electric energy.

Source: GOE/DOE [1]

electricity production. The possibility for further development of the Nile rests with smaller scale hydro facilities. Electrification of the barrages at Asyut, Nag Hamadi and Esna, and repowering the old Aswan dam could yield 300 MW.[15,16] At present, new generating capacity is fossil-fueled.

There are no official statistics on the use and availability of noncommercial energy sources in Egypt. However, a tentative summary of the past and future availability of the principal noncommercial fuels is given in Table VIII based on informal data supplied by the Egyptian counterpart team.

In addition to these local energy sources, Egypt may continue to require imports of butane and kerosene to the year 2000, due to lack of domestic refining capacity and the characteristics of Egyptian oil and gas fields.[14]

Although the foregoing conventional fuel will continue to provide the bulk of Egypt's growing future energy requirements, it is most likely that solar, wind and other renewable energy sources will have a limited contribution through the year 2000.

An overview of the Egyptian Energy System (i.e. supply-demand situation) based on 1975 figures in quadrillions of joules is given

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(15) Egyptian Ministry of Electricity and Energy, Water Power of the Nile: Identification of the Most Promising Sites for Hydroelectric Development Downstream of Aswan, Final Report, SWECO, January 1979.

(16) All-Union Designing, Surveying and Research Institute, Power Utilization of Esna, Nag Hamadi, Asyut Dams, Extension of the Old Aswan Hydroelectric Station, HYDROPROJECT, Moscow, 1977.

(14) GOE/DOE Report, op. cit., Vol. I, 1979.

TABLE VIII

PROJECTIONS OF NONCOMMERCIAL FUEL

HUMAN AND ANIMAL ENERGY

(10^{15} Joules)

NONCOMMERCIAL FUEL	1975	1985	2000
Firewood	1.5	1.5	1.5
Crop Residues	172.0	200.0	250.0
Animal Dung	43.0	46.0	50.0
Human Energy	2.3	3.1	4.0
Animal Energy	4.3	5.2	6.5

Source: GOE Team

in Table IX. The rate of growth in the use of commercial energy is calculated from sectoral energy demand projections to be 6 percent per year over the period 1975 to 2000. The use of noncommercial energy is estimated to grow at a significantly lower rate of 1.36 percent per year as more commercial energy (and possibly renewable energy) becomes available to and adopted by rural households.

It should be noted that current electric power tariffs do not reflect the supply costs in economic terms because fuel is subsidized.(17) Marginal grid generation costs are shown in Table X. Industry, which consumes about 60 percent of electricity sold, pays an average of 7 milliemes* per kwh which is only half the cost of generation and does not even cover the fuel costs of 8.5 milliemes per kwh. The two most important industrial consumers, the aluminum smelter at Nag Hamadi and the Kima fertilizer complex in Aswan are paying 2.5 milliemes per kwh and 1.8 milliemes per kwh, respectively.

Municipalities buy power at 10.5 milliemes/kwh and bill all medium and low voltage customers in the cities and towns beyond Cairo and Alexandria.

3.8 Context for Selecting Options

Reasons for the choice of both triads and criteria are detailed in Chapter 2 and are summarized in Table XI. The process led to a categorical ordering of triads along the following broad lines: (a)

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*1 millieme = L.E. 0.001 = $0.0014.

(17)Egyptian Electricity Authority, Tariff Study Report.

TABLE IX

OVERVIEW OF EGYPTIAN ENERGY SYSTEM

(1975 FIGURES IN 10^{15} JOULES (=9.5×10^{11} BTU)

DEMAND SECTOR	ENERGY SOURCE							
	ELEC-TRICITY	OIL	CROP RESIDUES AND WOOD	ANIMAL WASTE	COAL	GAS	MUSCLE POWER	HYDRO
Rural Residential	0.9	29.9	173.5	43.0	-	-	-	-
Agriculture	-	15.4	-	-	-	-	6.6	-
Urban Residential	5.2	26.0	-	-	-	-	-	-
Industry (Iron & Steel)	17.4	60.9	-	-	30.0	-	-	-
Industry (Feedstocks)			-	-	-	8.2	-	-
Industry (Other)			-	-	-	5.5	-	-
Public Utilities	2.0	-	-	-	-	-	-	-
Transportation	0.7	64.8	-	-	-	-	-	-
Other	1.4	66.1	-	-	-	-	-	-
Electric Generation	-	46.9	-	-	-	-	-	78.0*
Exports (Net)	-	114.5	-	-	-30.0	-	-	-
Losses	2.3	24.5	-	-	-	124.6**	-	-
Domestic Consumption	27.6	310.0	173.5	43.0	30.0	13.7	6.6	78.0
Domestic Production	29.9	449.0	173.5	43.0	-	138.3	6.6	78.0

* Valued as Equivalent Energy Input to Fossil-Fired Stations
** Nearly All Flared or Reinjected

Source: GOE/DOE (1)

TABLE X

EGYPTIAN ELECTRICITY GENERATION COSTS

Total marginal grid production costs including primary distribution (MMS)*.

SEASON & DAY	WORLD PRICES		EGYPTIAN PRICES	
	PEAK	SLACK	PEAK	SLACK
Winter Weekday	33.3	24.1	16.4	6.3
Winter Friday**	24.1	24.1	6.3	6.3
Summer Weekday	47.2	16.1	30.3	2.4
Summer Friday	18.1	13.1	2.7	2.0

* 1MM = L.E. 0.001 = $0.0014 = 1.4 Mills

** Friday is the Moslem Sabbath

Source: Egyptian Electricity Authority

TABLE XI

ASSESSMENT CRITERIA FOR PROGRAM SUITABILITY

TRIAD RESOURCE/TECHNOLOGY/END USE	ENERGY RESOURCE BASE	RELATIVE COST	MARKET POTENTIAL	SOCIAL IMPACTS	INFRA-STRUCTURE	CRITICAL RESOURCES	ENVIRONMENTAL IMPACT	BALANCE OF PAYMENTS EFFECTS	DONOR ACTIVITIES
Solar collectors for hot water and space heating	excellent	excellent	excellent	positive	good	domestically available	benign	positive	France, W. Germany
Solar collectors for industrial process heat	excellent	good	good to excellent	limited	good	domestically available	benign	positive	None known
Solar flat plate collectors for refrigeration and cooling	excellent	good	good	positive	good	domestically available	benign	positive	France, W. Germany
Solar flat plate collectors for food drying	excellent	excellent	excellent	positive	excellent	domestically available	benign	positive	Canada
Photovoltaics for remote applications: clinics, communications, water pumping	excellent	poor at present	good	positive	poor	key components imported	benign	negative	France, W. Germany
Wind energy conversion systems for water pumping	good	excellent	excellent	positive	excellent	domestically available	benign if carefully implemented	positive	Oklahoma St. Univ.
Wind energy conversion systems for off-grid electric generation	good	excellent	excellent	positive	excellent	domestically available	benign	positive	None known

TABLE XI

ASSESSMENT CRITERIA FOR PROGRAM SUITABILITY (continued)

TRIAD RESOURCE/TECHNOLOGY/END USE	ENERGY RESOURCE BASE	RELATIVE COST	MARKET POTENTIAL	SOCIAL IMPACTS	INFRASTRUCTURE	CRITICAL RESOURCES	ENVIRONMENTAL IMPACT	BALANCE OF PAYMENTS EFFECTS	DONOR ACTIVITIES
Wind energy conversion systems for grid-integration	excellent in certain locations	excellent	fair to good	positive	fair	domestically available	moderately negative	initially negative	None known
Biogas digesters for cooking, lighting, and water heating (family and community scale)	excellent in certain locations	excellent	excellent	positive	excellent	domestically available	benign	positive	NSF, AID
Passive solar architecture	(conservation technique)	excellent	excellent	positive	fair to poor	domestically available	benign	positive	CARE
Improved rural cooking stoves	(conservation technique)	excellent	excellent	positive	excellent	domestically available	positive	positive	None known
Large-scale hydro-electric generation	good	excellent	good	positive	excellent	limited siting	generally benign	positive	W. Germany
Solar desalination	good	costs of alternative water sources unknown	limited	positive	good	domestically available	benign	neutral	None known
Anaerobic digestion of municipal sludge	moderate to fair	fair	fair	limited	good	modest land requirements	positive	ultimately positive	United Kingdom

TABLE XI

ASSESSMENT CRITERIA FOR PROGRAM SUITABILITY (concluded)

TRIAD RESOURCE/TECHNOLOGY/END USE	ENERGY RESOURCE BASE	RELATIVE COST	MARKET POTENTIAL	SOCIAL IMPACTS	INFRA-STRUCTURE	CRITICAL RESOURCES	EN-VIRONMENTAL IMPACT	BALANCE OF PAYMENTS EFFECTS	DONOR ACTIVITIES
Anaerobic digestion of municipal solid waste	fair to good	poor/ fair	limited	none	fair	fair/ poor	positive	negative	World Bank
Composting of municipal solid waste	(not an energy product)	fair/ poor	excellent	positive	good	water	positive	initially negative	World Bank
Solar concentrators for domestic cooking	excellent	excellent	poor	positive	poor/ fair	domestically available	positive	positive	CARE
Geothermal energy for electric generation and direct use	unknown	unknown	unknown	positive	excellent	key components imported	negative	initially negative	U.S. Geologic Survey
Biomass Plantation (tree farms)	poor	fair to good	good	negative	fair	large areas of very scarce land needed	unknown	negative	None known
Small-scale decentralized hydroelectric generation	unknown	excellent	unaccessi-ble at present	positive	excellent	key components imported	benign	initially negative	None known
Solar power tower for electric generation	excellent	poor	unaccessi-ble at present	probably positive	poor	key components imported	limited	negative	National Science Foundation/Univ. of New Mexico
Direct combustion of municipal solid waste	fair to good	excellent	good	negative	good	domestically available	negative	initially negative	None known

six program options with outstanding potential; (b) options with good potential; (c) other options considered; and (d) options needing either further study or later re-evaluation. The category of outstanding options was subject to further refinement after consultation with USAID/CAIRO. The six selected options were deemed to be suited both to the needs of Egypt and to AID's program mandate and policies. They are treated in detail in Chapters 4 through 9.

3.9 The Ranking of Program Option Areas

Options with Outstanding Potential Analyzed in Phases I and II:

- Solar Collectors for Process Heat, Hot Water, and Space Heating*
- Solar Crop and Food Drying
- Rural Biogas Digesters
- Wind Systems for Water Pumping, Electric Generation and Possibly Desalination**
- Solar Flat Plate Collectors for Refrigeration and Cooling
- Photovoltaic Collectors for Remote Applications

Options with Good Potential:

- Passive Solar Architecture
- Improved Rural Cooking Stoves
- Large Scale Hydro-Electric Generation
- Solar Desalination (Solar Stills)
- Anaerobic Digestion of Municipal Sludge

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*Two triads combined.

**Three triads combined.

- Anaerobic Digestion of Municipal Solid Waste
- Composting of Municipal Solid Waste

Other Options Considered:

- Solar Cookers
- Geothermal for Electric Generation and for Direct Use
- Direct Combustion of Municipal Solid Waste and Agricultural Residues
- Tree Farms

Options Needing Further Study or Later Evaluation:

- Small Scale Decentralized Hydro-Electric Power
- Solar Power Tower

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4.0 SOLAR COLLECTORS FOR INDUSTRIAL AND DOMESTIC APPLICATIONS

4.1 Conclusions and Recommendations

There are four broad program areas of potential USAID involvement in the development of solar water heating in Egypt. These are:

- Technical Assistance
- Demonstration Program
- Infrastructure Development
- Production Development

It is envisaged that both industrial and domestic application will be handled in a consolidated program, and are discussed together. The industrial program is felt to offer better opportunities for USAID involvement because: (1) the industrial potential is larger, and (2) it can be achieved with a smaller number of relatively large projects which will be easier to manage and implement. Each of the four program areas are discussed in turn:

- Technical Assistance. Objective: to enhance Egyptian capabilities in solar water heaters in the following areas:
  - quality control
  - design selection and improvement
  - manufacturing techniques
  - performance standards

  Discussion: These sub-elements can be pursued through joint programs with the National Research Center (NRC), the Center for Industrial Development, and possibly the High Voltage Laboratory of the Ministry of Electricity. Assistance in manufacturing techniques and quality control may require cooperation with private manufacturers, such as the Arab Company for the Utilization of Solar Energy, as well as research institutions.

- Demonstration Programs: Objective: To demonstrate the potential of solar water heating in industrial applications.

  Discussion: An agricultural/industrial process heat demonstration program should concentrate on a relatively small number of large units. Ten to twenty units should be considered, mainly in the food processing and textile industries, and located primarily in the Delta Region where industry is concentrated. Possible applications include bottle and can washing (e.g., the Egyptian Dairy Company), chicken shed heating, textile washing and dyeing, soap manufacture (e.g., at Wadi el Natrum), and perhaps bread baking (e.g., Biscomisr Company). Specific selection of industrial demonstration types and sites would need further analysis. Domestic applications are sufficiently advanced for a demonstration program to be unnecessary.

- Provision of Units. Objective: To provide units to selected target groups.

  Discussion: USAID can directly or indirectly provide solar water heaters to selected targets, such as health clinics, hospitals, schools, and the urban poor. This option should be carefully evaluated.

- Infrastructure Development. Objective: To develop a strong supporting infrastructure.

  Discussion: Good opportunities exist for USAID involvement via carefully selected assistance projects.

  - Training for installation and maintenance. The NRC is currently planning to start some courses in 1980; if significant utilization is to be achieved these efforts could be expanded through existing educational institutions.

  - Legal solar rights, i.e., the right to avoid blocking of solar radiation by new construction on adjacent sites.

  - Layout and design of new cities. If, as envisaged, a significant portion of the domestic solar water heating market is to come from the new cities, it is essential that these be laid out and designed in such a way as to maximize the ease of solar utilization. Street orientation and building design are relevant areas of concern.*

*Careful building design may also minimize the need for external heating and cooling methods, which is an important consideration.

- Financing Mechanisms. Availability of financing and the financing costs will have a significant influence on market penetration in domestic applications, especially at the lower income levels of society. Banks, mortgage companies, cooperative societies and the manufacturers are possible sources of financing whose needs and attitudes should be taken account of in program planning.

- Distribution System. It must be made clear which institutions will handle the units. This may be done by the manufactuers or by middlemen. In any case, the quality of the distribution system will have a strong influence on market penetration for domestic applications. The adequacy of stocks of new units and spare parts will be dependent upon availability of financial backing. Installation and maintenance adequacy will depend partly on availability of trained workers, as noted above.

- Production Development. If the planned private manufacturing ventures fail to materialize, USAID should consider involvement in the establishment of a factory. This element should be evaluated in a year or so, after monitoring Egyptian production experience. USAID assistance may also be useful in establishment of production facilities for industrial units, especially if these use more sophisticated collector design (such as concentrating collectors).

- Phosphate drying. Objective: To apply solar energy to phosphate drying.

  Discussion: Drying phosphate slurry (e.g., at El Hamrawain on the Red Sea Coast) should be considered a separate element. Large potential petroleum savings (up to 90,000 tonnes/year) exist. The technology could be based on hot water or steam, or, perhaps, hot air. This could be a large program element, and would be relatively simple to administer, being a single application in a single place. A program in this area would cover:

  - Research and Development - theoretical and experimental studies should be undertaken first to determine feasible technologies. Technology assistance from U.S. experience would be useful here. Cooperation with the NRC is indicated.

  - Pilot Scale Testing - An initial pilot-scale process could be developed in a relatively short time scale (about 2 years).

- Full Scale Implementation - assuming success on the pilot-level, full scale implementation could start in as little as three years. The process could be designed to be modular, replacing only a small part of the fossil fuel usage initially until technical and economic viability is proven.

4.2 Technology Description and Relative Costs

The technology for solar water heating is very simple and basically consists of a flat collector plate, covered with glass, containing a blackened backplate and a number of tubes through which water* can flow. As the water passes through the tubes, it becomes heated as the result of solar radiation penetrating the glass cover. The heated water passes either directly to a storage tank, or to a heat exchanger to heat the storage tank indirectly (see Figure 10). In some cases, collectors which concentrate the sun's rays by refraction or reflection may be used to achieve higher temperatures for industrial applications. The technology is well understood and is used in many countries.

Domestic units, suitable for applications in Egypt, are typically capable of producing 100 to 200 liters of water per day at 60°C for an output of 1.5 to 3 x 10^7 J/day.(18) Institutional units range from 500 liters/day up; they may be modular. Industrial units may have a capacity up to several hundred thousand liters/day of hot water at up to 150°C.

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*In climates where freezing occurs, the circulating fluid must incorporate anti-freeze (which then requires the use of a heat exchanger to prevent contamination of the output water), or provision for automatic draining of the collector must be made.

(18) National Academy of Sciences, Energy for Rural Development, 1976.

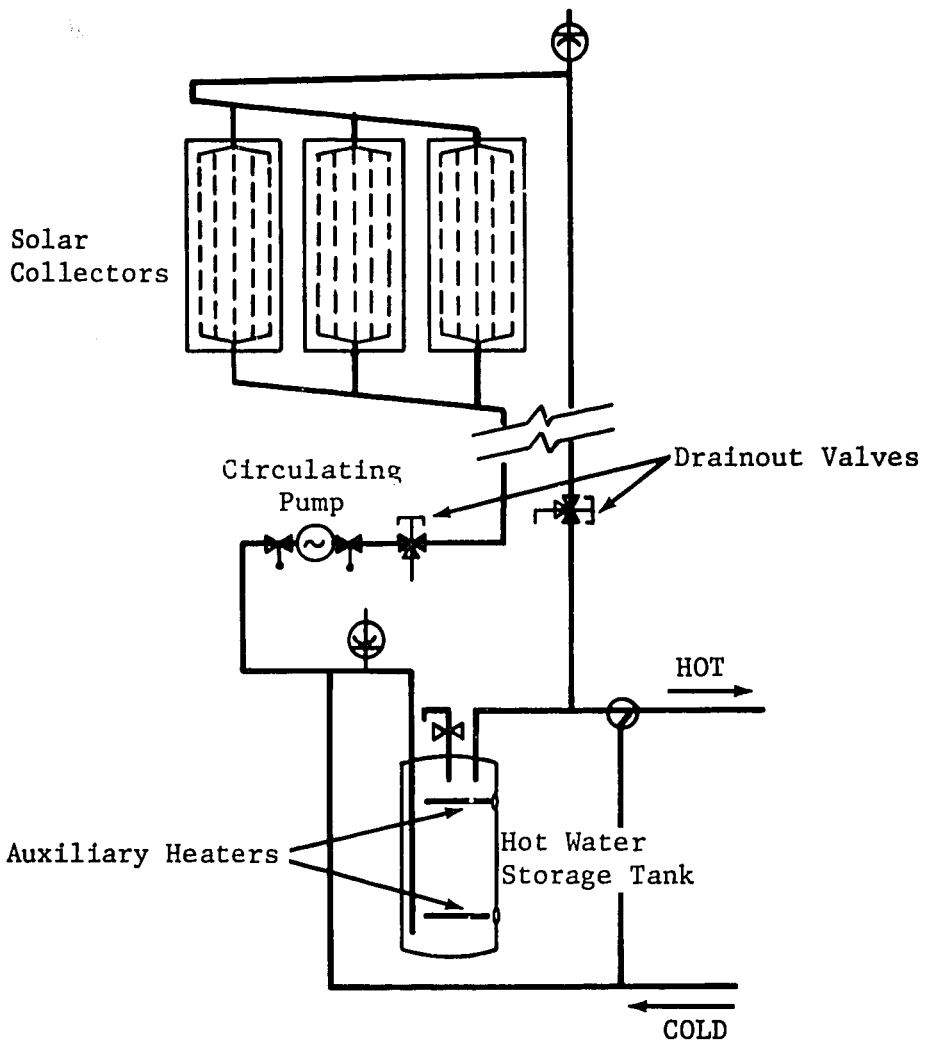

FIGURE 10
SCHEMATIC OF SIMPLE DOMESTIC SOLAR WATER HEATER

The capital costs of domestic systems available in Egypt are L.E. 1.40/liter/day for systems of Egyptian manufacture and L.E. 2.60/liter/day for imported systems.* Annual operating and maintenance costs are estimated at 2 percent of the capital cost. In the excellent solar conditions prevailing in Egypt, levelized energy costs over a 10-year life cycle are about L.E. 4-6/10^9J for Egyptian units and L.E. 7-10/10^9J for imported units. Capital, operating and maintenance, and delivered energy costs for industrial systems vary depending upon output temperature, size, storage requirements and other factors, but are likely to be similar or lower due to economies of scale. (19) The Egyptian equivalent of U.S. costs amount to L.E. 1-3/10^9J.

Since the real world-market costs of fossil fuels are in the range of L.E. 3-9/10^9J, and are escalating rapidly, solar water heating is clearly competitive economically. In the industrial context, waste heat recovery represents another competitor. The costs of energy from this source are highly application-specific and cannot be estimated in a general sense. However, many industrial operations envisaged for solar applications use only low grade heat.

It must be noted that solar water heating is <u>not</u> competitive with the subsidized prices of fossil fuels in Egypt, which range from L.E.0.2 to L.E. 1.1 per 10^9 Joules.**

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*Figures obtained to GOE call for bids, Prices are (FOB) Alexandria.

**Data from Team Surveys and Egyptian Ministry of Petroleum.

(19) The Mitre Corp., <u>Systems Description and Engineering Costs for Solar-Related Technologies</u>, MTR 7485, Vol. III, 1977.

4.3 Utilization Potential

The potential market for industrial process heat applications is difficult to assess because the effectiveness of solar energy in an industrial setting is quite case specific. In 1975, Egyptian industry used about 65QJ of fossil fuel (excluding feed stocks and use of coal in steel making).[14] Food processing and textiles account for some 2/3 of the market value of all Egyptian industrial production and these industries are known to require considerable quantities of low temperature heat. This is especially true of the food processing industry.

Five case studies have been made which allow the potential market to be estimated.* These are:

- The Al Hamrawain Phosphate Mine on the Red Sea Cost currently produces 150,000 tpy of phosphate. Its design capability is 600,000 tpy but equipment problems limit output. The raw rock is crushed and washed to extract the phosphate which is then dried. According to mine personnel, the drying process requires approximately 0.2 tonne of fuel oil per tonne of phosphate produced, and probably could be augmented or replaced by solar heat. The exact technology required is not clear. Seventy-five percent replacement of fossil fuel by solar energy would save about 90,000 tpy of fossil fuel when the mine reaches full production, or about 4 QJ/year. This is an extremely large amount of energy, worth (as oil) about $20 million annually. Similar applications may be possible in other mineral extraction processes.

- The Egyptian Dairy Company has 60 milk collection centers and nine processing plants throughout Egypt. Annual production is L.E. 23 M. Water at 70°C is required for container washing at each collection center, and plans already exist to use

*Data obtained through personal interviews with plant managements.

(14)GOE/DOE, op. cit., Vol. I., 1979.

solar energy for this on an experimental basis at Imbaba, Damietta and Alexandria. The justification is that current equipment is becoming difficult to maintain and operate. At the processing plants, 7300 tpy of milk is heated from 4°C to 95°C for pasteurization. Yogurt, cheese and other products are made. About 0.1 QJ of total fossil fuel input is required annually.

- The Kaha Plant produces canned and bottled juices, jams, jellies, vegetables and meats. Annual production is L.E. 20 M. The plant currently produces 18 tph of steam at 10 atmospheres and $10m^3$/hr of water at 100°C for various processes. Preheating the water by solar energy to 90°C could save up to 0.06 QJ of fossil fuel input per year.

- The Biscomisr Plant uses steam at 180°-300°C for biscuit and wafer production; the fossil fuel needs are about 800 kg mazout per tonne. If 1/3 of this could be replaced by solar preheating, fossil fuel savings could be 0.06 QJ.

- Soap production in the Wadi El Natrun uses 2 tph water at 90° to 100°C, presently heated by residual fuel oil. Solar assistance could save about 0.002 QJ fossil fuel annually.

From the above studies, the maximum potental market for solar industrial process heat is about 15QJ/year. An optimistic but realistic projection assuming partial success at El Hamrawain is 10QJ/yr. This is about 1.6 million barrels of oil/year, or about 15 percent of present Egyptian industrial energy usage.

(b) Domestic

The primary potential for domestic applications of solar water heating is in new urban residential construction. Smaller but significant potentials exist in new and retrofit institutional applications (schools, clinic, hospitals, mosques, etc.). Urban residential retrofits and rural use offer still smaller major potentials at present.

Egypt's population is expected to increase by up to 20 million by the end of the century,[7] requiring the construction of about 4 million new residential units, plus associated schools, hospitals, mosques, etc. At least half of these buildings will be in built-up areas having piped water and will therefore represent excellent opportunities for solar water heater installation. This market is at least 100,000 units/year.

Retrofit of existing urban dwellings is difficult because of building design and ownership patterns. However, retrofit of existing schools, hospitals, etc., presents better opportunitities. The structure of the buildings is often such as to make installation of solar water heaters quite easy, and these institutions are mainly government owned.

Rural areas at present have rather limited potential for solar water heating. Many rural dwellings are built of mud bricks and lack running water, and rural patterns of life do not involve the use of much hot water, other than for cooking. However, the installation of solar water heaters on new brick or concrete rural houses with piped water (as at Mit Abul Kom) is desirable and will represent a growing potential as rural housing standards improve.

The installation of 150,000 units by 1990 would imply substitution of about 2QJ of fossil fuel annually. This number is in line with the projected manufacturing capability in Egypt under a "business as usual" type scenario. A vigorous program with the full

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[7] World Bank, World Development Report, 1978.

backing of the GOE could increase the above numbers by a factor of 3 (i.e., about 500,000 units and 6 QJ of impact, representing 20 percent of current urban residential fuel consumption). Long term prospects (post-1990) for greater penetration are excellent, given equalized subsidy treatment.

4.4 Social, Environmental and Other Impacts

The major impacts of solar water heating will be economic. The substitution of solar energy for oil-based fuels will release more petroleum for export, improving the balance of payments. In addition, Egyptian manufacture will provide employment and stimulate the national economy. It may eventually be possible for Egypt to undertake the export of solar collectors and systems to other countries in Africa and the Middle East.

The prime beneficiaries of a vigorous solar energy program will not, in general, be the end users, who already use extremely cheap subsidized fuels, but will rather be the GOE, which will have increased revenues from petroleum sales at its disposal. Of course, for solar water heating to succeed, the GOE will have to arrange subsidies to provide some economic incentive to the end users, so they will enjoy some benefits. Secondary beneficiaries will be those involved in the manufacture, distribution, installation and maintenance of solar collectors.

Limited direct social impacts are expected from industrial applications. Domestic applications may have greater social impacts.

Increased supplies of hot water for washing and bathing may have beneficial health effects. The use of solar-heated water as a starting point in food preparation will require changes in cooking methods[20] which may be slow to come to pass. Solar heaters require periodic cleaning so that some limited education of end user may be necessary.

Since the use of solar water heating will displace primarily fossil fuel combustion, the net effect will be an improvement in air quality. In rural areas, solar water heaters may, in addition, displace the use of animal dung and agricultural residues as fuel sources. Any dung and residue which is displaced in this way can be applied to the land, and will tend to increase soil quality and productivity. Moreover, the heavy smoke which is released when burning dung or straw will be reduced.

Required construction materials include: steel, copper, glass, wood, sealant, paint and fiberglass. These are readily available. Other resource requirements are not critical, but the intermittent nature of water supply in Egyptian cities may reduce the energy output of solar water heaters. Also, the space required to deploy solar collectors may constrain development in some urban areas.

4.5 Infrastructure

Solar water heating is a mature, commercially available technology. Current development activities in Egypt focus on: (1)

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[20] T.E. Bowman, Solar Cooker Fabrication in Upper Egypt: An Experiment in Appropriate Technology, Florida Institute of Technology, Melbourne, Florida 32901, 1979.

adapting systems and designs to local Egyptian conditions, and (2) facilitating the process of technology transfer, primarily for domestic and institutional applications.

On the subject of adaption to local conditions, priorities for research and development include: dust removal techniques, glazing protection, and the development of selective absorbing coatings for local manufacturers. In this regard, the Conseil National de Reserche Scientifique is testing solar water heaters at the High Voltage Laboratories of the Ministry of Electricity. This French donor activity does not at present represent a significant impact on the Egyptian energy scene, and should not preclude USAID involvement.

Technology transfer is being accomplished via the Solar Energy Laboratories at the National Research Center, the Cairo University, and the Center for Industrial Development. The National Research Center, particularly, is offering a training course on solar energy systems as part of its ongoing Programme of Training Course.

Domestic manufacturing capacity is now concentrated in one company, the Arab Company for Utilization of Solar Energy. Current output is about 5000 systems a year, in three sizes, 100, 150, and 200 litres/day. There are, however, six other commercial enterprises which are planned to soon begin producing water heaters in Egypt.* They are:

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*Data obtained from applications filed with the Five-Year Industrialization Plan Authority.

1. Commercial Solar Energy - a joint Egyptian (75%) and British (25%) venture. Capital assets are L.E. 400,000 and capacity is 5,000 units of various sizes/year normal production and 10,000 units per year at maximum production.

2. Thia - a joint Egyptian (60%) and Cypriot (40%) venture. Capital assets are L.E. 200,000 and production is 1,000 units/year normal, rising to a maximum of 5,000 units/year.

3. Ismailia - owner is Mohammed E. Desukey and 100 percent Egyptian owned. The factory under construction. Capital assets are L.E. 230,580 and capacity is 1,200 units per year of 150/litre/day size.

4. Military Factory #360 is intending to produce under license from Junker Company of the Federal Republic of Germany.

5. Osman Ahmed Osman is licensed and currently experimenting with an NRC design using all local materials except for paint. This company manufactures other goods. Solar water heaters would represent a new line of production.

6. ILMACO - a company formed by the Ministry of Electricity Company. They will soon be manufacturing.

Also, the Ministry of Electricity recently signed contracts with three European manufacturers to supply 1000 water heaters of varying designs. Following a period of testing, the Ministry will select the design most suited for use in Egypt and will begin manufacturing it locally. The three companies and designs involved in the program are:*

- CEDEM (Orleans, France) - single glazed collector with heat exchanger and either natural or forced circulation.

- Thermosolar (Montreal, Canada) - single glazed collector with auto drain (no heat exchanger) and forced circulation.

- SILE (Triesiso, Italy) - single glazed collector with heat exchanger and natural circulation.

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*Data obtained from material supplied by the companies concerned.

5.0 SOLAR CROP AND FOOD DRYING

5.1 Conclusions and Recommendations

Industrial-scale and domestic-scale applications are discussed separately. The industrial-scale market (i.e., dryers with outputs in the 0.5-10 tonne/day range and up) offers the most promising opportunities for USAID involvement and is discussed first. The industrial demonstration program is the most important element in this area.

- Industrial Applications. A program in this area will have the advantage of being able to concentrate on a limited number of individual applications, and will thus be easier to manage. Objectives and recommended support activities are discussed in detail:

  - Technology Transfer and Development. Objective: to adopt and adapt existing dryer technology.

    Discussion: Little experience exists with solar dryers in Egypt. However, solar dryers on the industrial scale are in use elsewhere in the world and the technology of these dryers should be modified and developed to suit Egyptian conditions. There is a good opportunity for USAID to cooperate with the NRC in this area.

  - Demonstration Program. Objective: To demonstrate the potential of commercial crop drying.

    Discussion: A limited number (10-12) of demonstration plants of at least several tonnes/day capacity each should be installed for different applications and at different localities in the agricultural and fishing regions. Logical choices for demonstration units include fish drying at Aswan and along the Red Sea, and cooperation with a company such as Kaha in onion drying in the Delta or Nile Valley.

  - Infrastructure Development. Objective: To develop a strong supporting insfrastructure.

Discussion: This area includes USAID assistance in training and development of maintenance capabilities. Technical assistance in manufacturing and financial aid to potential users who lack capital should also be considered.

- Production Facilities - should only be considered for USAID assistance if private investors are unwilling or unable to finance domestic production of industrial-scale dryers.

- Domestic Market: A program in this area will necessarily involve many thousands of small units if it is to be effective. As such, the management difficulties of this type of program are greater than for industrial applications. Close coordination with USAID agricultural programs and with GOE services such as the Agricultural Extension Service and with the local Cooperative will be essential.

  - Technology Transfer. Objective: To transfer existing dryer technology.

    Discussion: Many designs of solar dryers have been developed. It will be necessary to select those which are appropriate for Egyptian crops and conditions and which can be made in Egyptian towns with locally available materials. USAID should cooperate with the NRC and other Egyptian research institutions.

  - Demonstration Program. Objective: To demonstrate the potential of domestic solar crop drying.

    Discussion: Once suitable designs have been selected and tested, a substantial number of demonstration models should be made available to individual farmers through local cooperatives, or to the local cooperatives themselves. Guidance will be required to instruct recipients in correct methods of use, and the major emphasis and costs of this program will be associated with personnel.

  - Infrastructure Development. Objective: To develop a strong supporting infrastructure.

    Discussion: This element includes training of local artisans in dryer construction, making available financing for setting up production facilities, setting up credit mechanisms to allow individual farmers or cooperatives to purchase dryers, and preparing collection and distribution channels for the dried produce where these channels do not already exist.

5.2 Technology Description and Relative Costs

The technology employs solar collectors to heat air which is then used to dry crop and food products. A typical dryer is illustrated in Figure 11. The scale of units may range from small chest-type collectors with a few square meters of area for use at the domestic and single farm level, to much larger commercial-scale units capable of producing several tonnes or tens of tonnes per day of dried goods.

Dryers generally consist essentially of a wooden rectangular box covered with glass. Air circulates through vents by either natural or forced draft. The drying trays are removable.

Larger commercial units may resemble greenhouses, being wood-framed rectangular buildings with glass roofs. Drying platforms are placed inside the building and air circulates by either natural or forced draft, usually exiting through vents at the peak of the roof. If auxiliary fossil heating is used, burners are usually placed in rows under the drying trays.

The energy output of the units usually lies in the range 14 to 22 x 10^6 J/M^2 per day (4 to 6 kWh/m^2/day) under Egyptian conditions. The output of dried material varies widely depending on crop type, dryer design, climate, and moisture content, but a range of 0.2 to 1.8 kg/m^2day is representative.[21]

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[21] Brace Research Institute, A Survey of Solar Agricultural Dryers, T99, MacDonald College of McGill University, 1975.

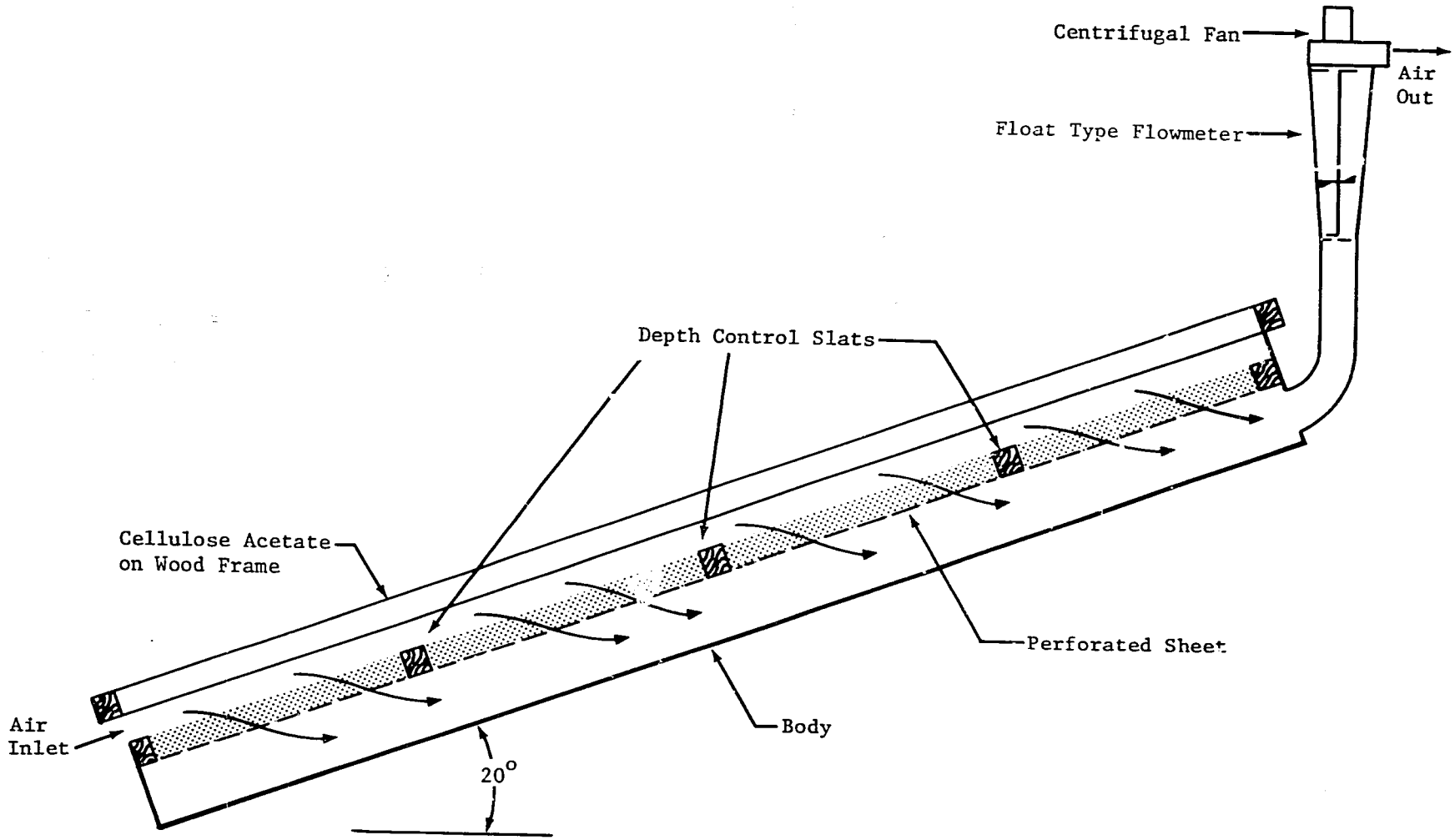

FIGURE 11
DIAGRAM OF TYPICAL SOLAR CROP DRYER

The capital costs of dryers are also extremely variable. The simplest type of domestic dryers may, with careful selection of locally-available materials, cost as little as L.E. 1 to 5/m^2. At the other extreme, expensive and sophisticated collectors may cost as much as L.E. 14 to 24/m^2. Operating and maintenance costs also range widely from L.E. 14 to L.E. 60 per tonne of output.(21)

Combining all factors together, the levelized cost of solar crop drying are estimated to lie in the range L.E 15 to L.E. 100 per tonne of output. The real (world-price) costs of conventional fossil-fired drying are estimated to be L.E. 100 to L.E. 300 per tonne;(22) local (subsidized) costs are of course much lower.

5.3 Utilization Potential

Commercial food and crop drying already takes place on a large scale in Egypt, generally in conventional plants producing 0.5 to 10 tonnes/day output. Total tonnages of dried products are shown in Table XII.

A potential market exists for dried fish whether for human consumption or for poultry or animal feed.* The High Dam Lake and, especially, the Red Sea fishing industries could undergo considerable

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*Fish is dried commercially in the open air at Aswan on a small scale. A fish drying and processing plant existed at Alexandria until 1962, when it was nationalized and the equipment removed for use elsewhere.

(21) Ibid.

(22) Estimated from data in Government of Pakistan Report by Dr. M. Jamil, PCSIR, Labore (no date).

TABLE XII

DRIED FOOD PRODUCTION IN EGYPT

CROP	ANNUAL PRODUCTION (Tonnes)
Onions	80,000
Garlic	5,000
Other Vegetables	4,900
Dates	10,000
Grapes	1,000
Dried Meat	2,800

Source: Dr. A. El Mehelmy, Five-Year Industrialization Plan Authority

expansion. At the domestic or farm level, many crops are already sun-dried - tomatoes, okra, peppers, and maloukhia, for example.

There may also exist a potential market in drying hay or clover. Currently only 1 out of 3 annual crops is dried, due to insect infestation. One million feddans are in hay production with an annual wet crop of 5,000,000 tonnes.*

Penetration of 25 percent of the existing commercial drying market would save fossil energy at the rate of about 1 QJ/yr. Construction of new facilities and conversion of old could produce this result by 1990.

As an example of possibilities in this area, the Kaha Food Processing Company has installed new fossil-fired dryers in Badrashain Village for crop processing. They expressed great interest in solar augmentation of these units when interviewed by team members.

Domestic-scale dryers will, of course, not replace any fossil energy. It is estimated that a potential market for several tens or hundreds of thousands of these units exists.

5.4 Social, Environmental and Other Impacts

The major impact of the commercial use of solar crop drying will be economic. The substitution of solar energy for fossil fuels will release more petroleum for export, improving the balance of payments. In addition, Egyptian manufacture will provide employment and

*Data provided by Dr. A. El Mehelmy, of the Egyptian Five-Year Industrialization Plan Authority.

stimulate the national economy. In general, the prime beneficiary of commercial use will be the GOE, which will gain increased revenues from oil exports. Secondary beneficiaries will be those involved in the manufacture, maintenance and operation of the dryrs. End-users will see little apparent change in costs (since fossil fuels are highly subsidized) or service.

Widespread use of domestic-scale dryers will have significant social and economic impacts. Reduction of spoilage and losses due to open-air crop drying, and the production of a large higher-quality product, can significantly raise rural incomes. For certain crops, the value of high-quality produce is twice that of low quality product. In addition, manufacture of the dryers can be undertaken at the village or small town level.

Little resistance is foreseen to the wider use of dried foods, since they are already common in Egypt.

The environmental impacts of commercial solar crop drying will be beneficial since substitution of solar energy for fossil fuels will improve air quality. At the domestic level, the amount of land required for drying will be reduced, compared with open-air drying. Finally if production of dried foods is expanded, transportation needs may be decreased, compared with non-dried products.

Materials required for dryer construction are simple-steel, glass, wood, sealants, galvanized sheet. Manufacture could take place 100 percent in Egypt. Other resources needed present no

constraints, except possibly land. For commercial dryers, the increased space needed for solar collectors may compete with agriculture. It is also possible that rooftop location of domestic dryers may compete with storage or living space.

5.5 Infrastructure

Some R&D is being conducted at the National Research Center (NRC) and at the Faculty of Engineering of Helwan University. The International Development Research Center of Canada is cooperating with the NRC. This Canadian investment is of limited scale and should not preclude USAID activity in this area.

Construction of solar crop dryers is relatively straightforward, especially at the domestic scale. Manufacture of both commercial and domestic units is well within the capability of Egypt although none is taking place.

Egypt has well-established institutional channels for the distribution and use of dried foods, and the expansion of these channels would not be difficult. Close cooperation with existing institutions (such as Rural Cooperatives and the Agricultural Extension Service) will be essential.

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6.0 RURAL BIOGAS DIGESTERS

6.1 Conclusion and Recommendations

This technology is well-developed and widely used in India and China, so that a program could start almost directly with a large scale demonstration program, with infrastructure development and some R&D proceeding in parallel. Because of the significant changes required in agricultural methods, any program in this area must be carried out in cooperation with USAID and GOE agricultural services. Combination with other agricultural and community development programs would be highly desirable.

The program elements recommended are technology transfer, demonstration, and infrastructure development:

- Technology Transfer. Objective: To develop suitable designs.

  Discussion: Many thousands of biogas units are in operation in India and China, so that basic design principles are well-known. USAID is already providing assistance (via the University of Cairo at Fayoum) in developing biogas designs. This program should be strengthened to select and adapt those features of Indian and Chinese designs which are most suitable for Egyptian conditions and capabilities.

- Demonstration Program. Objective: To demonstrate the viability of rural biogas digesters.

  Discussion: A limited program of 100-200 units of varying designs, sizes and locations through the Delta, Nile Valley and Fayoum regions should be considered. Units should include larger-scale types based on existing large government and private dairy and poultry farms, as well as single-family units, and possibly, communal types if the potential management problems associated with these latter can be solved. The program should be oriented towards proving economic viability and enhancing rural Egyptian public awareness and

acceptance. This program would naturally be spread over a few (up to 4) years, and would have the objective of conclusively demonstrating the economic viability and social acceptibility of this option. The major costs of this program will be associated with personnel rather than the capital costs of the digesters themselves.

- Infrastructure Development. Objective: To develop a strong supporting infrastructure.

  Discussion: Parallel with the Demonstration Program, activities should be started to develop the infrastructure for constructing and operating large numbers of digesters in subsequent years. This program element will consist of several sub-elements including the following:

  - Technical Assistance and Training: Initial training may take place in China or India, followed by the use of existing educational institutions in Egypt to train agricultural extension agents and others in construction and operating techniques.

  - Financial Assistance: Because of the high subsidies on fossil fuels available to rural people in Egypt, acceptance of biogas digesters may be limited unless some financial incentives are provided. USAID can properly become involved in the provision of this assistance, which may be to existing institutions and cooperative societies or to individuals, but should be structured to ensure continued operation of the digesters.

  - Establishment of Manufacturing Facilities: Workshops for manufacturing gas-holders, gas stoves, lamps, pipes and burners should be established. Designs for accessories developed in India and China can be adapted.

  - Continuing Research: A continuing R&D program should be undertaken to improve biogas digester designs and techniques, including research on fermentation methods for pre-preparation of cellulosic materials, maximization of gas production under different circumstances, optimum methods of slurry and effluent utilization, and design changes to reduce construction and operating costs.

6.2 Technology Description and Relative Costs

Biogas digesters utilize the anaerobic digestion of human and animal wastes and some vegetable matter to produce:

(1) low-Btu gas (about 50 percent methane)

(2) slurry residue with high utility as fertilizer and soil conditioner

(3) nutrient-rich liquid effluent which can be used to grow algae or duckweed for poultry feed.

Digestion takes place in a chamber of about $10m^3$ volume for domestic units, or larger for multi-family or communal units. A typical digester is shown in Figure 12. The input part of the digester may be integrated with domestic sanitary facilities to reduce handling of human wastes.

According to personnel at the University of Cairo campus at Fayoum, normal operation of a domestic unit starts with an initial charge of about 800 kg of wet animal dung and human waste mixed with partially-composted vegetable matter. About 10kg of human and animal wastes and some water are added daily. After 6 months, the unit is cleaned, yielding 1 1/2 to 2 tonnes of fertilizer slurry, and the cycle repeats.

The output of biogas digesters depends on their size, the quantity and quality of input, and the temperature. Gas production is generally 0.3 to $0.4m^3$ per kg of cattle or buffalo waste, and up

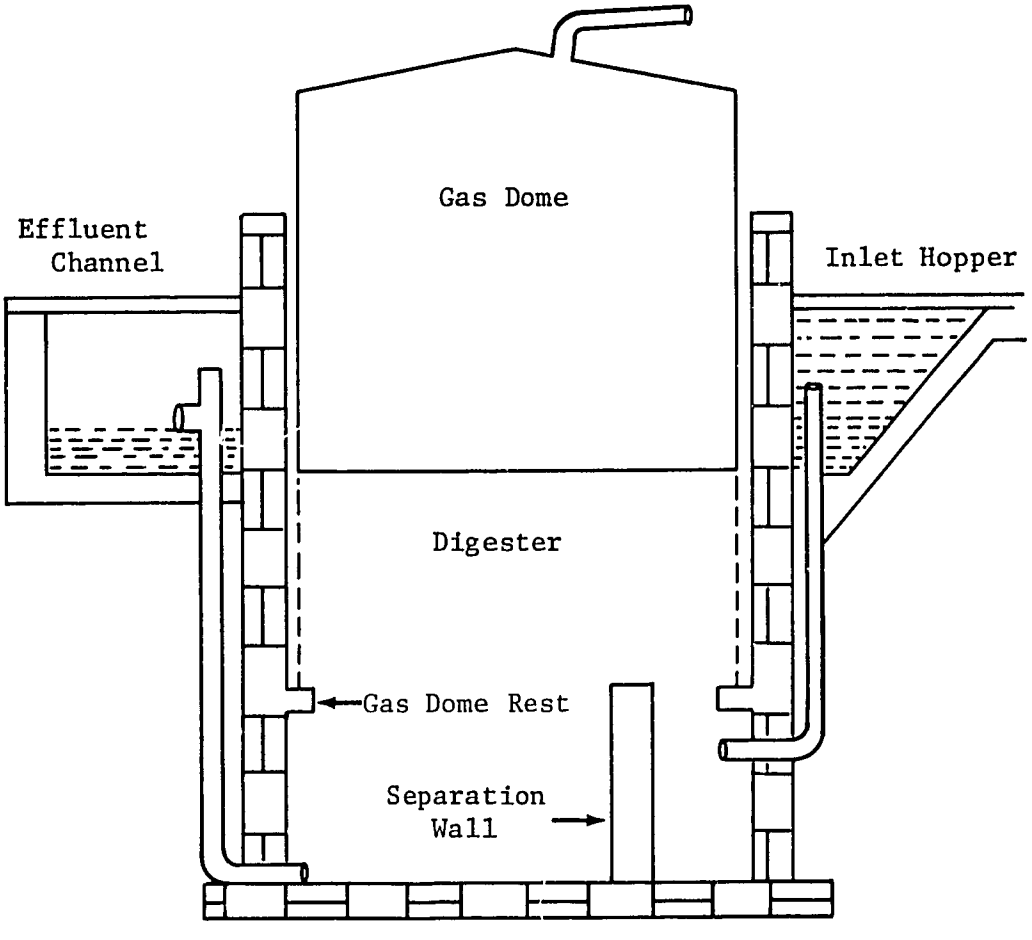

FIGURE 12
DIAGRAM OF TYPICAL RURAL BIOGAS DIGESTER

to twice this from human or poultry waste. A $10m^3$ unit will produce 3 to 4 m^3/day of biogas with an energy content of about 1.6 x 10^7 J/m^3.[23,24] The approximate annual yield is 2 x 10^{10} J, plus about 4 tonnes of fertilizer slurry, sufficient to treat 2 acres at 2 tonnes/acre.

It is estimated that the capital cost of a unit will be L.E. 150 to L.E. 200 in Egypt.* Annual O & M costs will be L.E. 15 to L.E. 20, excluding the imputed value of the operator's labor. Based on a 10- to 20-year equipment life, the levelized cost of the energy produced is L.E. 1.7 to L.E. 3.0 per 10^9J, excluding both imputed feedstock costs and imputed value of slurry and liquid effluent. The real cost of butagas on the world market is L.E. 9/10^9J, and kerosene is L.E. 4/10^9J. One $10m^3$ unit could thus produce energy with a real value at L.E. 100 to L.E. 200 annually.

6.3 Utilization Potential

The potential market for these units is the 4,000,000 farming families living in the Delta, Nile Valley and Fayoum regions. (Other regions lack settled agriculture and adequate water). The number of animals required to support a $10m^3$ unit is variously estimated at 2-5 large beasts (cows, buffalo) or equivalent (human and poultry

*Team estimate based on above mentioned data sources.

(23) National Academy of Sciences, Methane Generation from Human, Animal, and Agricultural Wastes, 1977.

(24) Food and Agriculture Organization, China's Recycling of Organic Wastes in Agriculture, FAO Bulletin 40, 1977.

wastes have particulary high value). The lower end of this range is well within normal Egyptian animal ownership patterns, but the upper end is rather high. Families which lack sufficient wastes to support an individual unit may be served by communal units.

Communal units may also find applications on large government or private dairy farms, and in particularly crowded villages where the land for individual units is unavailable. The management of communal units presents problems in deciding who is responsible for maintenance and feedstock collection, and in sharing all the benefits equitably.

Adoption of this technology by 10 percent of the 4,000,000 families could result in the production of 8 QJ per year in biogas worth L.E 3 to L.E 7 million at world fossil fuel prices. This penetration could be achieved by 1990 by a vigorous program since the basic resources (animals) are adequate. Associated slurry production would be 1.5 to 2 million tonnes per year, about 2 percent of current Egyptian manure production. At the penetration rate assumed, this should represent an increase of about 20 percent of the gross manure available to the families with biogas digesters. Much of this manure is now burned, so the net increase will be much larger.

6.4 Social, Environmental and Other Impacts

Major impacts will result from introduction of biogas digesters. Agriculture and domestic habits and patterns of work will be markedly changed. It will be necesary to convince rural families, by

education and demonstration, that adoption of biogas digesters will be beneficial.

The benefits will be:

- increased availability of fertilizer and soil conditioner
- decreased consumption of kerosene and butagas
- provision of rural employment in constructing digesters and in manufacturing accessories (simple lamps, burners, etc.)
- reduction of smoke in houses from dung cooking fires
- reduction of fire hazards due to present rooftop storage of combustible dung cakes and agricultural residues

Both the individual users and the GOE will benefit, the latter through increased availability of fossil fuels for export.

Negative aspects are:

- disruption of established agriculture and domestic patterns
- possible gain in value of dung, penalizing poor families who do not own animals
- psychologically distasteful task of handling human wastes
- danger of explosion of biogas

Biogas digesters can be constructed using materials which are easily available and locally produced in Egypt. They can be built by local labor, after suitable training.

The units must be very close to the houses, and there may be problems of space availability in densely populated villages. Space requirements after construction are quite limited, however, if an underground design is used.

6.5 Infrastructure

R&D capability exists in Egypt, with programs in biogas being underway at the National Research Center and at the University of Cairo campus in Fayoum. The basic technology is well understood and the primary problem is one of technology transfer (from e.g., India or the People's Republic of China) and adaptation to Egyptian conditions.

The biogas units can be manufactured 100% locally using bricks and cement and local labor. Training of artisans to construct these units will be needed.

The appliances to burn the gas (lamps, stoves) are quite simple and are amenable to local manufacture in small towns or even villages. Training and assistance to local craftsmen will be needed to initiate production.

The infrastructure to achieve distribution of units exists in the Agricultural Extension Service. Extension agents must be trained in construction, start-up and trouble-shooting of biogas digesters, and must additionally be trained to train users in correct operation and maintenance procedures.

For communal units, appropriate local institutions must be set up to ensure correct operation and maintenance (feedstock collection, semi-annual cleaning, gas distribution, etc.).

7.0 WIND MACHINES

7.1 Objectives and Recommendations

The recommended USAID program in wind machines covers three end-uses: irrigation, off-grid electric generation, and on-grid electric generation. The first two end-uses correspond essentially to the specific technologies of water pumpers, small electric machines and large electric machines (up to 2 MWe) and will be discussed under this classification, with irrigation and small electric machines being dealt with together first. For irrigation and small electric systems the recommended objectives and supporting activities are:

- Objective: Determination of Potential Market

  Discussion: These can be considered separately for irrigation and small electric systems.

  - Irrigation: Existing information on wind regimes, ground and surface water availability and soil types should be collected in detail, and supplemented where necessary in order to determine the potential land area open for wind irrigation which will determine the potential market for new units. In particular, care must be taken to avoid development which will overtax aquifers, leading to eventual loss of irrigation water.

  - Small Electric Systems: Small wind-electric systems can have a variety of uses, since the power produced can be used for mechanical purposes. The available technologies must be studied and the most promising ones selected.

These two tasks could be completed in less than a year.

- Objective: Establishment of Manufacturing Capability.

  Discussion: If the potential markets for irrigation and small electrical generation systems are promising, steps should be taken to re-establish an Egyptian facility for windmill development and production. Several activities would be necessary to accomplish this objective including:

- establishment of a windmill testing and development facility in a suitable location where the wind regime is adequate and where backup infrastructure is available.

- development of metallurgical capability necessary to produce specific aluminum alloys (this could be valuable for other applications in conjunction with Egypt's significant aluminum production capability).

- establishment of fabrication and assembly facilities.

- Objective: Infrastructure Development.

  Discussion: Parallel with the development of manufacturing capability, the distribution, financing and maintenance infrastructures must be established or improved. The deployment and maintenance of small wind-electric systems can most conveniently be carried out by the Egyptian Electricity Authority. Assistance in personnel training may be needed. For irrigation systems, the following factors should be considered:

  - distribution may be undertaken through rural cooperatives, the Agricultural Extension Service or by using the existing repairmen as selling agents.

  - financing must be made available to potential users. Since the competing irrigation methods (diesel or, sometimes, electric) are highly subsidized, the possibility of providing a capital subsidy for the purchase of windmills should be seriously considered in conjunction with the GOE.

  - the maintenance infrastructure may be strengthened by the provision of training and, possibly, financial assistance to the existing repairmen, or a completely new maintenance infrastructure may be developed based on whatever distribution channel is chosen. The latter alternative would probably involve some social conflict with the existing structure.

The possibility exists of combining a wind-irrigation program with other USAID activities, such as agricultural development. In particular, the agricultural programs should be sensitized to take

advantages of wind machines (rather than, e.g., diesel pumps) wherever practicable.

For large electric systems, the following steps are recommended:

- Objective: To Monitor U.S. Experience.

  Discussion: Several large wind-electric systems have been, or will soon be, deployed in the United States. This program should be closely monitored, including reviews of design and maintenance experience, independent checking of economic projections, and a determination of the earliest date at which an American unit (of about 1/2 MWe) might be deployed in Egypt.

- Objective: Deployment of an American machine.

  Discussion: If the analysis above is favorable, a site should be selected and an American machine deployed. The site selected should have adequate wind availability, be close to an area where backup infrastructure is available, and be close to a suitable load center. Installation and evaluation should be performed in conjunction with the windmill testing and development facility envisaged.

- Objective: Extended Deployment.

  Discussion: If initial experience is favorable, extended deployment of multiple systems (i.e., tens or possibly hundreds) should be undertaken, incorporating as much Egyptian manufacture as possible. Facilities established for small wind systems production may be valuable in this stage. This task would necessarily extend over several years.

7.2 Technology Description and Relative Costs

Simple windmills for pumping irrigation water have been used in both Egypt and the USA for many years. Designs commonly used in Egypt have multi-bladed fans of 2 to 3 meters diameter driving a simple submerged pump via a reciprocating connecting shaft (see Figure 13).

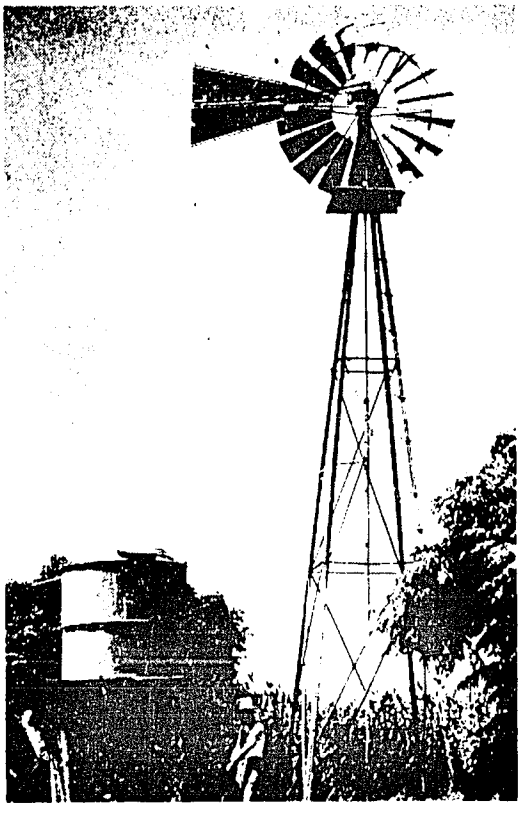

FIGURE 13
IRRIGATION WINDMILL

The range of outputs encompassed by practical wind electric machines ranges from some 2 kWe up to 2 MWe. The smaller machines look like irrigation pumpers, with a generator replacing the pump as a load. Large machines for electric generation, and some smaller ones, usually have only two blades, and resemble large aircraft propellors in appearance.

The output of any given windmill is critically dependent on the strength and duration of the wind. In particular, the power output is proportional to the cube of the wind speed. Thus, a 15 mph wind permits the generation of almost twice as much power as a 12 mph wind.

Irrigation pumpers generally produce about 3 kW equivalent, enough to irrigate about 5 acres. The Military Factory in Egypt which produced irrigation pumpers in the 1960's has estimated the capital costs of new units at L.E. 700 to L.E. 800.* The installed cost would then be about L.E. 900 to L.E. 1000 including well and collecting basin. The comparable cost of second-hand units in Egypt is L.E. 450 to L.E. 600 installed.** The operating and maintenance costs are about L.E. 30/year. This figure reflects the prices charged by local repairmen.

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*Personal communication with Mr. El Giar, the Plant Marketing Manager.

**Team Survey.

In comparison, the cost of an imported (American) irrigation pumper would be L.E. 2900 excluding well and basin.*

The capital costs of wind electric systems lie in the range L.E. 800 to L.E. 2000 per kWe.[19] Depending on location and system size. This cost includes power conditioning equipment to produce 220V AC but excludes storage. It is based on United States costs. Operating and maintenance costs are projected to be about 5% of the capital cost annually.

The resulting levelized electricity costs based on 20-year equipment life will be L.E. 0.05-0.08/kWh for small systems in 15 mph average winds, and L.E. 0.09-0.15/kWh for small systems and L.E. 0.05-0.09/kWh for large systems in 12 mph average winds. Diesel-electric costs are estimated at L.E. 0.06 per kWh at world fuel prices, and L.E. 0.02 at local Egyptian prices. Marginal grid generation costs are L.E. 0.013 to L.E. 0.047 per kWh at world prices (depending on season, time of day and day of week), and L.E. 0.002 to L.E. 0.030 per kWh at local prices. Wind electric generation is thus competitive in terms of real costs with diesel-electric systems, and may compete with other sources for grid connection.

In addition, wind-powered reverse osmosis may be capable of desalinating water at a cost of L.E. 1.5 per 1000 litres. The cost of alternative methods of fresh water supply is not known.**

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*Estimate by Dr. W.L. Hughes.

**See Chapter 10, Section 10.3 for a discussion of desalination.

[19] The MITRE Corporation, Op. Cit., Vol. VI, 1977.

7.3 Utilization Potential

Four factors regulate the application of wind energy conversion systems to the task of water pumping for irrigation: adequacy of wind; adequacy of ground water; insufficiency of alternate water supply; and suitability of soils for agriculture. An adequate wind resource exists along the Northwest coast between Alexandria and the Libyan frontier and along the Red Sea Coast generally (the resource along the Red Sea coast being better). Ground water is adequate and accessible along parts of the Northwest coast, but what little is known about the aquifers in the Red Sea littoral indicates limited promise. Availability of fresh surface water on the Northwest coast is limited to a small area west of Alexandria which is reached by the Nile canal system. Virtually no fresh surface water is to be found on the Red Sea coast, where precipitation is exceedingly infrequent and no rivers or streams exist.

Windmills are already widely used on the North-West coast, perhaps 1000 units being currently in use.* A thriving local industry exists for the repair and maintenance of these machines. The local farmers prefer wind pumpers to more powerful diesel pumps because the wind machines do not deplete the aquifers and cause saline intrusions. There may be a market potential along the Northwest coast for installing as many as 5,000 additional units in the next decade. Such a potential represents 15 MW and implies an

*Team survey.

increment of 25,000 feddans under cultivation. The Red Sea coast potential is speculative but likely to be considerably smaller.

Both off-grid and grid-integrated applications for wind energy conversion systems are promising options, the former being the more immediately feasible. Wind machines of about 10 kW_e to 100 KW_e, equipped with electric generators and 220V AC conditioners and operating in conjunction with diesel generators, or with simpler generators for mechanical applications, can provide electric power in a number of off-grid circumstances. Domestic life in remote villages and desert settlements, communications installations, and military outposts all provide suitable applications for off-grid wind energy--especially since electrification is a major development goal of the Egyptian Government. The size of this market is not precisely calculable at present but appears to be on the order of 1,000 units in the next decade, perhaps totalling 10 MW_e and concentrated along the Northwest and Red Sea coasts.

The present level of development of wind machines suitable for grid-integration causes a degree of uncertainty in assessing the potential. These systems typically feature large two-blade, horizontal-axis machines equipped with generators and power conditioning equipment for 220 V AC output ranging from 100 kW_e to 2 MW_e. Large wind systems need not, of course, be grid-integrated but can serve large loads, remote from the grid, in conjunction with diesel and gas turbine back-up generating capacity.

The potential market is large. If these systems are economically attractive it is possible to envisage several hundred being deployed in Egypt by the year 2000 (500-1000 MW_e).

A potential market for desalination by wind powered reverse osmosis exists along the arid Red Sea Coast. It is not possible to estimate the extent of this market because the costs of fresh water from other sources (e.g., other desalination methods, deep aquifers or pipelines from the Nile) are unknown. If wind desalination is economically attractive, it could be the key factor in permitting development along the Red Sea.

7.4 Social, Environmental and Other Impacts

Social impacts may be discussed separately for irrigation, and electric generation.

(a) Irrigation. Irrigation permits more food to be grown, increasing rural incomes and aiding the national economy. New areas may also be opened up for settlement, reducing population pressures elsewhere. Wind irrigation is likely to substitute for diesel pumps, freeing diesel fuel for export and benefiting the balance of payments. The immediate beneficiaries will, of course, be the farmers using wind pumpers.

(b) Electric generation. Electrification is a major goal of the GOE.

Egyptian rural households with electricity use it for lighting (100%) and TV (70%); only a few have refrigeration (27%). Annual usual is low (60-90 KWh).

Benefits include:

- broadening of village and personal activities, including adult education classes and health clinics in the evening.

- induction of small commercial enterprises (cottage industries) and associated infrastructure.
- potential reduction of birth rate.

- eventual use for water pumping and commercial and light industrial development.

Electrification has only limited impact on the consumption of fossil fuels, and acts mainly to augment the energy supply and usage system.

In all cases, local manufacture in Egypt of wind machines is feasible and would stimulate the national economy. Some components would probably be imported with negative initial balance of payments impacts. Against this, it is possible to envisage the development of exports of Egyptian windmills to other countries, especially in Africa and the Middle East.

The environmental impacts of windmills are mixed. In so far as wind power substitutes for fossil fuel combustion, benefits to air quality are expected. Negative impacts include visual clutter and possible interference with radio and T.V. signals due to the effects of the rotating blades. Irrigation pumping of any sort may, of course, deplete ground water resources, leading to loss of water or increasing salinity. Wind pumpers appear to present smaller risks in this area than diesel pumps, because of their lower pumping capacity.

The materials of construction are readily available in Egypt for smaller machines, but some components might be imported. A larger proportion of larger machines would be imported.

7.5 Infrastructure

The technology of small wind machines is well understood in Egypt. Some research and development capability exists at the National Research Center but would need augmentation if a major wind energy program were initiated. While no manufacturing is currently taking place, about 900 irrigation units were manufactured by the Military Factory at Helwan during the 1960's.* Aluminum and steel, the resources critical to fabrication, are readily available domestically. Some improvements would be desirable in materials to reduce corrosion of certain parts and metal fatigue in pump assemblies. Additionally, changes in gear box design might reduce production costs and maintenance problems.

Infrastructure capabilities to produce larger systems are mixed. Additional development would be necessary for the production of certain aluminum alloys and the construction of small electric generators. Other items (such as power conditioning and control equipment and, for the larger machines, blades) would most probably be imported.

More extensive use of wind machines for irrigation or other purposes would necessitate expansion of repair and parts supply capability. A small but vigorous local industry of repairmen and parts fabricators has grown up in the Alexandria area despite the lack of a well-developed marketing channel for factory-built spare parts and

*Personal communication from factory management.

new machines.* A domestic market of sufficient scope could support an Egyptian manufacturing capability--provided adequate credit arrangements can be devised to translate need for wind pumpers into effective demand. Hearsay evidence indicates that lack of just such a credit system was in large measure responsible for the abandonment of the Military Factory's production effort.

Installation and maintenance of wind electric systems could most effectively be carried out by the Ministry of Electricity and the Egyptian Electricity Authority through their normal institutional channels. Some expansion and special training of staff would of course be necessary.

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*Team survey.

8.0 SOLAR REFRIGERATION AND COOLING

8.1 Objectives and Recommendations

Possible USAID program elements in the area of solar refrigeration and cooling for food preservation and other applications are outlined below. Objectives and recommended supporting elements are discussed:

- Objective: To enhance Egyptian R&D capabilities.

  Discussion: Some R&D capability exists in Egypt in this area at the NRC. USAID should initiate technical assistance to enable Egyptian expertise to be developed, to select suitable designs for local development, and to undertake research.

- Objective: Pilot Development.

  Discussion: Experimental or pilot scale models of different types of active and passive systems can be built and tested in Egypt, perhaps using some U.S. components.

- Objective: To demonstrate the potential of solar refrigeration.

  Discussion: If success is obtained in pilot development, a number of various-sized units can be placed in service at various existing refrigeration and cooling plants throughout the country. One or two new completely solar-powered refrigeration plants can also be built, perhaps in areas where electricity or fossil fuels are difficult to obtain. However, accessibility to maintenance infrastructure is important.

- Objective: To develop a strong supporting infrastructure.

  Discussion: If solar refrigeration and cooling is to play a significant part in Egypt's future, a complete supporting infrastructure must be developed, covering production, distribution, and operation and maintenance of these units. USAID assistance activities can be developed in the areas of personnel training for operation and maintenance, production facility development, and user financing.

8.2 Technology Description and Relative Costs

Many technologies are available for solar* refrigeration including both passive and active types. In the Egyptian context the most promising are absorption systems of either the continuous or intermittent types.

The continuous type (see Figure 14) uses solar energy to cause a refrigerant to vaporize from an absorbant solution. The refrigerant is then cooled and liquified and passes through a valve to an evaporator coil. It vaporizes in the coil, absorbing heat and cooling the surrounding space. The refrigerant vapor is then absorbed in the absorbant solution and recycled. Intermittent types employ the same cycle on an alternating rather than continuous basis.

Passive designs can use convective, conductive, radiative or evaporative cooling. Other types of systems operate on the vapor compression cycle and are more mechanically complex in solar applications although they can also be driven by wind energy.

Intermittent-type systems were widely used in the United States in rural areas before electrification. They could find wide application in Egypt, including substantial local manufacture. It is also possible that continuous absorption systems could have significant local manufacture.

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*Systems could also be wind-powered in favorable locations, i.e., along the Northwest and Red Sea coasts.

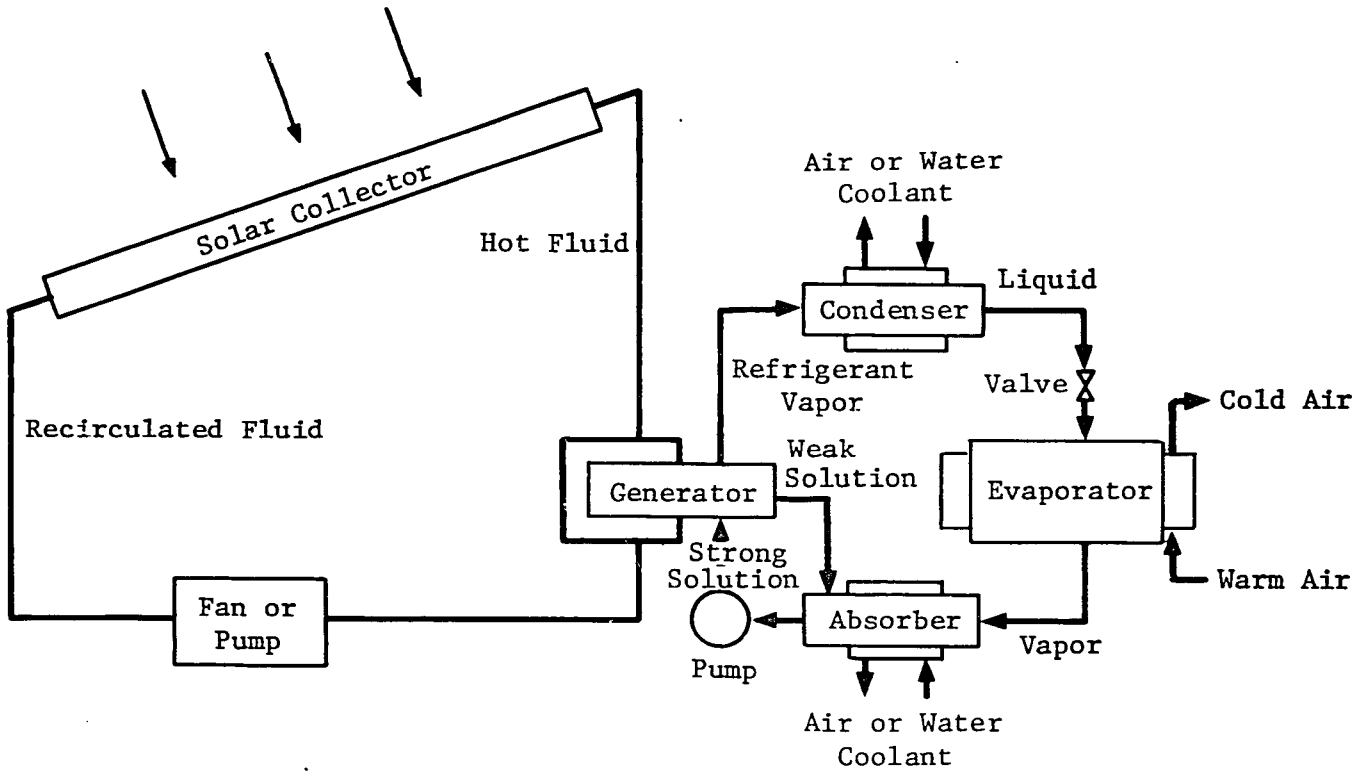

FIGURE 14
DIAGRAM OF A SOLAR OPERATED ABSORPTION REFRIGERATION SYSTEM

Costs are difficult to determine in the Egyptian context. U.S. systems typically cost L.E. 100 to L.E. 120/m^2 (\$140 to \$170/m^2),or up to \$20,000 per kW.* The U.S. Department of Energy has estimated delivered energy costs at L.E. 4 to L.E. 5 per 10^9 joules.(1) This should be competitive with fossil or electric fueled refrigeration plants in real terms. The fossil and electric subsidy structure in Egypt will require countervailing measures to allow solar energy to compete on an equal basis.

The real costs of passive-type systems are estimated at L.E. 600 to L.E. 2000 for household cooling (space cooling).

8.3 Utilization Potential

Egypt currently has some 250,000 tons of conventional commercial cold storage or freezing capacity, of which about one-third is government owned.** Fish, vegetables, dairy products, and poultry are typical of commodities stored in these facilities. Because these facilities are inadequate to meet demand, expansion is underway. The potential for additional cold storage capacity seems high in farm areas around the larger cities, which serve as markets for their fresh fruits and vegetables throughout the year. In rural areas at some distance removed from the urban centers, the potential diminishes because of the necessity of refrigeration in transit from farm

*Estimate by R. Alward (a consultant to Mitre).

**Personal communication with Five-Year Industrialization Plan Authority officials.

(1)DOE/GOE, Op. cit., Vol. IV, 1979.

to market, which would add considerably to the cost of the produce to the consumer.

The fishing industries in the Red Sea and Aswan Governorates were found, in field visits, to offer significant potential for solar refrigeration applications. An ice-making and refrigeration plant presently services the small fishing fleet at Hurghada on the Red Sea and enables it to market fresh fish in the Cairo area. Most Red Sea fishing, however, occurs in the Gulf of Suez; and the fishing potential of Red Sea proper has hardly been tapped, in part because of wartime restrictions and sparseness of population. Interviews with officials of the Governorate and with the leadership of the fisherman's cooperative at Hurghada disclosed a high level of interest in expansion of the fishing industry and in the application of solar or wind-powered refrigeration to enhance marketing opportunities.

The fisheries of the High Dam Lake are served by the Jericho Refrigeration Facility at Aswan which, in late 1979, was in the process of nearly doubling its refrigeration capacity. Additional refrigeration plant capacity is currently under consideration, according to the High Dam Lake Development Authority.

Solar's potential market for space climatization is more problematic from a program development viewpoint. The hotel sector and the high-income segment of the domestic sector appear to offer the best opportunities for active systems. While the hotel sector is integral to Egypt's thriving tourist industry and, thus, is responsible for substantial foreign exchange earning, its appropriateness as

a target for a possible USAID assistance program is at least open to question. The same reservation applies more strongly to the affluent domestic market for solar cooling.

8.4 Social, Environmental and Other Impacts

This is a commercial enterprise which should be accepted at a level according to its economic viability. Expansion of cold storage facilities will increase the availability to consumer of vegetables and fruits during the off season, and will increase farmers' incomes by allowing them to increase production and sell the extra crop over a longer period, or by allowing them to produce more valuable crops.

Solar cooling and refrigeration by active systems is essentially benign, except for e.g., the risk of coolant (ammonia) leaks. Passive systems are benign.

8.5 Infrastucture

R&D capability exists at the National Research Center. Theoretical work on solar absorption refrigeration for small (household size) units has been continuing since 1973. A solar absorption refrigeration unit supplied by the Federal Republic of Germany is undergoing tests at the NRC. This unit uses Dornier heat pipes to transfer heat from the absorber plate to the refrigerant vaporizer. Design capabilities also exist at the Ministry of Energy.

Flat collector plates for such systems can be made almost entirely in Egypt, since they are closely similar to the collectors for domestic hot water applications which are now being produced in

Egypt. Concentrating collectors and other components might have to be imported.

No production, distribution or maintenance infrastructure exists at present.

Other foreign donors active in this area include:

- France - the Conseil National de Reserche Scientifique has initiated a project at Aswan which is planned to use a 10 kw SOFRETES motor to power a vapor compression 6-day refrigeration unit for fish preservation.

- Federal Republic of Germany - Ministry for Research and Technology has built an absorption refrigeration unit at the Solar Energy Lab, of the National Research Center. This unit utilizes Dornier heat pipes to transfer heat from the absorber plate to the refrigerant vapor generator.

- Federal Republic of Germany - currently designing a 30 room central air conditioning system for El Maadi Hospital. Equipment selection was to be completed by November 1979.

These programs do not represent a significant impact on the Egyptian energy scene, and although the future size of assistance efforts in solar refrigeration and cooling by these countries are unknown, there appears to be ample scope for USAID initiatives.

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9.0 PHOTOVOLTAIC REMOTE APPLICATIONS

9.1 Objectives and Recommendations

Potential applications exist for photovoltaic cells in refrigeration and lighting for remote rural health clinics, in telecommunications and perhaps in water pumping. The main obstacle at present is the cost of the cells. However, the United States Department of Energy projects large cost reductions for photovoltaic cells in the near future.

- It is recommended that developments in the United States be monitored for applications in Egypt.
- Initially, a small program of electrification of remote health clinics should be started because of the health benefits. (Several hundred unelectrified clinics exist in Egypt.) The size of this program should be dependant upon continuing major reductions in photovoltaic cell costs.
- Infrastructure development and establishment of Egyptian R&D and production expertise should be evaluated later when the technology is more mature.

9.2 Technology Description and Relative Costs

Photovoltaic cells convert light energy directly to electricity. They have no moving parts, are modular, and are very reliable.

Photovoltaic cells convert incident solar radiation to electrical current in the following way: photons (i.e., light) strike the collector panels and are absorbed into silicon molecules. In so doing, the photons energize electrons in the outer (valence) bands of n-type silicon crystals (i.e., silicon crystals containing phosphorous atoms). As they accelerate, electrons in the n-type crystal leave the valence bands and cross the junction between n-type and

p-type crystals (i.e., silicon crystals containing boron atoms). This free movement of electrons creates a direct current, which is produced in amounts proportional to the amount of incident light (Figure 15). Storage batteries and/or power conditioning equipment (inverters and transformers) are required for many applications.

Refrigeration and communications applications generally require 1 to 2 kWe peak power (photovoltaic cell array outputs are conventionally measured in terms of peak output), while water pumping requires rather more, 4 to 6 kWe peak.

Present real capital costs are high: L.E. 10,600 per kilowatt peak installed with storage in Egypt but U.S. Department of Energy cost estimates for 1985 put the cost at L.E. 1,800/kW peak installed with storage. Further cost reductions are unlikely.[25] Real O&M costs amount annually to only 1 percent of capital cost. Electricity costs based on a 15-year equipment life range from L.E. 0.6 to L.E. 0.9/kWh presently and are projected to range from L.E. 0.09 to L.E. 0.15/kWh by 1985. (It should be observed that the decline in cost experienced to date is consistent with DOE forecasts.) Diesel electric power, the main competitor of photovoltaics for remote applications, now costs L.E. 0.06/kWh (real or world price) or L.E. 0.02/kWh (local or subsidized price). Battery power for remote communications is considerably higher still. Real costs of these

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[25] Moore, Cost Predictions for Photovoltaic Energy Sources, Photovoltaic Conversion Research Program Review, Philadelphia, PA, December 16, 1974.

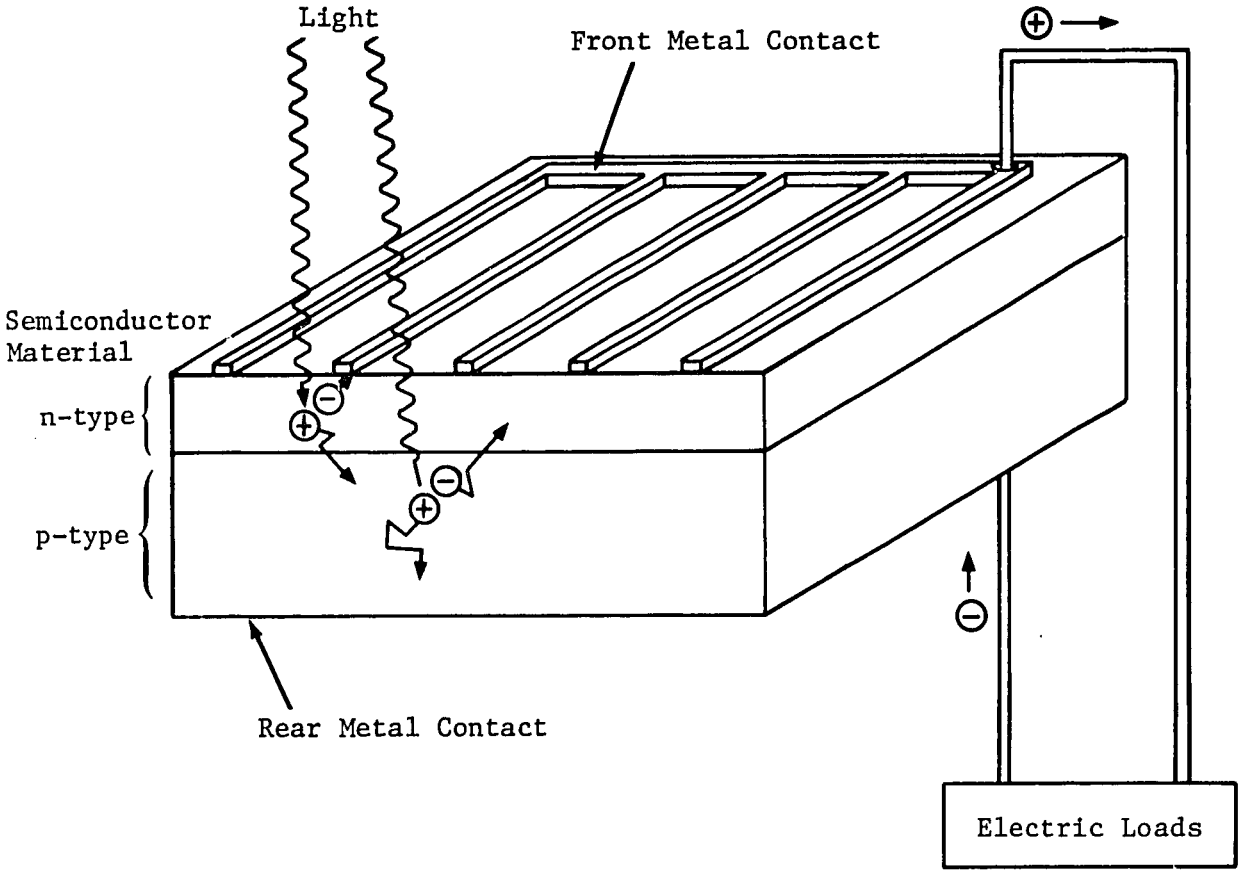

FIGURE 15
TYPICAL PHOTOVOLTAIC DEVICE

sources in 1985 may be as much as 50 percent higher while local costs could rise by an even greater percentage if subsidies were reduced or eliminated.

9.3 Utilization Potential

Inquiries undertaken during the in-country phase of the project permitted estimates of market potential for photovoltaic units. There is a need for refrigeration of medications and vaccines at remote rural clinics, a need which is presently inadequately met. Perhaps 200 clinics could be outfitted with photovoltaic units in the Eastern and Western Deserts, the Sinai, and the Red Sea and Northwest Coasts. An additional market for some 900 units for remote communications and 1,600 units for lighting and educational television applications. Water pumping from rural canals represents a potential perhaps as high as 2,000 MW in 400,000 units, though the cost of photovoltaics in this application makes them currently uncompetitive.[26] Indeed, when current prices are considered, only remote rural clinic refrigeration applications appear justifiable (on the grounds of health benefits) over wide areas of the country. Provision of refrigeration will allow a wider range of vaccines and drugs to be kept. This may have especially beneficial effects on infant mortality rates. Communications and television applications may be justifiable for selected areas. Other competing energy sources include fossil-fuel fired pumps and refrigerators. In remote areas,

(26) French, Dr. D., The Economics of Renewable Energy for Developing Countries, AID, 1979.

the supply and distribution system for diesel fuel and butagas are considerably less than certain, and supplies are subject to interruptions.

If and when photovoltaic cell costs are radically reduced, more applications will become economically viable. These should be monitored and examined for USAID assistance opportunities.

9.4 Social, Environmental and Other Impacts

Provision of electricity at remote clinics could have significant health benefits. Communication and film projection or TV uses contribute to broadening of village and personal activities, including education and leisure. Eventual use in water pumping for irrigation could enable increased crop production and expansion of cultivated lands. This would raise rural incomes, reduce food imports, and alleviate population pressures.

Photovoltaic cells are environmentally benign at the point of use. Manufacture of the cells may have negative effects depending upon the techniques used.

The balance of payments of photovoltaic cells is likely to be strongly negative initially, since they will have to be imported. As long as they remain uncompetitive in real cost terms with other energy sources their use will remain a bad bargain for Egypt except in special cases (such as clinic refrigeration and some communications needs).

9.5 Infrastructure

No research and development capacity currently exists in Egypt concerning photovoltaic cell production or use. Some familiarization exists with use of the technology in various locations and applications. Current photovoltaic cells have a high labor content in the assembly stages.* It is possible to envisage assembly of cells in Egypt to take advantage of low labor costs. Cells would then be available for domestic use or export.

Activity in photovoltaic cells in Egypt includes the following applications by foreign donors:

- Federal Republic of Germany - for 8 different applications. Viz: 2 pumps (drinking and irrigation water), water desalination, loud speaker, refrigeration, lighting.
- France - for 2 television sets in a village.

These activities do not represent significant impacts. While the future scopes of these countries' activities are unknown, there appears to be ample opportunity for USAID initiatives.

*This may not be true of more advanced types now in experimental development.

10.0 OTHER OPTIONS

10.1 Other Options With Good Potential

An additional seven options explored in Phase I were judged to have good, though not outstanding, potential. As these options did not feature in Phase II, they are treated briefly below. Full details and data sources are given in Appendix A.

Passive Solar Architecture- Two factors--the intense solar radiation and rapidly increasing population--make passive solar design for new construction an attractive renewable option for Egypt. Passive solar is essentially a technique to conserve energy and to enhance indoor living and working conditions. Space heating is generally not a priority concern in Egypt where winters are short and mild. Cooling of work and living space is, however, an important consideration--the more so since population pressures in the next two decades will dictate the addition of tens or hundreds of thousands of new dwelling units each year. It can be estimated that at least 4,000,000 new dwelling units will be required by 2000. Plans for the new cities alone call for constructing an average of 4000 new units annually through 1985 and then an average of 17,000 a year for the remainder of the century. Additional schools, factories, office buildings, shops and hospitals will be required on a commensurate scale. Under these pressures, architectural design in Egypt has departed from the passive climate control techniques traditionally employed. Decisions are now being taken in urban and rural development projects that will

determine the circumstance under which much of the additional population will live and work. Passive solar techniques can prevent the discomfort that leads to extensive reliance on electric air conditioning with all the energy consumption and peak system planning problems such reliance entails.

Passive techniques primarily involve orientation and construction of buildings and imply higher construction costs, but lower operating costs. Among the standard features of passive solar design are thick walls of high thermal capacity, carefully planned fenestration to enhance penetration of solar radiation in winter, overhangs to exclude the sun's rays from the interior in summer, appropriate ventilation, and in some cases roof ponds to serve as a sink for summer heat and a reservoir for available winter insolation.

Some limited passive solar activity is taking place in Egypt. Most notably CARE has constructed some experimental structures in Aswan; and The American University in Cairo has done some preliminary work in the field, generally revolving around concepts for desert development. Other experiements were undertaken in the 1940's and 1950's near Luxor and Alexandria. Government programs in the area of passive solar design are undeveloped at present; and architects, engineers, and technicians appear generally unconversant with passive techniques.

Improved Rural Stoves - Some 1.6 million Egyptian families use non-commercial fuels such as dried animal wastes and agricultural

residues in cooking and water heating. Combustion takes place in open fires or extremely inefficient stoves. For relatively small real capital cost (L.E. 10-20/unit), open fires or current domestic stoves could be replaced by new simple stoves of more efficient design. The time spent in collecting fuel would be reduced, and additional organic material would be available for fertilizer and soil conditioning. The new stoves would require only mud, clay, brick and a small amount of metal for their fabrication; and with modest training effort by such organizations as the Agricultural Extension Service, local enterprise and labor could easily construct such stoves. No acceptance problems need arise since new stoves would not necessitate any significant change in cooking habits. If 25 percent of the 1.6 million target families adopted the new stove designs, a total annual biomass energy savings of 4-10 QJ could result.

Large-Scale Hydroelectric Generation - Along with the muscle power of animals and human beings, the power of the Nile has historically done the most useful work in Egypt. In recent years, the river's flow has been converted to electrical energy through impoundment and controlled release. A limited number of suitable sites still exists along its length for additional hydroelectric installations and these sites, if developed, could provide electricity at a cost competitive with fossil-fired and nuclear baseload plants. The possibility exists for 300 MW_e (run-of-the-river) at the Old Aswan Dam and at

the existing barrages at Asyut, Nag Hamadi, and Esna. On a different scale, the proposal to generate electricity from the flow of Mediterranean seawater into the Qattara Depression shows promise of providing 600 MW_e of additional capacity (run-of-the-river) and up to 2400 MW_e of pumped storage. Other pumped storage opportunities at various sites throughout Egypt may offer an additional several hundred MW_e of capacity.

Solar desalination units - (stills) of family size (10-80 litres/day) and of community size (up to 50,000 litres/day) show good potential in sea coast and inland areas where there are no competing sources of fresh surface or underground water. Basically stills powered by solar radiation, these units could provide fresh water to a limited number of communities along the Red Sea Coast, in Sinai and the Eastern and Western Deserts, and in the Baheira Governorate, as well as to nomadic groups of Bedouin. The real capital cost of these units ranges from L.E. 5 to L.E. 7 per liter of output capacity per day, and their fresh water output can cost between L.E. 0.002 and L.E. 0.0005 per litre. Market penetration is, however, speculative even despite these supportable costs, since costs of competing methods of fresh water supply are not known. Also, wind-powered desalination using reverse osmosis has been included in the recommended potential program elements in the Wind Systems section. The whole question of fresh water supply is addressed in Section 10.3

Three good options relying on municipally generated biomass were also studied. Anaerobic digestion of municipal sewage sludge can produce biogas to generate electricity for in-plant consumption. A plant with an input of 400,000 m^3 of sewage daily could produce enough biogas to run generating capacity of 2.8 MW_e at 80 percent capacity factor. The electricity so produced would cost between L.E. 0.006 and L.E. 0.009 per kWh. The marginal grid production costs lie in the ranges of L.E. 0.002-0.030 (local price) and L.E. 0.013-0.047 (world price). Given the small number of sewage treatment plants now in operation, the total contribution to Egypt's energy picture would not be large. There might be a total of 11 MW_e in the Cairo area, for example; and this capacity could meet only 40-60 percent of plant energy needs. A 2.8 MW_e plant would save only about 4,000 barrels of oil a year, and an aggregate total of 11 MW_e might save no more than 16,000 barrels.

Municipal solid waste also presents two other good program opportunities. The Cairo metropolitan area currently generates 4,200 tons per day of solid waste. Some of this (1500 tpd) is recycled by the Zebaleen, the city's trash collection caste. The remaining 2,700 tpd could be employed in several ways. First anaerobic techniques could be applied to derive enough gas (1.2 QJ) annually to supply 50,000 to 60,000 dwellings at present consumption levels. The cost, excluding distribution system costs, would be L.E. 5-9 per 10^9J. Anaerobic digestion could also provide enough effluent to

condition soil over 30,000-40,000 acres. The major cities could presumably provide as much trash per capita as does Cairo. The main problem which diminishes the attraction of a program in this area is that the energy produced is currently more expensive than that from competing fossil fuels, especially if the cost of a dedicated distribution system for the low-Btu gas is included. The co-mingling of biogas with pipeline-quality natural gas may be feasible, but would necessarily have to wait until the development of natural gas distribution systems in Cairo and other cities. Upgrading the low-Btu gas is feasible but would be expensive.

Second, Composting is an even more attractive option for using municipal solid waste, by the construction of 500 tpd composting plants. The output of the plant would be materials for fertilizer and soil conditioning. Egypt has approximately six million feddans* of arable land concentrated in the immediate vicinity of the Nile. Since the annual floods which renewed soil nutrients have been eliminated by the High Dam at Aswan, serious concern has arisen about progressive soil deterioration. The result has been a marked and continuing increase in the use of chemical fertilizers to do artificially what formerly was done naturally by the Nile. In addition, population pressures have spurred attempts to add arable land in frontier areas to Egypt's limited store. These reclamation

*1 feddan is about an acre.

efforts demand not only fertilizers but conditoners to improve soil texture and water retention characteristics. While not strictly an energy production option, composting was investigated for its indirect energy effects: it uses a high energy feedstock (MSW) and offsets energy used in fertilizers production and may free animal wastes and agricultural residues for other uses. On the whole, while meritorious as a program option, composting belongs more properly to agricultural than to energy assistance program. In addition, current activity in the area involving the World Bank and the Egyptian Government seems adequate to fulfill current needs.

10.2 Other Options Considered

Four other options were judged as having the most limited USAID program potential of all the 20-25 options considered. These are discussed individually below.

Solar concentrators for domestic cooking (1-2 kw output) have a large potential market (400,000 rural families) and exhibit reasonable delivered energy costs (L.E. 2-13/10^9 J) when compared to the real or world cost of butagas (L.E. 9/10^9 J) and kerosene (L.E. 4/10^9 J). Solar cookers do not, however, appear competitive with other traditional rural cooking fuels such as animal dung (L.E. 0.5/10^9 J local price). Nor can these cookers compete with the subsidized costs of butagas (L.E. 1/10^9 J) and kerosene (L.E. 0.5/10^9 J). The main constraint to their introduction in rural villages, however, is social acceptance, judging from experience in Egypt and

elsewhere over the past thirty years. The locus and circumstances of food preparation are the habits of millenia, and demands and results of solar cooking so deviate from tradition that acceptance has been limited. The near-term potential seems most favorable in the temporary encampments characteristic of military, mining, recreational, and construction activities.

Geothermal energy can be directly used or converted to electricity by well-head generators. Typically, generating units of 1 MW_e are seen at geothermal sites around the globe, but larger multi-unit arrays of 50 MW_e in the aggregate can be deployed. Direct use might achieve an output of 5-10 MW_{th} per well. Costs depend critically upon field depth, well flow capabilities, and resource temperature. Scattered evidence amassed by the U.S. Geologic Survey suggests the presence of an as yet uncharacterized resource around the Gulf of Suez, the Red Sea Coast, and possibly in the Helwan, Qatrani, and Western Desert areas. Evidence is fragmentary and presently admits of little clear inference. What evidence has been amassed suggests a potential limited to low temperature applications (100°C).

Direct combustion of Municipal Solid Waste (MSW) could fuel a 45 MW_e plant in the Cairo area where a 2700 tpd of MSW is available. Additional potential exists in other urban centers. Strong official opinion, however, militates against combustion of Egypt's solid waste for energy. For the reasons set forth above in the discussion of the

MSW composting option, a pronounced preference exists for recycling the organic matter in trash to the soil (rather than combusting the the waste) in order to combat the soil losses experienced in recent years. However technically feasible, a program in this area would probably find a dubious audience in Egyptian government circles.

Tree farms to provide biomass for various energy purposes were briefly examined. The extreme shortage of suitable land in Egypt makes this option inadvisable.

10.3 Options Needing Further Study or Later Evaluation

Two other options were considered but not enough data exist to categorize them definitively. Small-scale hydroelectric generation (1-10 MW_e units) may have some potential, but topography and initial data suggest that this potential is small, because of resource limitations. Lack of data prevented a clear finding, and a more intensive enquiry targeted at small-scale hydropower would be needed to characterize the resource. If, despite indications to the contrary, a significant resource exists, fully developed technology exists to exploit its potential. Electric generating capacity can be installed for L.E. 700/kW_e; and depending on use level, generators can produce electricity at L.E. 0.009 to L.E. 0.034 per kWh. The power costs would compare very favorably with diesel-electric costs whether at world (L.E. 0.06/kWh) or local subsidized (L.E. 0.02/kWh) prices.

The solar power tower* is the second of the options needing later evaluation. The concept is being explored by a division of the McDonnell-Douglas Company in the United States. The technology, if successfully developed, would generate electricity by concentrating solar rays on a boiler mounted atop a tower at the focal point of a large flat mirror array. The McDonnell-Douglas project in Barstow, California, is scheduled for operation in the early 1980's and is designed to provide 10 MW_e in capacity. This application should be re-evaluated when the technology matures and operational experience (especially under desert and sandstorm conditions) is available. Furthermore, today's estimated costs of L.E. 0.07-0.26/kWh are in excess of marginal grid electricity costs, even at world price levels (L.E. 0.013 to L.E. 0.047/kWh, depending on season and time of day generated).

Finally, the question of desalination should be studied as a matter of priority. At least two energy resources/technologies studied in this report have desalination applications (wind machines and solar stills). However, it is not clear to what extent desalination should be regarded as an energy option.

There are many methods of fresh water supply, including:

- reverse osmosis
- single- or multi-stage flash

*Strictly described, this is a central receiver solar-thermal electric generating plant.

- stills
- deep wells
- overland pipelines from fresh water sources

Each method has particular strengths and weaknesses. In view of the great importance of fresh water supply for Egypt's plans for land reclamation and population resettlement, we feel that USAID or the GOE should undertake a comprehensive study of methods of fresh water supply for Egypt. This study should determine the technical and economic viability of different methods, determine their potential for different regions of the country, and suggest a coherent program of action to implement the selected methods.

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APPENDIX A

This appendix contains details of the information gathered and analyses performed for all resource/technology/end-use combinations considered. Sections A.1 through A.6 cover the six options which have been analyzed in detail to develop programmatic recommendations for USAID, and Sections A.7 through A.19 cover the combinations which were not selected for further consideration, and describe why these combinations were not selected.

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A.1 SOLAR COLLECTORS FOR INDUSTRIAL AND DOMESTIC APPLICATIONS

System Components. Solar water heaters consist in most cases of a flat collector plate, covered with glass, containing a blackened backplate and a number of tubes through which water can circulate. As water passes through the tubes it is heated by absorption of solar radiation which penetrates the glass cover. The heated water then passes to a storage tank. In the former case, drainout provision must be made in climates where freezing occurs. In some cases the water is stored in the tank directly, in others it passes through a heat exchanger to heat the water in the tank. In the latter case, the circulating water is usually mixed with anti-freeze and corrosion inhibitors. Circulation can be either natural thermosiphon convection flow, or forced flow using a small pump. Thermostats and other controls are used to ensure efficient system operation. Figure A-1 illustrates a typical domestic installation.

Temperatures of up to 80°C are attainable with flat-plate collectors. Higher temperatures require more expensive concentrating collectors. These systems can be used for industrial application requiring low-temperature steam, or the steam may be further heated by conventional means if still higher temperatures are needed. In the latter case, the solar system operates as a "fuel-saver" and reduces the amount of conventional fuel required.

A simple and cheap variant suitable for rural areas without piped water in individual homes consists of a blackened collector which is filled daily in the morning and allowed to heat up in the

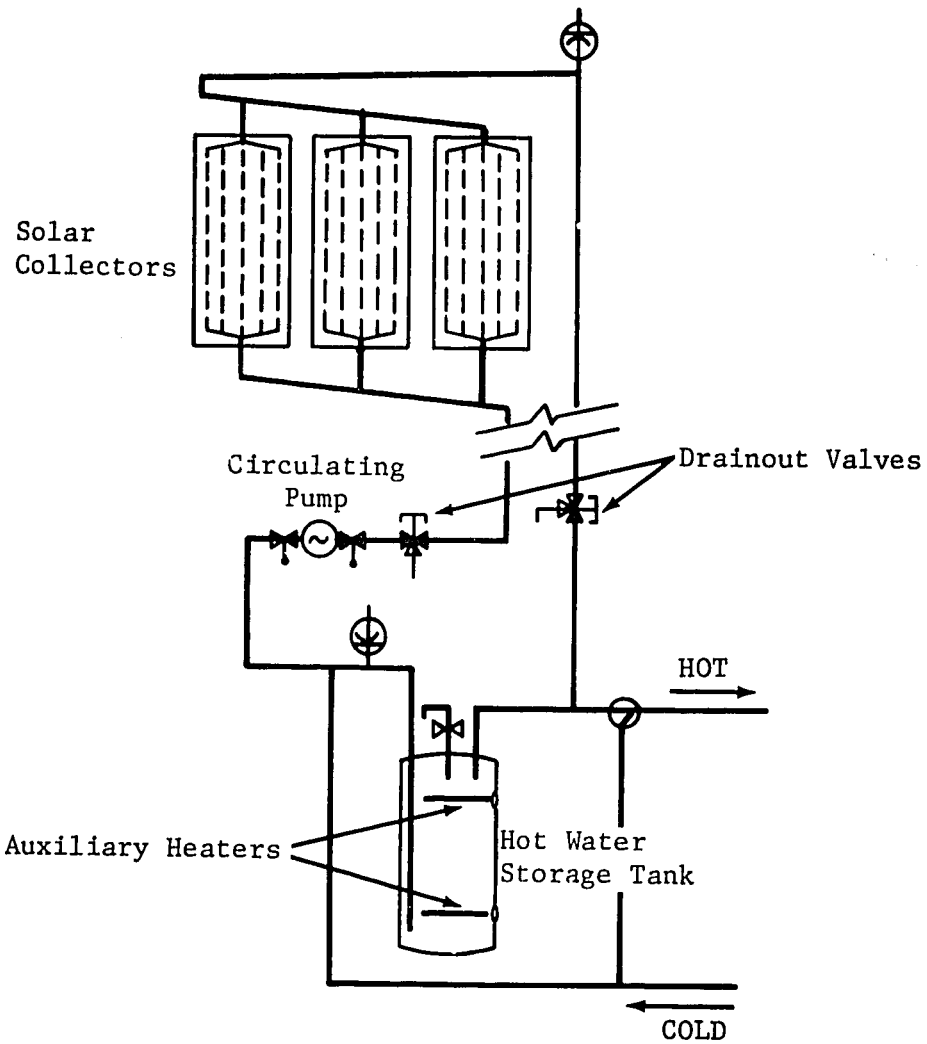

FIGURE A.1
SCHEMATIC OF SIMPLE DOMESTIC SOLAR WATER HEATER

sun's rays. The hot water can be drawn off in the afternoon and evening for domestic use.

Output. Collector areas range from as little as two square meters for some domestic systems up to hundreds of thousands of square meters for industrial applications. Similarly, the daily hot water production can range from 100 liters for domestic use up to millions of liters for industry. A simple domestic unit would deliver about 1.5×10^7 Joules per day,[18] while institutional-type systems (e.g., hospitals, clinics) would be an order of magnitude larger (say 2×10^8 Joules/day) and industrial systems might deliver 10^9 - 10^{11} Joules/day.

Resource Requirements. Construction materials are available in Egypt. These include steel, copper, glass, wood, sealant and paint.

Water supply may be critical in some cases. Often in the urban centers the demand for water is so great that either the system water pressure is too low for a continuous supply to roof top collectors, or else water supplies are cut off for significant portions of the day, thus reducing the capabilities of some solar water heater types.

In domestic applications, the space requirements of solar water heater collectors may compete with living or storage space on roof-tops.

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[18] National Academy of Sciences, Energy for Rural Development, 1976.

Environmental Impacts. Solar water heaters are environmentally benign at their point of use. Some negative impacts will be associated with manufacture.

Reduction in fossil and noncommercial fuel consumption resulting from utilization of solar water heating on both industrial and domestic scales will have positive impacts on air quality. Rural domestic use would benefit soil fertility (by releasing dung from burning to be used as fertilizer).

Social Impacts. Social impacts from industrial and institutional use will be very small, while social impacts from domestic use may be significant. These are summarized below:

- Water heating is estimated to account for some 50 percent of domestic energy usage, partly for washing and bathing, partly for cooling.*
- Use of solar-heated water for washing and bathing will present few acceptance porblems in urban areas; in rural areas, little hot water is used for washing and bathing, which is mostly done in canals.
- Use of solar-heated water as a starting point for cooking and beverage preparation will require changes in culinary methods and may not be widely acceptable.
- Greater availability of hot water will have health benefits.
- Roof location of water heaters may compete with living and storage space. Location of the heaters on the ground would require stronger and more expensive collectors.

In addition, significant Egyptian manufacture of these units will provide local employment and stimulate the Egyptian economy.

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*Data supplied by Dr. G. Self, AID.

Costs. Capital costs for units for domestic use range from L.E. 1.38/liter/day for units of Egyptian manufacture to L.E. 2.60/liter/day for imported units.* Operating and maintenance costs are estimated at 2 percent of the capital cost annually, and the equipment life is expected to be 10 years. Delivered energy costs are then about L.E. 4-6 per 10^9 Joules for Egyptian units and L.E. 7-10 per 10^9 Joules for imported units. The main competing energy sources are:

- butagas at a local price of L.E. 1.1 per 10^9 Joules, and a real (world) price of L.E. 9 per 10^9 Joules**
- kerosene at a local price of L.E. 0.5 per 10^9 Joules, and a real (world) price of L.E. 4 per 10^9 Joules**
- noncommercial fuels at a local price of about L.E. 0.4 - L.E. 0.6 per 10^9 Joules***

Capital costs for industrial-scale units in Egypt are unknown, since none are in use. In the United States, capital costs are about \$25/ft^2 of (flat-plate) collector area, with operating and maintenance costs running at about 2 percent per year.(19) Such systems in Egypt could deliver energy at costs competitive with the real costs of fossil fuels, or about L.E. 1-3 per 10^9 Joules.

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*Figures obtained in response to GOE call for tenders. Prices are FOB Alexandria.

**Egyptian Ministry of Petroleum data.

***Team survey data.

(19)The MITRE Corporation, Systems Descriptions and Engineering Costs for Solar-Related Technologies, MTR-7485, Vol. III, 1977.

Balance of Payments Impact. Application of this technology would be beneficial to Egypt's Balance of Payments. A high proportion of the systems could be manufactured in Egypt, and substitution for fossil fuels would release these for export.

Development Status. The basic technology is well understood and is in use world-wide. The problem is mainly one of transfer of technology and adaptation to Egyptian conditions, needs and capabilities. Significant R&D capabilities for solar water heaters exist at the Solar Energy Labs at the National Research Center and at Cairo University. More research and development activity is required in such specific areas as dust removal techniques, glazing breakage protection and selective absorbing paints for local manufacture. Design capabilities both for collectors and for total systems exist at the Solar Energy Labs of the National Research Center, at the Center for Industrial Development and at several of the Universities.

Existing manufacturing capability is located at one factory in Egypt, The Arab Company for Utilization of Solar Energy. This company currently produces three different sizes of water heaters: 100/150/200 litres/day units. The company has a capital of L.E. 269,150 and is able to produce a maximum of 5,000 units/year.* Units manufactured by this company which have been examined under operating conditions by the team have exhibited consistent defects in

*Data obtained from applications filed with the Five-Year Industrialization Plan Authority.

quality control and installation. In particular, separation of the water pipes from the backplate in the collector by up to 1 cm was common. It is estimated that this reduces collection efficiency by 20-30 percent. Additionally, insulation of hot water pipes was haphazard, even within individual installations. However, all users interviewed were happy with the performance of the units.

Six other commercial enterprises are planning to begin production of various types of solar water heaters, some by early 1980:*

1. Commercial Solar Energy - a joint Egyptian (75%) and British (25%) venture. Capital assets are L.E. 400,000 and capacity will be 5,000 units of various sizes/year normal production and 10,000 units per year at maximum production.

2. Thia - a joint Egyptian (60%) and Cypriot (40%) venture. Capital assets are L.E. 200,000 and production will be 1,000 units/year normal, rising to a maximum of 5,000 units/year.

3. Ismailia - owner is Mohammed El Desukey and 100% Egyptian owned. The factory is under construction. Capital assets are L.E. 230,580 and capacity will be 1,200 units per year of 150/litre/day size.

4. Military Factory #360 is intending to produce under license from Junlar Company of the Federal Republic of Germany.

5. Osman Ahmed Osman is licensed and currently experimenting with an NRC design using all local materials except for paint. This company manufactures other goods. Solar water heaters would represent a new line of production.

6. ILMACO - a company formed by the Ministry of Electricity Company. They will soon be manufacturing.

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*Data obtained from applications filed with the Five-Year Industrialization Plan Authority.

The local content in all the above solar water heater systems varies between 60-70 percent. If all these plans materialize, the production capacity will exceed 7,000 units/year.

There appears to be a need for formulation of standards of performance for solar water heaters in Egypt. Standardization and control capabilities exist at the National Research Center and at the High Voltage Laboratories of the Ministry of Electricity.

Maintenance capability: currently the only company that is manufacturing and selling solar water heaters also installs and maintains their own units.

Training and Education Capability: the National Research Center is offering a training course beginning early in 1980 on solar energy systems, as part of their ongoing Programme of Training Courses (curriculum approved). In addition, the Egyptian Electrical Authority offers yearly courses to various national laboratory and government employees on solar energy. These courses are often sponsored by foreign governments and agencies.

Commercialization capability: the Ministry of Electricity has recently (10/79) finalized the second stage of their commercialization program. A request for tenders was placed on the international market for the production and delivery of solar water heaters. Contracts have been signed with the three winning companies for delivery of a total of 1,000 water heaters by 1980. These water heaters will then be installed in highly visible places throughout Egypt. The

third stage of the program involves the manufacture in Egypt of the most successful of the three solar water heater systems. The criteria for evaluation are based on the manufacture and operating costs of the system, the capability for manufacture in Egypt, and suitability to the Egyptian climate. The systems selected for this program are manufactured by the following companies:*

- CEDEM (Orleans, France) - single glazed collector with heat exchanger and either natural or forced circulation.

- Thermosolar (Montreal, Canada) - single glazed collector with auto drain (no heat exchanger) and forced circulation.

- SILE (Tresiso, Italy) - single glazed collector with heat exchanger and natural circulation.

This program represents a good start toward widespread implementation of this technology. However, the scope for potential USAID assistance remains wide, as discussed in the main body of the report.

- Currently there is no legislation existing concerning rights to solar energy. However, a document was put before the Supreme Council on Renewable Energy Technology in September 1979 that would protect the solar rights of buildings on which there are solar collectors.

- Building codes are currently being reviewed, particularly in the case of new towns and cities being planned or built, to ensure that rooftops are capable of supporting the added weight of solar water heater installations.

- Codes and specifications are required for both material use and product capabilities. This will be primarily for consumer protection. The enacting agency will be the Egyptian Authority for Standardization.

- Manufacturer service contracts and warranties are not yet legal requirements. However, with the number of companies

*Data obtained from literature supplied by the companies concerned.

entering the field, this could soon become an area of abuse unless manufacturer and distributor responsibilities are guaranteed in law.

- If solar water heaters are to proliferate on any reasonable scale in the retrofit market there will need to be credit extension facilities from the manufacturer or other sources.

- Local manufacturing capability is lacking in the areas of valves, temperature and liquid control systems, and circulating pump manufacture. There is the need to extend existing capability to produce a new high heat resistant insulation material. In addition, minor extensions to the manufacturing capabilities of the Egyptian Paint and Chemical Company would permit production of selective paint coatings.

Two other donors are active in this technology:

- France - the Conseil National de Recherche Scientifique is involved in a program of solar water heater testing at the High Voltage Laboratories of the Ministry of Electricity. SOFRETES collectors are being installed as water heaters in a hospital, and this same company has an agreement with a local company to manufacture solar water heaters.

- Federal Republic of Germany - arrangements being made through a German company to manufacture collectors locally.

Neither of these programs is large enough to make USAID involvement unnecessary.

Market Potential. The market potential is discussed separately for industrial applications (which are felt to offer the better prospects) and for domestic and institutional applications. Industrial applications have the potential of more rapid penetration because of the larger size of individual systems, extensive government ownership of production facilities, and availability of technically trained personnel to operate and maintain the systems. An assistance program consisting of a small number of large projects would also be easier to manage.

The potential market for industrial applications is difficult to assess quickly in detail because the viability of solar energy in an industrial setting is quite case-specific. In general, food processing and textiles account for some 2/3 of the market value of all Egyptian industrial production and these industries are known to require considerable quantities of low temperature heat. This is especially true of the food processing industry.

Four case studies have been made, three in food processing and one in the soap industry:*

- The Egyptian Dairy Company has 60 milk collection centers and nine processing plants throughout Egypt. Annual production is L.E. 23 M. Water at 70°C is required for container washing at each collection center, and plans already exist to use solar energy for this on an experimental basis at Imbaba, Damiette and Alexandria. The justification is that current equipment is becoming difficult to maintain and operate. At the processing plants 7300 tpy of milk is heated from 4°C to 95°C for pasteurization. Yoghurt, cheese, and other products are made requiring about 0.1 QJ of total fossil fuel input.

- The Kaha Plant produces canned and bottled juices, jams, jellies, vegetables and meats. Annual production is L.E. 20 M. The plant currently produces 18 tph of steam at 10 atmospheres and $10m^3$/hr of water at 100°C for various processes. Preheating the water by solar energy to 90°C could save up to 0.06 QJ of fossil fuel input per year.

- The Biscomisr plant uses steam at 180°-300°C for biscuit and wafer production; the fossil fuel needs are about 800 kg mazout per tonne. If 1/3 of this could be replaced by solar preheating, fossil fuel savings could be 0.06 QJ.

- Soap production in the Wadi El Natrun uses 2 tph water at 90°-100°C, presently heated by fuel oil. Solar assistance could save about 0.002 QJ fossil fuel annually.

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*Data obtained through personal interviews with plant managements.

From the above case studies, the potential market for industrial solar heating might amount to up to 10 QJ; this estimate is extremely rough but is probably correct to within a factor of 3.

Penetration of the market is difficult to estimate; since most plants are government-owned, active government policies could result in very high penetration in a relatively short period; perhaps as much as 1 or 2 QJ which could be achieved by as few as 500 systems within a few years.

- Another potential use of solar heat for industrial process concerns mineral processing.* The team visited the Al Hamrawain Phosphate Mine on the Red Sea Coast which produces 150,000 tpy of phosphate. Its design capability is 600,000 tpy but equipment problems limit output. The raw rock is crushed and washed to extract the phosphate which is then dried. The drying process requires approximately 0.2 tonnes of fuel oil per tonne of phosphate produced, and probably could be augmented or replaced by solar heat. The exact technology required is not clear. 75 percent replacement of fossil fuel by solar energy would save about 90,000 tpy of fossil fuel when the mine reaches full production, or about 4 QJ/year. This is an extremely large amount of energy, worth (as oil) about $20 million annually. Similar applications may be possible in other mineral extraction processes.

- Opportunities also exist for agricultural applications. One example is chicken raising; the chicken-sheds must be kept at stable temperatures above 90°F for about half the rearing cycle. Several thousand such installations exist in Egypt.

In the domestic and institutional market, solar water heating is applicable to all regions where water is available (both urban and rural) and all income groups, although the acceptance rates may vary widely for different locations and social strata.

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*Data obtained through personal interview with plant management.

The potential market can be divided into new construction and the retrofitting of existing structures:

- New construction: Egypt's population is likely to increase by 20 million by the year 2000,[7] necessitating the construction of up to 4 million new dwelling units. At least 2 million of these are likely to be in urban settings, the majority in or around existing cities.

  - new residential construction in and around existing cities represents a major potential market of up to 100,000 units/year.

  - new residential construction in new cities and satellite towns is planned to be 4,000 units/year through 1985, and an average of 17,000 units/year for 1986 through 2000.* Because of standardized designs and centralized planning this market may be relatively easy to break into. If units are integrated into housing designs and covered by mortgages, penetration could be near 100 percent.

  - new rural construction will also amount to some 2 million dwellings by 2000. Penetration of this market is very problematical, based on current envisaged usage of hot water for washing, bathing and other domestic purposes in rural areas. Capital costs of heaters are high compared with rural incomes.

  - new institutional units (schools, clinics, community centers, etc.) offer an excellent potential market of a few thousand units/year. With appropriate government policies, penetration could be very high.

- Retrofits: It is generally more expensive to retrofit a solar water heater onto an existing building than to incorporate it in a new building. However, some limited potential exists in this area, especially for urban single-family homes and for existing schools, clinics, etc. The physical structure of institutional buildings makes retrofits quite attractive. Current urban structures and ownership patterns limit residential retrofit potential.

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(7)World Bank World Development Report, 1978.

*Personal communication from Dr. A. Hegazi, Egyptian Electricity Authority.

The total market for solar water heaters for domestic (and institutional) hot water is estimated to be about 6000 units/year in the near future, increasing to 12,000 units/year by 1985, and up to 50,000 units/year by 2000. The market could be higher if vigorous measures are adopted by the GOE to expand and accelerate solar usage.

Annual energy output from 150,000 units by 1990 is 1.5 QJ/year, equivalent to perhaps 2 QJ of fossil fuel input.

A.2 SOLAR CROP AND FOOD DRYING

System Components.

1. Simple flat-plate chest-type collectors with removable shelves for drying agricultural produce, meat and fish. These devices can be used at the domestic, farm or small cooperative level. Figure A.2 illustrates a typical dryer.

2. Industrial-scale dryers of various designs, perhaps employing forced draft or fossil-fired heat boosting. Large units may be formed by the replication of smaller ones.

Output. The energy output of solar crop dryers is equivalent to 4 to 6 $kWh/m^2/day$, or 14 to 22 x 10^6 $J/m^2/day$. The total output of a given crop dryer depends upon the collector area. Typical sizes range from a few m^2 (for domestic use) up to several thousand m^2 (for commercial use).

The output of dried material varies widely depending on crop type, dryer design, climate and moisture content, but a representative range is 0.2 to 1.8 $kg/m^2/day$.[21]

Resource Requirements. Construction of solar crop and food dryers requires only steel, glass, wood, sealants, galvanized sheet. However, space considerations may be important for the following reasons:

- potential competition with land for crop production when replacing fossil-fired dryers.
- rooftop location of domestic dryers may compete with storage or living space.

Environmental Impacts. The environmental impacts associated with solar crop and food drying are benign. They comprise:

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[21] Brace Research Institute, A Survey of Solar Agricultural Dryers, T99, MacDonald College of McGill University, 1975.

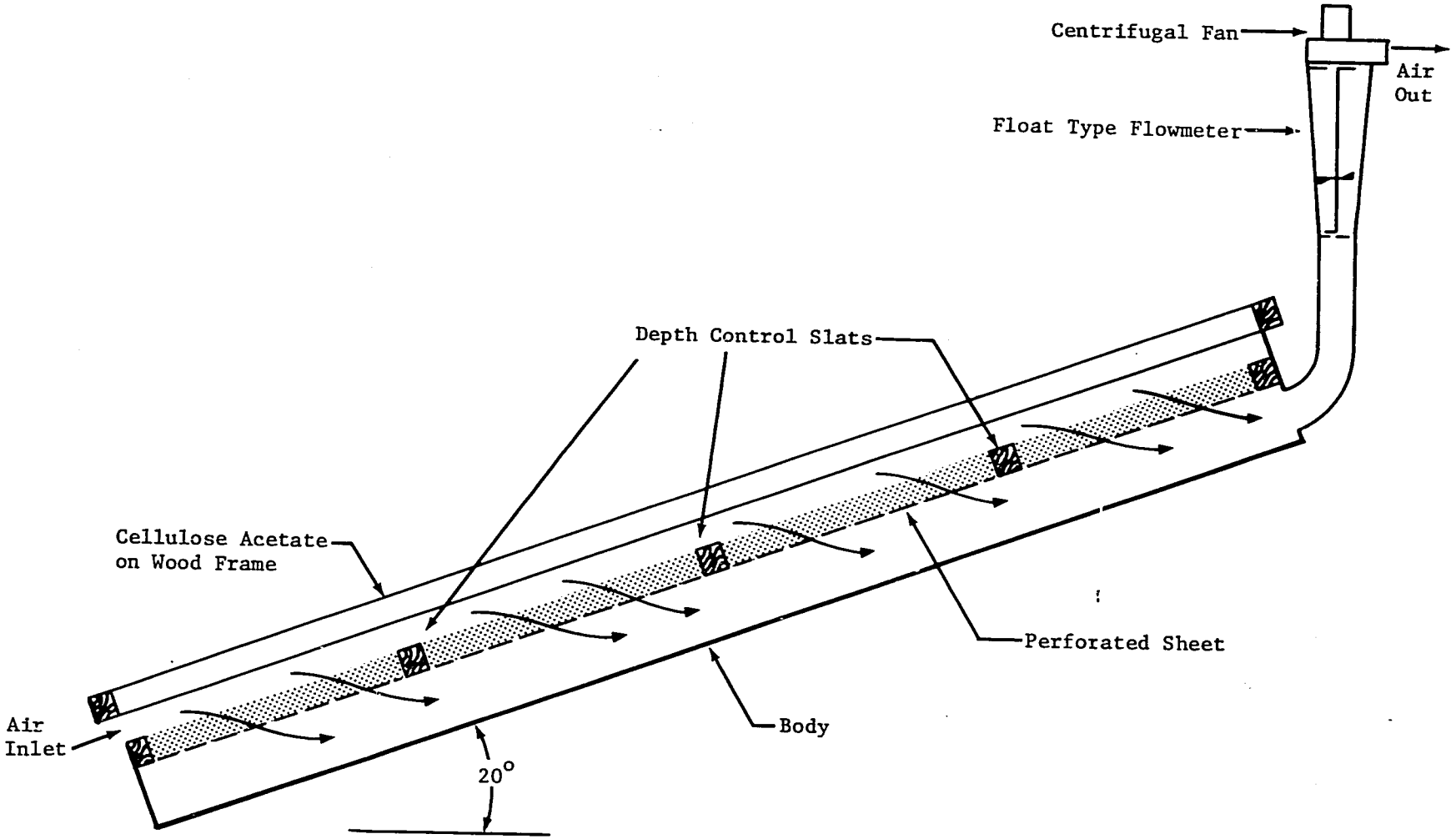

FIGURE A.2
DIAGRAM OF TYPICAL SOLAR CROP DRYER

- reduced transportation needs as compared with non-dried product
- reduced fossil-fuel use for other drying processes
- reduction in land area used for open-air drying.

Social Impacts. Dried foods are already well-known and widely-used in Egypt, so that expansion of food drying should not encounter social acceptability problems.

The major impact of the commercial use of solar crop drying will be economic. The substitution of solar energy for fossil fuels will release more petroleum for export, improving the balance of payments. In addition, Egyptian manufacture will provide employment and stimulate the national economy. In general, the prime beneficiary of commercial use will be the GOE, which will gain increased revenues from oil exports. Secondary beneficiaries will be those involved in the manufacture, maintenance and operation of the dryers. End-users will see little apparent change in costs (since fossil fuels are highly subsidized) or service.

Widespread use of domestic-scale dryers will have significant social and economic impacts. Reduction of spoilage and losses due to open-air crop drying, and the production of a higher-quality product, can significantly raise rural incomes. In some cases, high-quality product is priced twice as high as low-quality. In addition, manufacture of the dryers can be undertaken at the village or small town level, benefiting the rural economy.

Costs. The costs of dryers are quite variable. Expressed in Egyptian terms, the real capital costs of dryers developed and manufactured in other countries break down as follows:(21)

simple dryers	-	L.E. 1 to L.E. 5/m^2
intermediate dryers	-	L.E. 6 to L.E. 13/m^2
expensive dryers	-	L.E. 14 to L.E. 24/m^2

The real operating and maintenance costs are estimated to be L.E. 14 to L.E. 60 per tonne of output. These values, with a 10-year equipment life, yield drying costs of L.E. 15 to L.E. 100/tonne. In comparison, the real (world price) costs of conventional fossil-fired dryers are in the range L.E. 100 to L.E. 300/tonne.(22) Local (subsidized) costs are considerably lower than this.

Balance of Payments Impact. Since the dryers could have a high proportion of local Egyptian manufacture, widespread implementation of this technology would have a positive impact on Egypt's Balance of Payments due to substitution for fossil fuels and the release of the latter for export.

Development Status. Solar crop and food dryers are quite widely used in many countries, and many different designs have been developed to suit different conditions. In Egypt, R&D is being conducted at the National Research Center and at the Faculty of Engineering at Helwan University. The program at the NRC is at least partly funded by the

(21) Ibid.

(22) Estimated from data in Government of Pakistan Report by Dr. M. Jamil, PCSIR, Lahore (no date).

International Development Research Center of Canada. This is not a large program and is not expected to have major impacts in the near term.

Market Potential. Commercial and domestic food drying already takes place on a large scale in Egypt. Total annual tonnages of commercially-dried foods are:*

- Onions	80,000 tonnes
- Garlic	5,000 tonnes
- Other Vegetables	4,900 tonnes
- Dates	10,000 tonnes
- Grapes	1,000 tonnes
- Dried processed meat	2,800 tonnes
TOTAL	103,700

Production is split roughly equally between government and private plants. The team visited the Kaha Food Processing Company, which has installed new air dryers in Badrashain Village for crop processing. They expressed great interest in solar augmentation of these units.

It is estimated that 25 percent penetration of the existing commercial drying market would save fossil energy at the rate of 1 QJ/yr.

A potential major new market involves fish drying. The Red Sea in particular and the High Dam Lake to a lesser extent, appear to

*Personal communication from Dr. A. El Mehelmy, Five-Year Industrialization Plan Authority.

have great potential for fishing expansion. Fish can be easily dried by solar means either for poultry or animal feed or for human consumption. Fish is currently dried for animal feed at Aswan, and fish was dried at Alexandria until 1962 when the factory was nationalized and the equipment used elsewhere.

At the domestic or farm level, many crops, including tomatoes, okra, peppers, and mauloukhia are sun-dried in rural (and some urban) areas. Thus there exists a potential market for small dryers costing a few pounds, capable of producing several kg/day, perhaps up to a few hundred thousand units.

There may also exist a potential market in drying hay or clover. Currently only 1 of 3 annual crops is dried, due to problems with insect infestation. 1,000,000 feddans are in hay production with an annual wet crop of 5,000,000 tonnes. Improved drying could significantly increase the nutrient value of the material and speed up the cropping process, releasing the land for other purposes.*

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*Personal communication from Dr. A. El MeHelmy, Five-Year Industrialization Plan Authority.

A.3 RURAL BIOGAS DIGESTERS

System Components. Anaerobic biogas digesters of sizes appropriate to individual families ($10m^3$ or to communal applications (about $100m^3$).

These units take human and animal wastes and some agricultural residues and water and produce biogas (with approximately 50 percent methane content), slurry which can be used as fertilizer, and liquid effluent which can be used to grow algae or duckweed for fish or poultry feed. Normal operational cycle involves an initial charge of 800 kg of a mixture of wet animal dung and partially-composted agricultural residues, followed by daily charging with about 10 kg of dung and human wastes, and some water. After 6 months the unit is cleaned and the cycle repeats.* Figure A.3 shows a typical digester.

Output. A $10m^3$ (family-size) plant will produce about $3\text{-}4m^3$/day of biogas with an energy content of about 1.60×10^7 J/m^3, thus yielding about 2×10^{10} J/yr. Gas production is about $0.4m^3$/kg wet manure from cattle or buffalo, and up to twice this from human or poultry waste.[23,24]

The rate of gas production depends upon the ambient temperature and upon the chemical and bacteriological state of the mixture in the digester.

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*Data obtained from Fayoum Campus, University of Cairo.

(23) National Academy of Sciences, Methane Generation from Human, Animal and Agricultural Wastes, 1977.

(24) Food and Agriculture Organization, China: Recycling of Organic Wastes in Agriculture, FAO Bulletin 40, 1977.

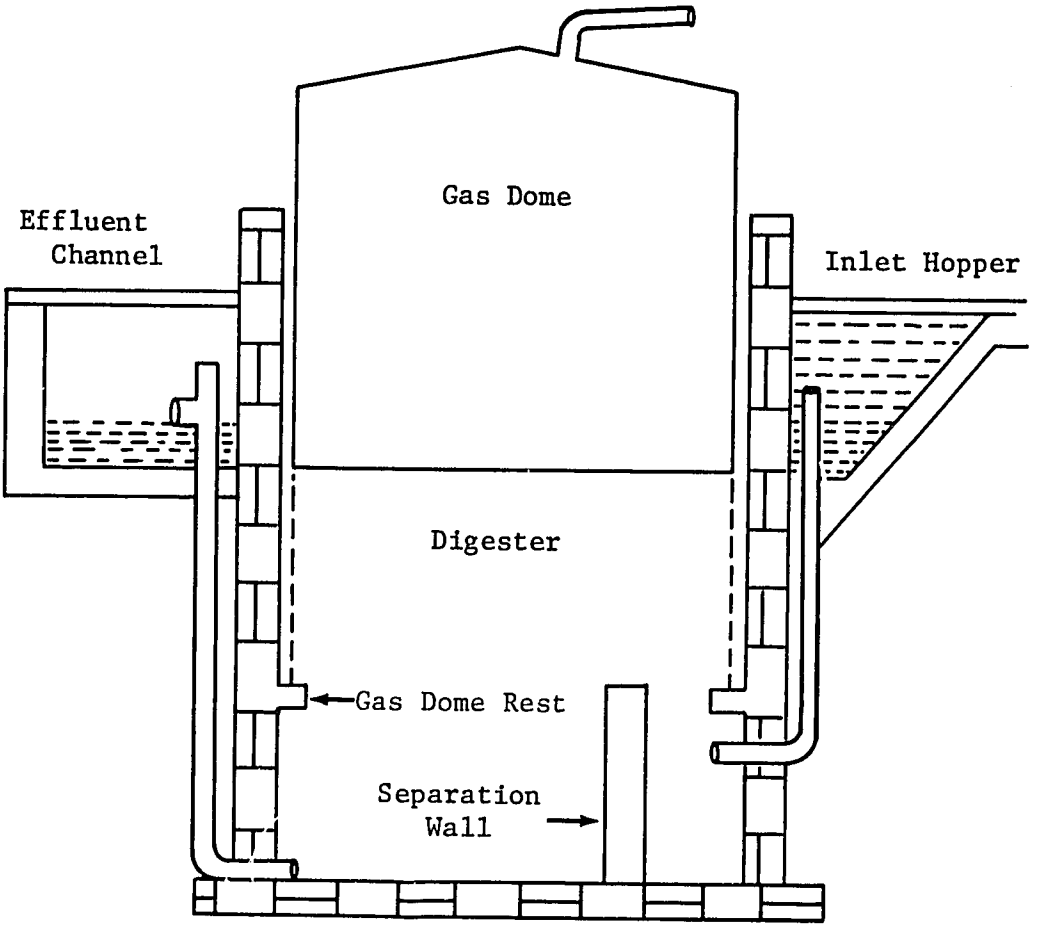

FIGURE A.3
DIAGRAM OF TYPICAL RURAL BIOGAS DIGESTER

About 1-1/2 to 2 tonnes of fertilizer slurry is obtained each time the unit is cleaned.

Resource Requirements. Biogas digesters can be built of locally-obtainable materials such as brick, stone or concrete. Construction can be undertaken by local artisans (after training). Plastic piping for the gas can be used. Some simple burners, valves and fittings are required.

The units must be located very close to the houses, which may present problems in densely-populated villages. However, if an underground design is used, space requirements after construction is completed are small.

A steady supply of animal and, perhaps, human waste is required, together with some water.

Environmental Impacts. The environmental impacts of rural biogas digesters are on the whole positive:

- Positive impacts include improved sanitation, increased overall efficiency of farm energy use, recycling of nutrients to animals* and nutrients and organic material to soil, reduction of fire hazards due to domestic storage of dry agricultural residues, and reduction of smoke concentrations from cooking fires in houses.

- Negative impacts include water requirements, land requirements, danger of explosion.

Social Impacts. Handling of animal wastes will present no psychological problems. Handling of human wastes may be distasteful, but can

*If the fish or poultry feeding option is adopted.

be minimized by location of facilities which connect directly to the digester.

The biogas is expected to be used primarily for cooking, lighting and water heating. However, it is doubtful that it will replace the traditional oven since bread baking requires a slow burning, low heat fuel (e.g., dung cakes). Also, water is sometimes boiled for tea and coffee by an intensive hot fuel source (e.g., butagas or agricultural wastes). Biogas may not heat water as quickly, therefore target populations will have to appreciate and want the biomass savings to switch fuel sources. Use of biogas for other forms of cooking and for lighting is not expected to pose any social acceptance problems.

When these units are introduced, dung gains in economic value. This may penalize poor families who must scavenge or buy dung for cooling.

Major changes are required in agricultural and domestic waste handling methods to successfully implement these units, and this must be regarded as representing a potential barrier to utilization.

The construction of biogas digesters and manufacture of associated simple lamps and burners will provide employment and stimulate the rural Egyptian economy. Similarly, increased fertilizer availability will increase crop yields and raise rural incomes.

Costs. The real capital costs of biogas digesters in Egypt is estimated at L.E. 150-200 per family unit. This estimate is based on

data from NAS (op. cit.) and from the Fayoum Campus of the University of Cairo. Operating and maintenance costs are estimated at L.E. 15 to L.E. 25 per year, excluding the value of the operator's time.

Estimating the delivered costs of energy from a biogas digester presents problems associated with valuing the manure and labor inputs, and the slurry and effluent outputs. Estimates of these values vary widely;* here it is assumed that the value of the output, excluding gas, is equal to the value of the input, because it captures essentially all the nutrient values in a usable and convenient form. Under this assumption, the resulting cost of gas is in the range of L.E. 1.7 to L.E. 3.0 per 10^9 J, based on 10- to 20-year equipment life.

Competing fuels are butagas at L.E. $1.1/10^9$ J local (subsidized) cost and L.E. $9/10^9$ J real (world) cost, kerosene at L.E. $0.5/10^9$J local cost and L.E. $4/10^9$ J real cost,** and agricultural residues at about L.E. $0.5/10^9$ J local cost.***

Balance of Payments Impact. Since biogas digesters would be almost entirely manufactured in Egypt, and would substitute for some fossil fuel, their Balance of Payments impact would be positive. The market potential is estimated at 8 QJ/yr (see below); if 25 percent of this were fossil fuel, the value on the export market would be about L.E.

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*See, for example, NAS (op. cit., 1977), FAO (op. cit.) and French, Dr. D., The Economics of Renewable Energy Systems for Developing Countries, AID, 1979.[26]

**Data from Egyptian Ministry of Petroleum.

***Team survey data.

7 million. Benefits might also be obtained from increased Egyptian food production or reduced domestic chemical fertilizer demand as the result of increased recycling of nutrients to the soil.

Development Status. Rural biogas digesters are widely used in India and China, and the technology is quite well understood. In Egypt, R&D programs are under way at the National Research Center and at the Fayoum Campus of the University of Cairo. The primary problems appear, then, to be technology transfer and adaptation of existing designs to Egyptian conditions and, later, familiarization of Egyptian farmers with the new methods necessary to make the digesters effective.

The appliances to burn the gas (lamps, stoves) are quite simple and are amenable to local manufacture in small towns or even villages. Training and assistance to local craftsmen will be needed to initiate production.

Distribution of units may be achieved by agricultural extension services. Extension agents must be trained in construction, start-up and trouble-shooting of biogas digesters, and must additionally be trained to train users in correct operation and maintenance procedures. The acceptance of digesters may be accelerated by a successful, widespread demonstration program.

For communal units, appropriate local institutions must be set up to ensure correct operation and maintenance (feedstock collection, semi-annual cleaning, gas distribution, etc.).

Market Potential. The potential market comprises the approximately 4,000,000 rural farming families living in the Delta Nile Valley and Fayoum regions.

The number of animals required to support a $10m^3$ unit is variously estimated at 2-5 large beasts (cows, buffalo), or equivalent[23] (human and poultry wastes have particularly high value). The lower end of this range is well within normal Egyptian animal ownership patterns, but the upper end is rather high. Families which lack sufficient wastes to support an individual unit may be serviced by communal units.

Adoption by 10 percent of the rural farming families would result in biogas production of 8QJ/year. This penetration level is speculative, but is felt to be achievable in the absence of severe problems. Market penetration of communal or institutional units is very uncertain due to the management problems associated with them.

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[23]NAS, op. cit., 1977.

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A.4 WIND MACHINES

System Components

Two different applications are included in this category, namely water pumping and electricity generation. The basic equipment comprises a wind turbine and a load device. Small wind machines suitable for irrigation of a few acres of land or generation of a few kW of electricity usually have a multi-bladed fan of 2 to 3 meters in diameter (see Figure A.4), while large machines, suitable for electric generation in the mW range, usually have only two large blades. Other designs, such as vertical-rotors, have been developed but have not yet achieved widespread acceptance.

The load comprises a pump for irrigation machines or a generator and power conditioning equipment for electric generation. Direct usage of the electric current for simple mechanical uses (e.g. grinding corn) may be possible using simpler generating equipment than required for production of 220 V. A.C. needed for grid-compatible devices. Desalination by reverse osmosis may also be undertaken.

Output

The range of outputs encompassed by practical wind machines ranges from 2 kWe up to 2 MWe. The output of any given windmill is critically dependent on the strength and duration of the wind. In particular, the power output is proportional to the cube of the wind speed. Thus, a 15 mph wind permits the generation of almost twice as much power as a 12 mph wind.

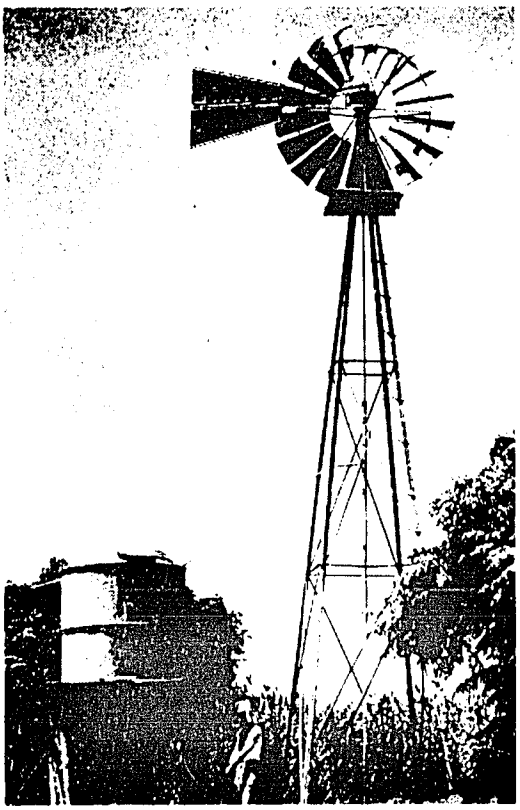

FIGURE A.4

Irrigation pumpers generally produce about 3 kW equivalent, enough to irrigate about 5 acres, while electric generators range from a few kWe up to 2 MWe.

Resource Requirements

Construction of wind machines requires aluminum, steel, copper and plastics. These materials are readily available in Egypt, and no resource constraints are foreseen to widespread windmill deployment.

Environmental Impacts

Some negative impacts on the environment will be associated with the manufacture of windmills. The impacts at the point of use are relatively limited, comprising

- benefits due to substitution of wind power for fossil fuels
- visual clutter and possible radio or TV interference due to the action of the rotating blades
- danger of overpumping aquifers and causing saline intrusions of failure of wells - this danger is common to all types of well irrigation, and windmills apear preferable to diesel pumps in this respect because of their lower pumping rate.

Social Impact

Irrigation permits the production of more food, raising farm incomes. In addition, increased water availability would permit greater development of the North West and Red Sea Coasts, reducing pressures on other areas.

Electrification is a major goal of the GOE. Egyptian rural households with electricity use it for lighting (100%) and TV (70%);

only a few have refrigeration (27%). Annual usage is low (60-90 kWh). Benefits of electrification include:

- broadening of village and personal activities, including adult education classes and health clinics in the evenings.
- induction of small commercial enterprises (cottage industries) and associated infrastructure.
- potential reduction of birth rate.

Significant Egyptian manufacture of wind machines would provide employment and stimulate the local economy.

Costs

The capital costs of small irrigation wind pumps in the U.S.A. is about $3,000*, which would translate to $4,000 installed in Egypt. Estimated cost of local manufacture is L.E. 700 to L.E. 800 (or $1,000 to $1,100).** Small electric generating machines are estimated to cost $2,700/kWe installed for 220 V A.C. output (L. E. 1900/kWe),* while larger machines, above 100 kWe capacity, are estimated to cost $1,200 to $1,000/kWe (L. E. 1000 to L. E. 2000) installed, depending on size and location.(19) Operating and maintenance costs are estimated at 5% of the capital cost per annum, and equipment life in 20 years.

Under these assumptions, irrigation pumping appears competitive with diesel power in terms of delivered energy. For electric

*Team estimate, based on knowledge of Dr. W. L. Hughes.
**Military Factory estimate.
(19)The MITRE Corp., Systems Descriptions and Engineering Costs for Solar-Related Technologies, MTR-7485, Vol. VI, McLean, Va., 1977.

generation, small system yield costs of L. E. 0.05 to L. E. 0.08/kWh in 15 mph average winds and L. E. 0.09 to L. E. 0.15/kWh in 12 mph average winds. Large systems have costs of L. E. 0.03 to L. E. 0.06/kWh in 15 mph average winds and L.E. 0.05 to L.E. 0.08/kWh in 12mph average winds.* In comparison, diesel-electric costs are estimated at L. E. 0.06/kWh at real (world) prices and L. E. 0.02/kWh at local (subsidized) prices. Egyptian grid costs are L. E. 0.013 to L. E. 0.047 at real prices and L. E. 0.002 to L. E. 0.030/kWh at local prices, depending on season, day of week and time of day. Thus, in real terms windmills are economically competitive with diesel-electric generation in remote areas, and may be competitive with the grid under the favorable circumstances of high average wind velocities.

Balance of Payments Impact

The Balance of Payments effects of widespread utilization of wind machines would depend upon the size of machines installed. Small machines could be largely manufactured in Egypt, while larger ones would have a higher import content. The long-term effects would be positive, due to fossil-fuel displacement.

Development Status

In general, this technology is well-developed and well-understood for pumping, and is in a state of development for electric generation.

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*15 mph average winds appear to be found only along the Red Sea coast, where it is not expected that large wind machines will be deployed for some time, due to limited local demand for electricity.

About 900 irrigation units were produced in Egypt by the Military Factory in the 1960's,* and were supplied to farmers along the North-West Coast, and new units are still occasionally supplied out of limited remaining stock. Current production capacity could be 400 units/year; the capability to produce certain aluminum alloys needs to be developed to allow full local production.

Local credit facilities may be inadequate for financing purchases of windmills; hearsay evidence indicates a high default rate on machines bought from the Military Factory. Existing units of Egyptian and foreign manufacture along the North-West coast are kept running by a locally-based system of small repairmen and parts fabricators. This system appears to be quite successful despite the lack of any developed infrastructure for obtaining factory-built spare parts and new windmills. Perhaps 50% of the originally-installed windmills are still running, a remarkably high proportion in view of the age of the units, the difficulties of obtaining spare parts, and the availability of very cheap subsidized diesel fuel.

It appears that manufacture of irrigation units could be readily re-started. At the same time, interest exists concerning wind machines for electrical generation.

Some R&D capability exists at the National Research Center jointly with the University of Oklahoma. If a large-scale development and testing program were initiated this capability would need augmentation.

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*Private communication from Factory Management.

The manufacturing capability to produce a large proportion of the total unit for small electric system in Egypt either exists or can be readily developed. Possible areas where development would be needed include the production of certain aluminum alloys and the construction of small electric generators. It is likely that imported items would be limited to power conditioning and control gear.

The capability of Egypt to manufacture large electric systems is unclear. Significant parts of the system, such as the tower, the hub, shaft, and gearbox, and perhaps the generator could be locally manufactured (maybe after some enhancement of existing capabilities) but the blades, control system and power conditioning equipment would be imported.

Some small windmills are used for electricity generation at remote military and communications installations. These are of the Australian Dunlite type. Plans exists for introducing small (3-kw) units at Berg-El-Arab in conjunction with the existing diesel electric capacity on an experimental basis.* Generally, however, there is little experience in Egypt with small wind electric systems. A wide variety of such systems is available world-wide, but mostly they are of recent design and have not been extensively deployed. It

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*Private communication from Engineer H. Amr, Egyptian Electricity Authority.

is expected that civilian electrical installations would be handled and maintained by the Egyptian Electricity Authority through their normal institutional mechanisms.

Market Potential

Clearly, the scope for introduction of wind machines is limited to those areas of Egypt with good wind conditions, namely the North-West Coast and (especially) the Red Sea Coast. The potentials for irrigation and for electric generation are discussed separately.

As noted, windmills are used for irrigation pumping along the North Coast where ground water is adequate and where other water supplies are unavailable. The number of operating units is variously estimated as several hundred to a few thousand.

Apart from availability of wind, the potential market for irrigation is determined by three factors:

- adequacy of ground water
- lack of other (surface) water supplies
- suitability of soil for agriculture

Groundwater is available and adequate along parts of the North-West Coast; little is known about groundwater along the Red Sea.

Surface water is available only in a restricted locality west of Alexandria where the Nile canal exists; local topography restricts the area in which this water can be used. Essentially no surface water is available along the Red Sea Coast.

No information has been discovered regarding suitability of soils along the North-West and Red Sea Coasts for agriculture. Observations by the team indicate apparently good fertility when water is supplied.

All told, there may be a market potential along the North-West Coast for the installation of up to 5000 new units over the next 5-10 years (representing up to 15 MW, capable of irrigating up to 25,000 feddan). Market potential along the Red Sea Coast is speculative and likely to be considerably smaller.

Electric generation systems, of both small and large sizes, have a more uncertain potential. Their use would initially be restricted to remote villages and settlements, mines, and communication and military installation, along the North-West and Red Sea Coasts. Large systems may eventually be integrated with the grid or used for large remote loads in conjunction with conventional generating systems.

The size of the market for small systems may amount to 1000 units over the next 5 to 10 years, totalling perhaps 10 MWe. If large systems prove economically attractive for grid integration it is possible to envisage several hundred being deployed in Egypt by the year 2000 (roughly 500 to 1000 MWe).

In addition, a speculative potential exists for the use of windmills for desalination along the Red Sea Coast if goundwater proves to be inadequate. (This technology should be examined in conjunction with all other desalination technologies.)

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A.5 SOLAR REFRIGERATION AND COOLING

System Components and Principles of Operation

Several types of system are suitable for operation with solar energy,* including both active and passive types. The most promising are:

- Vapor cycle systems - flat plate collectors heat an organic fluid, vaporization takes place and this vapor is supplied to a reciprocating engine which drives the compressor of a refrigeration unit.

- Absorption type systems - the sun's rays strike a flat plate collector, directly or indirectly, causing refrigerant to vaporize. The vaporized refrigerant is recovered for recycling by absorption into a solution of the refrigerant and a salt. The low pressure of the expansion/vaporization region is maintained by the reduced vapor pressure of the refrigerant above the solution, and the vapor is regenerated by allowing the solution of refrigerant and absorbent to flow back into the generator where solar heat is supplied. This system is the more promising in the Egyptian context. It may operate on a continuous or intermittent basis. A typical system is shown in Figure A.5.

Output

Solar refrigeration systems may be built in a variety of sizes. A representative range is 4 to 20 kW; individual units may, of course, be combined to generate larger capacities. As an illustration of the relative size of units, the Jericho Fish Freezing Plant at Aswan has a combined total of 80 kW installed and can store up to 200 tonnes of frozen fish, with a normal throughput of 100 tonne/day.**

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*System may also be wind-powered.

**Data obtained by team visit.

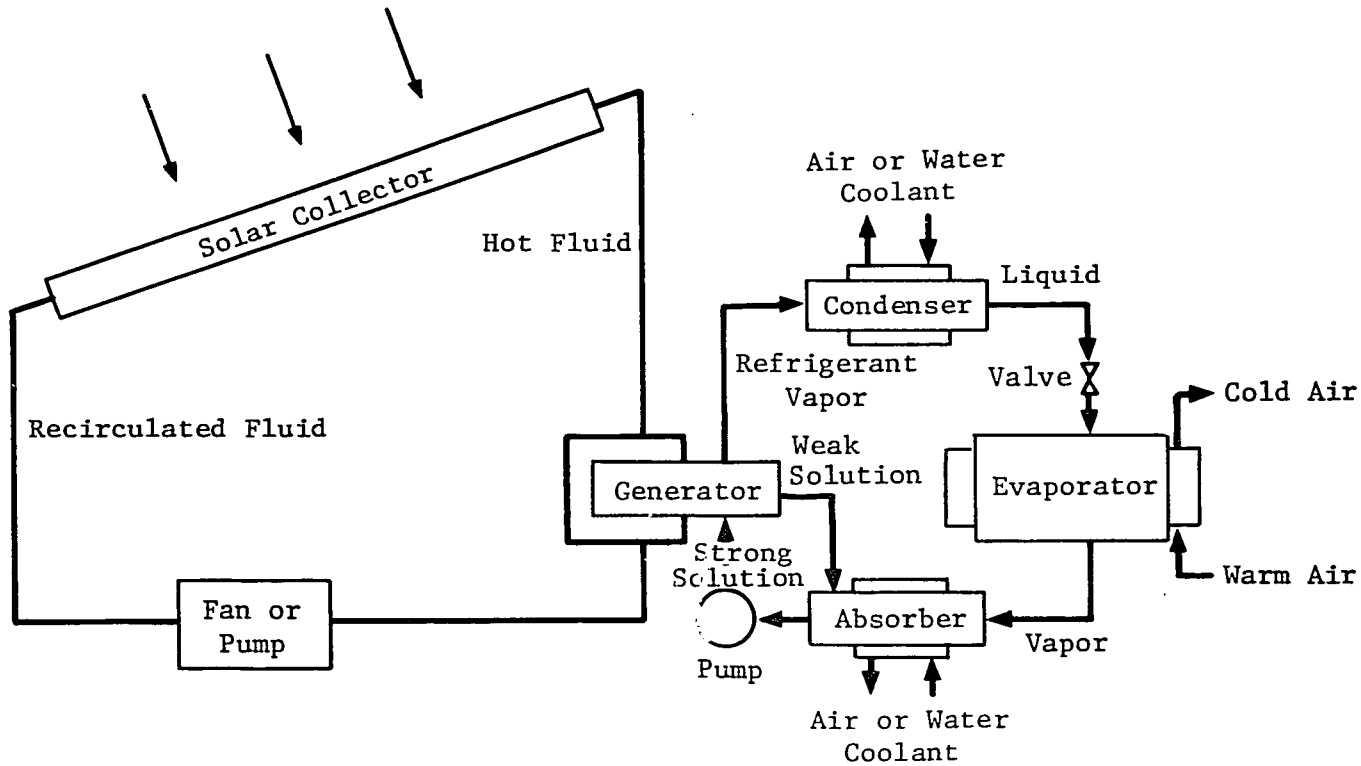

FIGURE A.5
DIAGRAM OF A SOLAR OPERATED ABSORPTION REFRIGERATION SYSTEM

Resource Requirements

Construction materials required include wood, sheet steel, aluminum, galvanized steel, glass, cement, and insulation materials, as well as pumps, valves, controllers, etc.

Environmental Impacts

Solar cooling and refrigeration is essentially benign at the point of use. This is especially true for passive systems. Active systems may suffer coolant leaks. Negative environmental impacts are associated with manufacture of the systems.

Social Impacts

Solar food refrigeration is a commercial enterprise which will be adopted or accepted due to its economic feasibility. Farmers are presently utilizing fossil or electric fueled cold storage supplied by the government or private industry. Expansion of the storage facilities will increase the availability of fresh vegetables and fruits (e.g., potatoes and onions) during off season, and also increase farmers' incomes by allowing them to increase production and sell this extra production over a longer period.

Climatization of buildings is an application which could have significant impacts in terms of improving comfort levels. However, this technology is likely to be confined to commercial buildings and the affluent middle-class, on cost grounds. Passive building design (see Appendix A.10) has more potential for helping the vast bulk of Egypt's population.

Costs

Costs are difficult to determine in the Egyptian context. Systems in the U.S. typically cost \$140 to \$170/m^2 (L. E. 100 to L. E. 120/m^2) or up to \$20,000/kW. The United States Department of Energy has estimated delivered energy cost from solar cooling and refrigeration systems at L. E. 4 to L. E. 5/10^9J.(1)

Competing systems are:

- passive building design for climate control.
- fossil fuel or electric refrigeration systems.

Current fees are 2% of the market value of the crop for government systems, and L. E. 15-20/tonne/month for cold storage and L. E. 35-40 for freezing.

Balance of Payments Impact

This will be somewhat negative initially, due to a certain proportion of imported parts in the systems. The eventual balance will probably be positive, because of substitution for fossil fuels, either directly or via electricity from fossil-fired power stations.

Development Status

This technology is in a development stage in the U.S., with some systems in operation in Egypt, R&D capability exists at the National Research Center. Theoretical work on solar absorption refrigeration for small (household size) units has been continuing since 1973.

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(1)GOE/DOE Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment, Vol. IV, 1979.

Design capabilities also exist at the Ministry of Energy. The collector plates for solar refrigeration systems can be made almost entirely in Egypt, since they are closely similar to the collectors for domestic hot water applications which are now being produced in Egypt. Other components might have to be imported.

No production, distribution or maintenance infrastructure exists in Egypt at present.

Other donor nations are active as follows:

- France - the Conseil National de Resherche Scientifique has initiated a project at Aswan using a 10 kw SOFRETES motor to power a vapor compression 6-day refrigeration unit for fish preservation.

- Federal Republic of Germany - Ministry for Research and Technology has built an absorption refrigeration unit at the Solar Energy Lab, of the National Research Center. This unit utilizes Dornier heat pipes to transfer heat from the absorber plate to the refrigerant vapor generator.

- Federal Republic of Germany - currently designing a 30 room central air conditioning system for El Maadi Hospital. Equipment selection to be completed by November 1979.

These programs do not as yet add up to a significant foreign effort in this area. Their immediate potential impact is small. It is not known how they will develop in the future, but it is clear that ample scope is left for USAID assistance.

Market Potential

Egypt has some 250,000 tons of cold storage or freezing capacity, about 2/3 privately owned. This is inadequate to meet

demand, and new facilities are being planned. Produce stored includes fish, vegetables, milk and milk products, and poultry.

The potential is significant in those farming areas which supply year round fresh vegetables and fruits to the larger cities. As an example, Sandyan Village, some 30 km to the north of Cairo has 4 government cold storage warehouses, each capable of storing several hundred tonnes of produce. There appears to be less potential for cold storage warehouses in rural areas more remote from cities, because refrigeration during transportation would also have to be considered, adding considerably to the cost of the produce.

In particular, there is good potential for added fish freezing capacity at several locations, particularly along the Red Sea Coast. Fishery in the Red Sea is felt to be very underdeveloped because of the lack of population along the littoral. Most fishing takes place in the gulf of Suez and hardly any in the Red Sea proper. If this potential were developed, several new facilities would be required. Some prospects also exist along the Mediterranean Coast. Again, refrigeration during transportation must be considered.

The potential market for space climatization systems will probably remain in the hotel sector for the short and medium term. Most older large buildings, if not subsequently broken up by interior partitions allow cooling air cross-currents. Newer building designs have lost many of the traditional passive climate control techniques.

A significant impact of passive cooling design into this sector would reduce the potential for active cooling systems.

The private domestic sector also offers a significant market for household sized solar air conditioning systems. However, this market is affluent, and urban, and is probably not the intended recipient of USAID programs.

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A.6 PHOTOVOLTAIC REMOTE APPLICATIONS

System Components and Principles of Operation. Photovoltaic cells consist of a thin p-type and a thin n-type semiconductor crystal (usually silicon) bonded together (see Figure A.6). They convert incident light radiation to electricity in the following way: photons (i.e., light) strike the collector panels and are absorbed into silicon molecules. In so doing, the photons energize electrons in the outer (valence) bands of the n-type silicon crystals (i.e., silicon crystals containing phosphorous atoms). As the electrons accelerate, electrons in each n-type crystal leave the valence band and cross the junction between n-type and p-type crystals (i.e., silicon crystals containing boron atoms). This free movement of electrons creates a direct current, which is produced in amounts proportional to the amount of incident light. Hence storage batteries and/or power conditioning equipment (inverters and transformers) are required for many applications.

Output. Photovoltaic cells are completely modular, and hence any desired level of output may be achieved by the use of enough collector area. Because of their high costs (see below), photovoltaic cells have been limited to low-power applications in locations where other electricity supplies are unavailable or expensive. For the applications considered here the following outputs are necessary:

- Clinics require 1 to 2 kW peak for refrigeration and lighting.
- Communication units generally need about 1 kW peak.

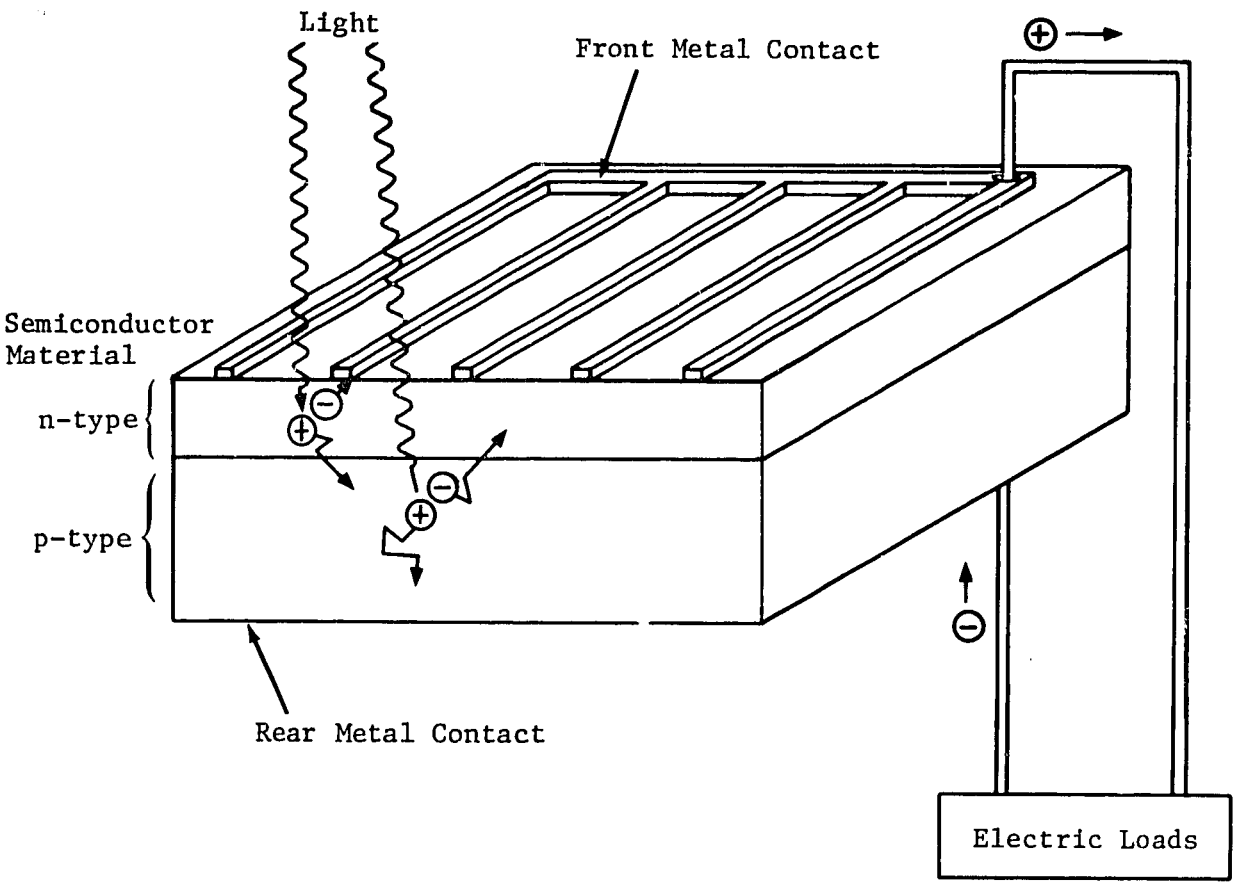

FIGURE A.6
TYPICAL PHOTOVOLTAIC DEVICE

- Water pumping requires 4 to 6 kW peak.

The output of photovoltaic cells is, of course, highly dependent upon the incident solar radiation and as such reaches a peak at local noon under normal conditions. Effective output is usually concentrated in 6-10 hours of the day. Array power is usually specified in terms of the peak output.

Resource Requirements. Manufacture of photovoltaic cells and ancillary equipment requires steel, glass, batteries, electronic power conditioning equipment and controls.

For pumping installations, there may be some conflict between the use of ground area for the photovoltaic cell array and for crop production. A 5-kW peak array operating at 10 percent efficiency would cover an area of about 25 m^2, excluding supports, etc.*

Environmental Impacts. Photovoltaic cells have no known negative environmental impacts at the point of use. Replacement of fossil-fired pumps or generators would have a beneficial environmental effect.

Some negative impacts are associated with the manufacture of photovoltaic cells.

Social Impacts. Provision of electricity at remote clinics could have significant health benefits. Communication and film projection

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*Based upon maximum solar radiation intensity of 2 kW/m^2; see The MITRE Corporation, Systems Descriptions and Engineering Costs for Solar-Related Technologies, Vol. VIII, MTR-7485, 1977.[19]

or TV uses contribute to broadening of village and personal activities, including education and leisure. Eventual use in water pumping for irrigation could enable increased crop production and expansion of cultivated lands. This would raise rural incomes, reduce food imports, and alleviate population pressures.

Costs. Present real capital costs are high: L.E. 10,600 per kilowatt peak installed with storage but U.S. Department of Energy cost estimates for 1985 put the cost at L.E. 1,800/kW peak installed with storage. The likelihood of further reductions is low.[25] Real O&M costs amount annually to only 1 percent of capital cost. Based on 10-year equipment lifetimes, calculated electricity costs range from L.E. 0.6 to L.E. 0.9/kWh presently and are projected to range from L.E. 0.09 to L.E. 0.15/kWh by 1985. (It should be observed that the decline in cost experienced to date is consistent with DOE forecasts.) Diesel electric power, the main competitor of photovoltaics for remote applications, now costs L.E. 0.06/kWh (real or world price) or L.E. 0.02/kWh (local or subsidized price). Real costs in 1985 may be as much as 50 percent higher while local costs could rise by an even greater percentage if subsidies were reduced or eliminated.

Balance of Payments Impact. Since manufacture of photovoltaic cells is a high-technology capital-intensive process, it is likely that

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[25] Moore, Cost Predictions for Photovoltaic Energy Sources, Photovoltaic Conversion Research Program Review. Philadelphia, PA, Dec. 16, 1974.

these components will be imported (although the final assembly of the cells may take place in Egypt), together with much of the power conditioning, storage, and control devices. Therefore, the initial Balance of Payments impacts would be heavily negative. Until the prices of photovoltaic cells come down, it is unlikely that this negative impact would be balanced by subsequent fuel savings (a 1 kW peak array costing L.E. 10,000 at present would replace about 6 barrels of diesel fuel a year, worth L.E. 150 on the World Market). As photovoltaic system prices decline, and fossil fuel prices increase, the situation will become more favorable to the photovoltaics.

Development Status. No research and development capacity currently exists in Egypt concerning photovoltaic cell production or use. Some familiarization exists with use of the technology in various locations in Egypt. However, all solar cell applications identified by the team can best be described as small and peripheral at present.

Foreign donor activities identified comprise:

- Federal Republic of Germany - for 8 different applications. Viz: 2 pumps (drinking and irrigating water), water desalination, loud speaker, refrigeration, lighting.
- France - for 2 television sets in a village.

Neither of these activities have had any significant impacts as yet. Although the future development of these countries' programs is not known, it appears that ample scope for USAID involvement remains.

Market Potential. The following market elements have been identified:

- Refrigeration at remote clinics (200 units).
- Communications in remote areas (900 units).
- Television and lighting (1600 units).
- Water pumping from rural canals (400,000 units). This application is totally uncompetitive in cost terms at present.
- Water desalination using vapor compression or reverse osmosis (unknown potential).

These represent a total potential market of up to 3,000 units, comprising up to 4,000 MW_e, or 400,000 units, comprising up to 2,000 MW if currently uneconomic pumping applications [26] are excluded.

Based on present prices, only remote clinic refrigeration appears fully justifiable in general on the grounds of health benefits - improved refrigeration would enable a larger supply of vaccines and drugs to be kept. Communications and TV may be justifiable in selected areas. Areas where remote clinics are to be found include the Eastern and Western Deserts, the Red Sea Coast and parts of the North West Coast. Such clinics may also be found in the Sinai.

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[26] French, Dr. D., op. cit., 1979.

A.7 SOLAR COOKING

System Components. Solar cookers generally use arrangements of plane or curved mirrors to concentrate the sun's rays on an exposed cooking pot or oven. The oven, if used, is usually double or triple glazed on the side exposed to the focussed rays. In some designs, a fluid or solid is heated at the focus of the mirrors, and is manually or automatically transported to a separate cooking unit. Temperatures up to 200°C are easily obtainable, but constant tracking of the sun is necessary to keep the rays focussed. Other designs use triple glazed flat plate collectors to heat water and cook food in a double boiler arrangement. These types need adjustment only twice a day and are little affected by occasional clouds. They cook foods very slowly, however, because temperatures in the pot remain below boiling.

Output. The thermal output of a solar cooker is highly variable, but an order of magnitude estimate is 1 to 2 kW peak.

Resource Requirements. Construction materials for this technology include: glass, steel, aluminum, insulation, and wood. With the possible exception of tempered glass, all of these are now available in Egypt and the manufacturing capability exists in numerous local workshops such as the Alometal Company, the Egyptian Copper Company, and Military Workshop 99 (all in Alexandria). The Government Workshop Production Center in Aswan has manufactured two cookers. As to glass, the Egyptian Glass and Crystal Company is installing new productive capacity and will soon be able to provide tempered glass.

Environmental Impact. Application of this technology would have positive impacts on the environment. To the extent that solar cookers displace the combustion of wood, straw, or dung, their use will reduce particulate concentrations, particularly inside homes.

Social Impact. Cooking uses by far the largest proportion of rural energy demand in Egypt. In villages near Cairo, an average household burns 1200 kg of dried dung, 300 kg of butagas and 840 litres of kerosene annually.* Solar cookers offer a potential alternative; however, as currently designed, solar cookers would conflict with Egyptian cooking habits.(20) This is a significant consideration because the greater the required deviation from cultural norms, the greater the resistance to using solar cookers. Critical factors in this regard include: the ability to cook at a comfortable elevation, the ability to control heat supply, the ability to cook inside or outside (in the shade), the ability to impart flavors from traditional cooking fuels, and the ability to cook in a variety of modes (i.e., fry, bake, boil, broil, and simmer).

Costs. If manufactured locally, solar cookers would cost about L.E. 60 to L.E. 140 per unit. Assuming annual operating and maintenance costs are 5 percent of capital costs and the life of the equipment is 10 years, this technology will supply heat for a cost of about L.E. 2 to L.E. 13 per 10^9 joules. By comparison, the price-controlled

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*Team survey.

(20)T.E. Bowman, op. cit., 1979.

fuels against which solar cookers would compete are: butagas (L.E. $1/10^9$ joules), and kerosene (L.E. $0.5/10^9$ joules). Other fuel alternatives include animal dung (L.E. $0.5/10^9$ joules), and crop residues (L.E. $0.5/10^9$ joules). These latter noncommercial fuels are not price-controlled although their prices are, of course, partially determined by the controlled prices of kerosene and butagas. The world-market price of butagas is about L.E. $9/10^9$ joules, and of kerosene is about L.E. $4/10^9$ joules.

Balance of Payments Impact. Application of this technology would have a small positive impact on Egypt's balance of payments position. We expect the cookers would be manufactured in Egypt, and would have greatest impact on the use of noncommercial fuels (i.e., dung and crop residues), although some substitution for butagas and kerosene would take place, releasing more of these fuels for export.

Development Status. Although solar cookers have been under development for at least two decades, they have not yet achieved commercial availability. The essential problem, as indicated above, is that solar cookers conflict too greatly with established rural lifestyles. In 1962, solar cookers were introduced along the southern Red Sea coast, but failed completely to win social acceptance. More recently, in June/July 1979, the international development agency, CARE, installed two solar cookers near Aswan.* The results have not

*Team visit.

yet been obtained from that project. In addition, some private individuals have maintained a hobby-type interest in solar cooking, most notably Engineer Sawab Sabri of UNDP in Cairo, who has made several cookers over the last 15 years. If solar cooking is ever to achieve commercial acceptance in Egypt, additional R&D will be needed to adapt existing designs to local Egyptian conditions. In particular, research is needed in the area of materials substitution. The Egyptian government is not presently conducting any R&D involving solar cooking technology, and the other activities taking place in this area do not represent a significant program.

Market Potential. We see no significant market for solar cooking technology in Egypt over the near to mid-term. Although cooking does account for the greatest portion of rural energy use in Egypt, past experience has shown that families will probably continue to use commercial fuels or dung and crop residues for this purpose. Solar cookers simply require the user to change his cooking habits too much. If there is any market for this technology at all, it is among organized temporary communities, such as military camps, mining and construction crews, or the boy scouts, and perhaps vacation resorts along the Mediterranean or Red Sea Coasts.

Discussion. We did not proceed further with solar cooking, since we regarded it as having poor potential on the basis of demonstrated resistance to this technology among rural users.

A.8 SOLAR DESALINATION

System Components. The typical solar desalination system is a still, consisting of a shallow, cement-lined basin covered with a sloped glass roof. The unit is usually so constructed that the central holding basin is framed on two sides by separate collection gutters.

Principles of Operation. Sunlight penetrates the glass roof and heats salt water in the central basin. The water evaporates and condenses on the glass roof. Since the roof is sloped, condensed fresh water runs down the roof and collects in the gutters on either side of the main basin.

Output. This technology is modular, i.e., there are no economies of scale. Depending on basin area, stills can produce from 10-80 liters per day (suitable for a single family), up to as much as 50,000 liters per day (for a small community).

Resource Requirements. Construction materials include: cement, glass, paint, and sealant (i.e., oil-based putty). Significant land areas may be required, because solar stills use a basin area of about one square meter for each 3.5 liters of freshwater produced daily. A supply of saline water is also needed.

Environmental Impact. The only significant environmental effects of this technology involve the concentrated brine effluent which is left behind after the freshwater has been evaporated off. For coastal areas, disposal is simply a matter of returning the brine to the sea. For inland areas, however, contamination of groundwater is a

potential problem. Brine-effluent can be eliminated by producing salt as a byproduct of desalination.

Social Impact. Solar desalination will benefit remote communities by providing reliable supplies of freshwater. Constant water supplies would stabilize nomadic groups, and might allow for the cultivation of certain high-value crops.

Cost. Solar desalination technology can be installed for about L.E. 10 to L.E. 20 per square meter of roof area. Average outputs are 2-4 liter/day/m^2.[18] Assuming that annual operating and maintenance costs total 5 percent of capital costs, and that the equipment will last 10 years, this technology then costs about L.E. 3.7 to L.E. 7.4 per liter per day, and can provide freshwater for about L.E. 0.002 to L.E. 0.005 per liter.

Balance of Payments Impact. Because solar stills could be constructed entirely in Egypt, their immediate balance of payments effects would be negligible. Over the long-term, solar stills may exert a positive influence on Egypt's balance of payments situation, by displacing fossil fuels which might otherwise be used for desalination or freshwater transportation.

Development Status. This is a simple, fully proven technology. R&D capability exists at the National Research Center in Cairo, which has been involved in solar still research since 1961. Also, personnel familiar with the construction and maintenance of solar stills are

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(18) National Academy of Sciences, Energy for Rural Development, 1976.

already available in Egypt. However, no field work in solar distillation has been undertaken in Egypt.

Market Potential. The demand for additional freshwater in Egypt is projected to total about 1 million liters per day by 1985. Solar desalination units could supply a large portion of this demand by providing water to several hundred communities of less than 2000 persons with access to saline water, as indicated below:

- Sinai & Red Sea Coast -- about 100 communities
- Northern Baheira Governate -- about 60 communities
- Eastern & Western Deserts -- about 20-100 communities
- Nomadic Bedouin Groups who may be willing to settle if offered secure water -- about 50-300 communities

The economic feasibility of such applications is unknown, however, because the cost of this technology relative to other water supply options has not been established.

Discussion. This technology was not selected for further analysis. We feel that a comprehensive review of all desalination methods and of alternative methods of obtaining fresh water (e.g., deep wells, pipelines from the Nile) must be undertaken before particular technologies can be recommended. Since freshwater supply is likely to be a crucial constraint on Egypt's efforts to develop its empty deserts and littorals, such a study should be undertaken as a matter of priority (see Section 10.3 of the main body of the report).

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A.9 CENTRAL-RECEIVER SOLAR THERMAL ELECTRIC GENERATION

System Components. Solar thermal power generation represents a new, untried technology - so it is impossible to speak in terms of a "typical" system. The "power tower" conceptual design being developed by the U.S. Department of Energy (DOE) consists of: a bank of heliostats (tracking mirrors), a 750-foot high receiver tower, a steam boiler located on top of the tower, a conventional turbogenerator located on the ground and connected to the boiler via steam lines (pipes), a dry cooling tower, and a pump to return condensed water from the cooling tower to the boiler.* The design also includes a master computer and a series of microprocessors which control the heliostats' elevation and azimuth tracking to ensure optimum heating conditions at the boiler. The U.S. design contains a thermal storage subsystem as well, but our description assumes the system operates without storage.

Principles of Operation. Sunlight strikes the heliostats and is reflected and concentrated onto the boiler on top of the receiver tower. Water circulating through the boiler is converted to steam, and is piped to the turbogenerator. Steam leaving the turbogenerator is condensed and pumped back to the boiler.

Output. The DOE design is for a pilot plant producing about 10 MW_e. Commercial-scale plants are envisioned in the 100 MW_e range. Such plants would likely have to be integrated into the

*See McDonnell-Douglas Company design.

Egyptian grid, as no isolated load centers approaching 100 MWe exist in Egypt.

Resource Requirements. Construction materials include: aluminum, concrete, copper, steel, glass, insulation, plastic, small amounts of chrome and titanium, and very small amounts of silver. Land is also a major requirement. A 10 MW_e plant in Egypt would require about 50 acres.

Environmental Impact. While solar thermal generating facilities are not expected to produce significant air, water, or solid waste pollution, large scale plants may effect the environment through thermal releases, glare, and certain land use effects (e.g., alterations in reflectivity, absorptivity, and emissivity). Such land use effects are highly speculative and will not be understood until actual operating experience is available, however it is likely that only unproductive land would be used for siting such plants. Overhead power transmission lines may have a negative visual impact.

Social Impact. The introduction of this technology is expected to produce positive social impacts in Egypt. Economic benefits will accrue as increased electrical supply encourages small commercial enterprises and industrial growth. Social development will also be stimulated, as electrification of villages improves health standards and enhances educational activities.

Cost. Solar thermal generating systems are estimated to cost $1300 to $2500 per kW_e of installed capacity in 1980 dollars, excluding

storage.[19] Costs in Egypt are likely to be much higher, because of transportation and the difficulties of construction in a remote area without infrastructure. A cost of L.E. 2000 to L.E. 4000 per kW_e in Egypt has been assumed. The electricity produced by such a system would cost about L.E. 0.07 to L.E. 0.26 per kilowatt-hour based on a 30-year plant life, and 1.5 percent O&M costs (both favorable assumptions). This latter price compares unfavorably with marginal generating costs on the existing Egyptian grid of L.E. 0.002 to L.E. 0.030 per kilowatt-hour. If subsidies were removed and the cost of electricity in Egypt reflected world oil prices, solar thermal generation would still appear to be rather uneconomic: marginal grid prices would then be L.E. 0.013 to L.E. 0.047 per kilowatt-hour.[17]

Balance of Payments Impact. The balance of payments effects of widespread deployment of this technology would be highly negative, due to the high capital cost of the plant, and the fact that at least 60 percent of the plants would have to be imported. The effects would be softened by the fact that a grid-integrated 10 MW_e solar thermal plant would displace an estimated 70,000 barrels of oil per year, worth at least L.E. 1.4 million. As far as electrification of remote areas is concerned, electrification usually acts mainly to augment the energy supply and usage system, rather than substituting for particular fuels.

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[19] MITRE Corporation, op. cit., Vol. V.

[17] Egyptian Electricity Authority, op. cit.

Development Status. While some solar thermal R&D work has been undertaken in Europe, the largest solar thermal generating plant currently in existence is the 10 MW_e pilot plant currently under construction by the DOE at Barstow, California. That facility is scheduled to begin operating in 1982.

The National Science Foundation is funding a joint project in solar power between the National Research Center in Cairo and the University of New Mexico. The N.R.C. team could act as a focal point for future developments and for monitoring and evaluating U.S. experience.

Discussion. This technology may have considerable potential for Egypt, because of that country's excellent insolation. However, the immature state of the technology, and the resulting cost uncertainties, indicate that a decision should be deferred until U.S. operating experience is available, and until projected costs are more competitive.

A.10 PASSIVE SOLAR ARCHITECTURE

System Components. Passive heating and cooling systems make use of natural thermal "sinks" (such as large volumes of water, or large concrete masses), and natural convection and ventilation to moderate temperature changes in living and working spaces. Among the components frequently incorporated into passive designs are: dense walls for high thermal capacity (i.e., the ability to store heat or the lack of heat); water ponds mounted on the roof, to store daytime solar heat in winter and nighttime coolness in summer; windows oriented to the south to permit maximum exposure to sunlight during winter months coupled with overhangs on all south-facing windows to shade out sunlight during summer months; cross ventilation to allow for heat exhaust during warm summer months; and adequate wall insulation to retard heat loss during cold months.

Principles of Operation. In the Egyptian context, cooling in summer is more important than heating in winter. Window overhangs and shades, and a low ratio of window area to wall area prevent entry of summer sun, while high arched or domed ceilings with carefully placed vents allow hot air to rise and escape. Thick walls provide thermal insulation.

Outputs. The exact energy value of the heating and cooling supplied cannot be quantified, but will vary according to system size, location, design, etc.

Resource Requirements. Passive solar development will require architects and engineers, building inspectors, and house builders with

solar-related skills and experience. The technology will not impose any requirements for new or unusual construction materials, since passive solar components can be fabricated out of conventional Egyptian building materials (e.g., concrete, glass, brick, and mud). Demands for insulation may be increased, however.

Social Impacts. Improved comfort without the use of energy-intensive heating and cooling devices. No changes will be required in construction materials and methods, so that social acceptability should be high.

Costs. If passive cooling techniques are integrated into the design of new buildings, the real cost of passive systems is very low; probably the lowest of any renewable technology considered in this study. Exact costs cannot be computed, but will depend on building design.

Balance of Payments Impact. The net balance of payments effect should be positive, since passive systems can displace the use of petroleum, and be built entirely in Egypt.

Development Status. Traditional Egyptian housing designs incorporate a number of passive cooling features which have not been carried over into more modern designs. Official Egyptian R&D capability in this area appears limited to Hussan Fathy, an architect who is testing and experimenting with ten passively cooled test cells at the National Research Center. In the 1940s Fathy designed Gourna Village to make use of certain passive techniques. The team also met Professor

Arussin, a civil engineer who has been involved in passive design for about 25 years. Arussin has developed a composite insulation material made of rice husks which was used in a resettlement project near the Aswan Dam and in his own house in Maadi, Cairo. The American University in Cairo has also done some preliminary work in this area and CARE has constructed two prototype passively-cooled dwellings at Aswan.

However, current Egyptian housing designs inspected by the team sponsored desert settlements show limited sensitivity to the resident's comfort. Walls and roofs are inadequately insulated, ceilings are low, orientation is haphazard, and little thought is given to ventilation. (Several settlers interviewed by the team had modified their houses by raising the roof 2 to 4 feet, blocking windows, and other methods.) Although more modern designs are better than earlier ones, a great potential remains untapped in this area.

Market Potential. Because of the climate, the demand for space heating is relatively soft in Egypt. Space cooling, however, is very much in demand. Every new building in Egypt is potentially part of the market for passive solar heating and cooling. In new cities alone, construction is expected at the average rate of 4000 units per year through 1985, then 17,000 per year to the year 2000, and the total demand for new housing by 2000 will exceed 4 million units.

Discussion. Passive solar architecture has excellent prospects in the long term for increasing the comfort levels of Egyptian houses

and work places without excessive use of fossil fuels or electricity. However, the GOE is not planning to conduct a program in this area in the near term. In addition, USAID has informally expressed reluctance to become involved.

A.11 IMPROVED RURAL STOVES

System Components. Simple but effective stoves and ovens can be made using readily available materials such as mud, clay, brick and a limited amount of metal.

Principles of Operation. Combustion of agricultural residues and animal wastes takes place in an enclosed stove with controllable draft. The thermal efficiency of these stoves may be 20 percent, compared with 5-10 percent attainable with the simple stoves or open fires now used in rural Egypt.

Output. We have estimated that a dung-fueled stove supplies about 1-2 kW peak.

Resource Requirements. The deployment of improved stoves is not constrained by any significant resource requirements. The stoves can be made of mud, clay, brick and metal.

Environmental Impact. Application of this technology will improve air quality inside rural homes by reducing the amount of smoke released by the kitchen fire. Land quality will be improved by the availability of more manure for fertilizing and soil conditioning. There are no adverse environmental impacts associated with this technology.

Social Impact. By improving the efficiency of dung combustion, improved rural stoves would benefit rural society in three ways: (1) rural families would spend less time collecting dung; (2) less dung would have to be burned for the same heat output -- so more will

be available for use on the land; (3) jobs will be created building stoves. Social acceptance should be good since the stoves will provide heat in the customary way, requiring little or no changes in domestic or culinary habits.

Costs. Improved stoves are estimated to cost L.E. 10-20 per unit, with negligible operation and maintenance costs.* The energy supplied by these stoves is estimated to cost less than L.E. 1 to L.E. 1.8 per 10^9 J. This is competitive with the current local prices of fuels used in cooking and water heating.

Balance of Payments Impact. Since this technology would use entirely local, noncritical resources, the balance of payments effects would be negligible.

Development Status. Many simple but effective designs have been developed (e.g. by VISTA). No Egyptian R&D or other activity is known in this area. Widespread distribution of this technology would require the training of many local people to make and use these stoves. In addition, loan or grant programs might be needed to help the poorest afford these stoves.

Market Potential. The potential users comprise some 1.6 million rural families who use noncommercial energy for cooking and water heating (an estimated 40 percent of the total rural population of 4 million families). If 25 percent successfully adopted the stoves

*Team estimate.

(i.e., 400,000 families), potential energy savings lie in the range 4 to 10 QJ/yr.

Discussion. This is a low-technology area. The GOE may be in a better position to pursue development on its own, and USAID has informally expressed reluctance to become involved. However, a high potential for improving the lives of the rural poor appears to exist here.

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A.12 COMPOSTING OF MUNICIPAL SOLID WASTE

System Components. Composting plants typically handle about 500 tonnes per day of refuse.

Principles of Operation. Municipal solid waste collected in Cairo and other Egyptian cities contains a high proportion of organic matter. Under controlled conditions this can be rapidly converted to compost for soil conditioning and fertilization.

Output. Composting technology produces soil conditioner/fertilizer, not energy. A facility handling 500 tonnes per day of refuse would produce about 245 tonnes per day of compost.

Resource Requirements. Land area and water are the only critical resource required for this technology.

Environmental Impact. Application of this technology will produce some air emissions in the form of particulates and hydrocarbons from municipal waste collection trucks, and possibly some odor releases. Water-borne releases may be produced by runoff and leaching from the compost pile. Also, the composting site may attract flies.

Social Impact. Composting operations will benefit society in two important ways: (1) sanitary conditions will improve as presently uncollected garbage is removed from city streets; (2) the agricultural use of compost will improve crop yields, and so improve food supply. A further consideration is that the availability of compost will release dung and crop residues for use as fuel and fodder.

Finally, composting will generate employment in MSW collection and compost processing and distribution operations.

Costs. Composting facilities would vary in cost, depending on the sophistication of the technology used. Capital costs are projected to range from L.E. 9300 per daily tonne of input capacity for high technology facilities, to L.E. 3400 per daily tonne of input capacity for intermediate technology. Operating and maintenance (O&M) costs are estimated to be L.E. 250,000 per year for a high technology plant of this size, or L.E. 155,000 per year for a plant using intermediate technology.[27] Equipment lifetime is assumed to be 20 years. This technology yields compost at a cost of about L.E. 4 to L.E. 5 per ton.

Balance of Payments Impact. The balance of payments effect of this technology will probably be negative. About 60 to 70 percent of the capital costs of the composting facility represents components and/or materials which must be imported.

Development Status. Composting technology is commercially available in Europe. The World Bank is funding a co-operative program in Egypt with the following schedule:

1980	10 tpd pilot plant
1981-82	200 tpd demonstration plant
1985	500 tpd commercial plant

(27) World Bank, Arab Republic of Egypt Urban Development Project Manual, Solid Waste Management in Cairo and Alexandria, 1978.

About 100 extra collection trucks will be required to gather the 800 tpd of refuse currently uncollected and left to rot on the streets.

Market Potential. The market potential for this technology is very good. Cairo generates about 4200 tonnes per day of MSW, of which about 1500 tonnes per day is already recycled by some 15,000 "Zebaleen," who make their living from this activity.(27) The remaining 2700 tonnes per day (of which 1900 tonnes is currently collected) could support five facilities of the size described above, and would produce enough compost for at least 80,000 acres of farm land. This technology is favored by the fact that Egyptian government policy strongly supports the use of MSW to replenish agricultural lands, which no longer benefit from the (heretofore) annual fertilization by the floods of the Nile River.

Discussion. This is, strictly speaking, not an energy option, although it uses a feedstock with high energy content, namely MSW. It appears to be the preferred use for MSW. A co-operative program involving the World Bank and Egyptian authorities is under way; therefore no USAID involvement appears called for.

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(27) Ibid.

A.13 COMBUSTION OF MUNICIPAL SOLID WASTE

System Components. Furnace, boiler and conventional steam turbine electric generator. Pre-processing of waste would be required (e.g. shredding).

Principles of Operation. Combustion of MSW boils water, and the steam drives a turbine-generator unit.

Output. A plant burning 2700 tonnes per day of municipal solid waste (MSW) will produce about 45 MW_e.

Resource Requirements. Assuming that most of the components used in this technology would have to be imported, major resource requirements would be limited to: capital, trained personnel and water supply. Capital investments would include about 100 additional refuse collection trucks.

Environmental Impact. Aside from impacts produced during construction (e.g., construction vehicle emissions, runoff from land), application of this technology would result in particulate emissions (from the plant itself and the MSW collection trucks) and hydrocarbon emissions (from the MSW collection trucks). In addition, the plant would separate ferrous metals for recycling, and would produce bottom ash and nonferrous heavy solids for landfill disposal.

Social Impact. MSW combustion plants would benefit society by increasing electrical supplies and reducing the health problems associated with uncollected garbage. (In the Cairo area, about 800 tonnes of garbage are now left on the streets each day.)

Costs. MSW combustion plants are estimated to cost about L.E. 20,000 per daily ton of input capacity. Operation and maintenance costs would be about 4 percent of capital costs, or L.E. 800 per daily ton of input capacity.* Plant life is assumed to be 20 years. Electricity from such a plant would cost about L.E. 0.02 to L.E. 0.03 per kilowatt-hour. For purposes of comparison, marginal generation on the Egyptian grid costs about L.E. 0.0020 to L.E. 0.0303 at currently subsidized prices; or L.E. 0.0131 to L.E. 0.0472 at world oil equivalent prices.(17)

Balance of Payments Impact. Over the near-term, application of this technology would produce negative balance of payments effects, since most essential components would have to be imported. Over the mid-term, however, the effects would be positive. Since a 45 MW_e MSW-fired generating plant would displace about 500,000 barrels of oil equivalent per year, worth at least L.E. 10 million (about $14 million), the technology would essentially pay for itself in 5 to 7 years. After this time, it would contribute toward a positive balance on current account.

Market Potential. The Cairo area generates about 4200 tpd of MSW; about 1500 tpd is collected and recycled by 15,000 "Zebaleen" who make their living by this activity.(27) The remaining 2700 tpd

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*Internal MITRE communication.

(17)Egyptian Electricity Authority, op. cit.

(27)World Bank, op. cit.

would support 45 MW_e of electric generation. At present 1900 tpd is collected and 800 tpd left to rot. 45 MW_e does not represent a significant addition to the approximately 900 MW_e fossil-fired capacity near Cairo.[17]

Under present government policies, there is no significant market for this technology in Egypt. Instead of burning MSW, the Egyptian government is attempting to recycle the material to improve the productivity of agricultural lands. Since completion of the Aswan Dam, Egyptian farmlands are not replenished by the silt of the Nile. For this reason, MSW is far more valuable to Egypt as a fertilizer than as an energy resource.

Discussion. MSW combustion technology was not selected for further analysis because of firm Egyptian opposition to the use of this technology.

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[17] Egyptian Electricity Authority, op. cit.

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A.14 ANAEROBIC DIGESTION OF MUNICIPAL SOLID WASTE

System Components. MSW handling and sorting equipment, digestion tanks, gas treatment equipment.

Principles of Operation. MSW can be broken down anaerobically (i.e. in the absence of oxygen) by bacterial action, releasing methane gas. A nutrient-rich sludge is left.

Output. A conversion facility which handles 500 tonnes per day of municipal solid waste (MSW) will produce about 13×10^6 standard cubic feet per day of synthetic fuel gas with a heating value of 500 Btu per standard cubic foot.[28] In terms of metric units, this equals about 6.8×10^{11} joules per day. The plant will also produce about 200 tonnes per day of effluent which can be used as a fertilizer and soil conditioner.

Resource Requirements. Some components will be imported. Local construction materials will include concrete and steel. This technology also requires approximately equal quantities of water. Furthermore, trained technicians would be needed for plant operation and maintenance.

Environmental Impact. Minor environmental impacts will be produced during construction, resulting from land use effects (runoff) and the operation of construction equipment (hydrocarbon/particulate emissions). Plant operation will require increased truck traffic, which will increase vehicle-related emissions.

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(28) Jones, J.L., Evaluation of the Proposed "Bio-gas" Project at Lamar, Colorado, U.S. Department of Energy, TID-29306, 1978.

Social Impact. The application of this technology would produce major social benefits in terms of improved health standards, increased food supply, and increased energy supply. The collection and use of garbage which would otherwise remain on city streets would, in the first instance, remove a major source of disease. Secondly, the effluent sludge produced in the conversion process contains many essential plant nutrients, so spreading the effluent onto arable land would increase crop yields or decrease demand for other fertilizers. Finally, the technology will produce a high-quality synthetic fuel, usable in virtually any application.

Costs. The cost of a conversion plant of the type described above is estimated to be about L.E. 22,000 per ton of daily input capacity.[28] Operating and maintenance costs are estimated to be about 4 percent of capital cost, or about L.E. 880 per year per ton of capacity. The plant lifetime is assumed to be 20 years, and the value of the slurry is L.E. 2/tonne. These costs translate into an energy supply costing about L.E. 5 to 9 per 10^9 joules; however, this estimate does not consider the cost of a distribution system (i.e., pipeline) which would at present be needed to distribute the gas. For purposes of comparison, petroleum costing L.E. 20 per barrel costs about L.E. 3.3 per 10^9 joules.

Balance of Payments Impact. Application of this technology would produce an initial negative balance of payment effects because waste collection trucks and many vital components of the conversion plant

(28) Ibid.

would have to be imported. The production of fuel gas and fertilizer would offset these negative effects in later years.

Market Potential. The Cairo area generates about 4200 tpd of refuse. About 1500 tpd is recycled by 15,000 "Zebaleen," who make their living from this activity. Of the remaining 2700 tpd, about 1900 tpd is collected and 800 tpd left to rot.[27]

At present, Cairo has no distribution system for piped gas. Most people use butagas or kerosene or electricity for cooking and water heating. Natural gas may be available for domestic use in a few years, but initial priority is given to industrial consumers.*

Development Status. Technology is available for production of low- to medium-Btu gas from biomass, as discussed above. High-Btu gas would be more desirable as it could be comingled with natural gas. Low- or medium-Btu gas can be upgraded at considerable cost. A great deal of work is needed to optimize process conditions before economic feasibility can be demonstrated. The first high-Btu facility of this kind remains to be built in the United States.

Discussion. At present, the preferred use for MSW in Egypt is composting. Also, the technology of anaerobic digestion appears uneconomic.

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[27] World Bank, op. cit.

*Personal communication, Engineer B.F. Barsom, Ministry of Petroleum.

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A.15 ANAEROBIC DIGESTION OF SEWAGE WASTEWATER

System Components. A representative, U.S.-designed anaerobic sewage treatment system consists of: five two-stage digester vessels, each measuring 100' by 31'; five filtration units, each powered by a 75-horsepower vacuum pump; a series of six 10-horsepower pumps; a series of five 5-horsepower pumps; and steel piping. Also included is a wet well for water purification.

Principles of Operation. Thickened sludge from a waste treatment plant is introduced into a two-stage digestion process. The first-stage digesters contain a culture of acidogenic bacteria which breaks down complex organic compounds (e.g., starches, cellulose, proteins, and lipids) into short-chain fatty acids, alcohols, carbon dioxide, and hydrogen. The effluent from first stage digesters is then piped into the second-stage digesters which contain a culture of methanogenic bacteria. These convert first-stage effluent into CH_4 (methane), CO_2, and traces of other gases, including H_2S. The raw gas produced in the second-stage digesters is processed in an amine absorption unit to remove ammonia, H_2S, and about 35 percent of the CO_2 present, yielding a synthetic fuel gas which is about 70 percent methane and 30 percent carbon dioxide.

Output. Based on an input capacity of 400,000 cubic meters per day, the anaerobic treatment plant described here would produce 1.1 million cubic meters of a synthetic fuel gas per day, with a heating value of approximately 700 Btu per standard cubic foot.[28] Total

[28] Jones, J.L., op. cit.

energy output would thus be about 8.2×10^{11} joules per day. The plant would also produce about 315 tonnes per day of effluent, suitable for use as a fertilizer/soil conditioner. The reader should note that all of the fuel/gas produced by the plant would be consumed in heating and mixing the digestors, or in the associated wastewater treatment plant, and would provide 40 to 60 percent of the plant's energy needs. Thus, the plant would not produce energy for commercial sale.

Resource Requirements. Assuming that most of the components used in this plant would have to be imported, the only critical resource requirements from the Egyptian point of view are: capital, land area near major urban centers, and trained personnel.

Environmental Impact. CO_2 is the only significant pollutant released during the digestion process itself. However, CO_2, SO_2, and NO_x will be released during combustion of the product gas; and the effluent may contain trace amounts of heavy metals. Nevertheless, these emissions are not expected to constitute a major health or environmental problem. The plant is not a major water user, since the feedstock already contains a great deal of water.

Social Impact. The social effects of this technology would be positive, and derive from: (1) the sewage treatment function of the plant (effluent does not smell and is virtually free of human pathogens); and (2) the nutrient value of the effluent. Since the treated sewage is safe for use in agriculture, the plant is effectively

producing some 315 tonnes per day of a renewable, non-petroleum-based fertilizer.

Costs. The anaerobic digesters for an existing sewage treatment plant of 400,000 cubic meter per day input capacity are estimated to cost about L.E. 2.2/m^3 of capacity.[28] Annual operating and maintenance costs are assumed to be 5 percent of capital cost, and plant life is assumed to be 20 to 30 years. If the resulting fuel gas were used to generate electricity, it would cost on the order of L.E. 0.006 to L.E. 0.009 per kilowatt-hour. This compares to marginal generating costs on the existing Egyptian grid of L.E. 0.002 to L.E. 0.030 (subsidized prices), or L.E. 0.013 to L.E. 0.047 (world prices).[17]

Balance of Payments Impact. The balance of payments effect of this technology would be negative, since most components would have to be imported. Moreover, the energy value of the fuel gas produced would be relatively small and would not offset the capital cost of the plant.

Development Status. Technology for the anaerobic digestion of sewage sludge is commercially available in the United States. We emphasize, however, that this technology is not applied in an energy-producing mode in the United States.

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[28] Jones, J.L., op. cit.

[17] Egyptian Electricity Authority, Tariff Study Report 1978.

In Egypt, the Ministry of Overseas Development of the United Kingdom Government has a joint project with USAID to improve wastewater treatment facilities.

Market Potential. The Cairo area produces about 1.2 x $10^6 m^3$ wastewater per day; this could support 11 MW_e of generating capacity and produce 1260 tpd of soil conditioner. It is believed other population centers produce amounts of wastewater in similar proportion to their populations. The Cairo area currently has about 900 MW_e of fossil-fired generating capacity.[17]

Discussion. We have not selected anaerobic digestion/electric power generation technology for further consideration because of its high cost. Considered by itself as a waste treatment technology, anaerobic digestion is fully demonstrated, both technically and economically. As we have configured the technology for applications, however, the technology is not economically attractive.

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[17] Egyptian Electricity Authority

A.16 BIOMASS PLANTATIONS

Discussion. Biomass plantations (e.g. tree farms) were considered as a means of energy production for Egypt. Two factors militate against their adoption:

- Large areas of arable land are needed (typically, several thousand areas to suport a 50 MW_e plant).[29] This type of land is exceedingly scarce in Egypt, and food production represents a higher priority.

- Establishment of plantations on reclaimed lands (desert lands) would require large quantities of water. The only surface water supply in Egypt, the Nile, is fully committed. In any case, reclaimed land has a higher use in food production.

[29] The MITRE Corporation, Silvicultural Biomass Farms, MTR-7347, 1977.

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A.17 LARGE-SCALE HYDROELECTRIC GENERATION

System Components. Water impoundments (e.g. dams), large water turbines, and generators.

Principles of Operation. Water is retained behind a high dam, and released through turbines in a controlled fashion. The turbines drive electric generators.

Output. The output of a hydroelectric plant is determined by the flow rate of water and the distance it is falling (i.e., its head). The largest hydroelectric plant in Egypt is the High Dam at Aswan, which has an installed capacity of over 2000 MW_e. For our purposes, we have assumed that large-scale plants produce more than 10 MW_e at peak capacity.

Resource Requirements. Turbine generators and power conditioning equipment will be imported. Significant local resource requirements are capital, concrete, steel, and trained personnal. Fossil-fuel inputs would also become a major requirement, for earthmoving, as the size of the facility increases.

Environmental Impact. Because of its scale, the application of this technology can entail major environmental consequences. The Aswan Dam, for example, has flooded the Nile Valley for 200 miles. Other potential impacts include induced seismicity, and the spread of waterborne diseases such as bilharzia. Counterbalancing these possible adverse effects is the fact that large hydro projects may displace fossil-fueled generating capacity, which releases CO_2 and a variety of noxious pollutants.

Social Impact. With the one qualification that large-scale hydro development does involve the necessary trade-off between electrical energy and land,* hydro projects produce positive social benefits by increasing the supply process of electrification. (See social impact discussion under photovoltaic technology summary.)

Costs. Exact cost data are not available, but large-scale hydro facilities are cost competitive with fossil-fueled alternatives.

Balance of Payments Impact. Large-scale hydro projects are extremely capital intensive. Because of the cost of imported components, the balance of payments effect, at least in the near-term, is negative. Over the long-term, however, large-scale hydroplants will displace fossil fuel for possible export.

Market Potential. Up to 300 MW_e additional capacity could be installed along the Nile, by repowering the old Aswan Dam and by installing turbines and generators at the barrages of Esna, Nag Hamadi and Asyut.[15,16] The potential exists for many hundreds of MW_e of pumped storage capacity at sites along the Nile and the Red Sea. Further, the Qattara Depression Project would allow the Mediterranean Sea to flow through tunnels into the Qattara Depression and, if realized, could provide up to 600 MW_e of continuous power, plus

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*In the case of the High Dam at Aswan, the land that was rendered unusable was largely nonarable desert.

(15) Egyptian Ministry of Electricity and Energy, op. cit., 1979.

(16) All-Union Designing, Surveying and Research Institute, op. cit., 1977.

2000 MW_e of pumped storage.* All these sites would be connected to the national grid so that the power could be effectively used.

Development Status. Large-scale hydroelectric technology is well developed and fully commercial. Egypt presently receives about 60 percent of its electrical energy from this source.

Planning work is currently taking place to exploit the possibilities at Aswan and the Nile barrages. The Qattara Project is in an early stage of planning and its economic viability has not yet been demonstrated.

Discussion. Although potential for significant additional capacity exists, and although this capacity would likely be economic, USAID has informally indicated that large centralized generating plants are felt to be inappropriate under a renewable energy program.

*Personal communication from Dr. K. Hamed, Qattara Project Authority.

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A.18 SMALL-SCALE DECENTRALIZED HYDROELECTRIC GENERATION

System Components. Small dams, water turbines, and generators.

Principles of Operation. Water is impounded behind a dam, and allowed to escape in a controlled fashion through a turbine which drives an electric generator.

Output. The amount of electrical energy which can be produced from falling water is a function of: (1) the flow rate of the source, and (2) the distance the water is falling (i.e., the head). We have defined small-scale hydroplants to be those producing up to 10 MW_e.

Resource Requirements. We assume the turbine generator and associated power conditioning equipment (e.g., regulators, inverters, transformers) would have to be imported. For the construction of the powerhouse itself, critical materials include reinforced concrete, structural steel, capital, and trained personnel.

Environmental Impacts. Application of this technology would produce negligible environmental impacts. Air pollutants would be released during construction, particularly hydrocarbons and dust, but the technology operates without significant pollution once in place.

Social Impact. Expected social impacts are generally positive, and are related to the benefits of increased electrification. (For more detail, see the technology description for photovoltaic conversion.) It should be noted, however, that small-scale hydro plants may conflict with agricultural water uses, particularly as to the timing of flows.

Costs. Low-head hydro technology costs about L.E. 700 per kilowatt of installed capacity. Operating and maintenance costs are about 1.5 percent a year, or L.E. 10.5 per year per installed kilowatt of capacity.[30,18] The equipment can be expected to last for 20 to 30 years. These figures translate into electrical power costs of about L.E. 0.009 to L.E. 0.034 per kilowatt-hour. For purposes of comparison, diesel generation produces electricity at about L.E. 0.02 (subsidized) to 0.06 (real) per kilowatt-hour, while Egyptian grid-electric costs are L.E. 0.002 to L.E. 0.030 (subsidized prices), or L.E. 0.013 to L.E. 0.047 (world prices).[17]

Balance of Payments Impact. Initial impacts would be negative due to importation of turbines, etc. Subsequent impacts would be positive due to savings of fossil fuel for electric generation.

Development Status. Low-head hydroelectric technology generation is well developed and commercially available. Moreover, the Egyptian Electricity Authority has the technical resources to construct and maintain small-head hydro projects.

Market Potential. Initial data available to the team* suggests that heads and flow rates on Egyptian canals are generally inadequate

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(30) U.S. Army Corps of Engineers, Hydropower Cost Estimating Manual, North Pacific Div., Portland, OR, 1979.

(18) National Academy of Sciences, Energy for Rural Development, 1976.

(17) Egyptian Electricity Authority, op. cit.

*From the Egyptian Ministry of Irrigation.

to support widespread implementation of this option. Even the major canals in the Delta, of which there are about 6, could apparently support only 2-3 MW_e each.

Discussion. It appears that the resource base in Egypt to support small-scale hydro plants is rather small. A detailed resource survey must be undertaken before this option can be finally categorized.

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A.19 GEOTHERMAL POWER GENERATION

System Components. Geothermal wells; flash vessels, steam turbines and generators for electric use; heat exchangers for direct utilization of the heat; disposal wells.

Principles of Operation. Geothermal energy uses water which has been heated by the earth's heat. Underground reservoirs of hot water or steam can be tapped by wells, and the water used to drive electric generators or used directly (e.g. for space heating or industrial heat).

Output. Geothermal wells may produce up to 500,000 kg/hr of steam or water at 200°C; most produce less than this. Typically, a good well can drive a generator producing about 2-5 MW_e; or several wells may be used to drive a larger plant (e.g. 50 MW_e).[31]

Resource Requirements. Well and generator construction materials include: steel well casings, steel piping, structural steel, stainless steel, and copper. Drill rigs and crews would have to be imported.

Environmental Impacts. Large-scale production of geothermal fluids can entail massive environmental impacts, in terms of: induced seismicity, land subsidence, H_2S emissions, and contamination of surface waters with mineral-laden geothermal solutions.

Social Impacts. The application of this technology in Egypt would produce social benefits as the result of increased electrification.

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(31) The MITRE Corporation, Site-Specific Analysis of Geothermal Development, MTR-7586, 1978.

Benefits would appear as improved health care; better education; and growth in the industrial sector, particularly mining (direct use of brines).

Costs. Costs of U.S. plants are about $1,000/kWe, but the cost is critically dependent upon the resource temperature, the flow rate of the wells and the depth of the reservoir.(31) In real terms, geothermal energy from a good field is competitive with fossil-fuel costs.

Balance of Payments Impact. The commercial development of geothermal technology would likely have negative balance of payments effects, since most of the system components (e.g., drilling rigs, turbine-generators) would have to be imported.

Development Status. Geothermal technology has achieved commercial status in at least the United States, Japan, Mexico, and El Salvador. In the United States, development efforts are now directed toward (1) providing better information about the geothermal resource base, and (2) improving the corrosion resistant characteristics of critical materials and components in geothermal power cycles.

Market Potential. The available information concerning potential Egyptian geothermal resources has been collated by USGS as part of the GOE/DOE Egyptian energy study.(1) The scanty information available indicates a rather poor-quality resource located in remote

(31) Ibid.

(1) GOE/DOE, op. cit., Vol IV, 1979.

areas, primarily near the Gulf of Suez and the Red Sea. If this analysis is correct, the potential for utilization is quite limited.

Discussion. Geothermal technology was not selected for further analysis as a near-term development option because Egypt's geothermal resource base remains to be characterized. Until better information is available concerning the geothermal resource potential, geothermal energy should not be pursued.

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APPENDIX B

ECONOMIC ANALYSIS METHODOLOGY AND ASSUMPTIONS

B.1 Approach and Methodology

The costs of delivered energy calculated for the renewable energy resource/technology/end-use triads analyzed in this report, and for their conventional competitors, have formed an important part of the selection process.

The costs have been used in the selection process primarily to eliminate uneconomic triads, and have not been used for selecting between triads with approximately the same projected cost. In these latter cases, other selection criteria dominated the process. Stated another way, any triad whose projected cost range overlapped the cost range of its conventional competitors was taken to be economically viable.

Table B-I consolidates the economic data used in developing the estimates for delivered energy costs. It shows that, in many cases, Egyptian cost figures were unavailable because no comparable systems exist or are planned in Egypt. In these cases U.S. costs were used, converted to Egyptian terms, or the teams made their own best estimates.

It must be noted that all the systems considered are generic, and use broad overall cost estimates which do not reflect detailed analyses of the specific conditions and needs of particular sites or applications. The costs are therefore, subject to some uncertainty.

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Trial	Estimated Delivered Energy Cost	Capital Cost	Equipment Life (Yrs.)	Operating and Maintenance Costs	Data Sources	Discount Rate	Notes	Main Competing Energy Sources and Costs
Selected Options:								
Solar Water Heating	L.E. 1-3/10^9J (Egyptian) equivalent of U.S. costs	\$25/ft^2 (U.S.)	20 to 30	2% of capital cost annually	MITRE[19]	17.7% & 23.1%	Delivered energy costs are case specific.	Fossil fuels at L.E. 0.5-101/10^9J (local costs) or L.E. 3-9/10^9J (world costs).**
Solar water Heating (Domestic)	L.E.4-6/10^9J (Egyptian units) L.E.7-10/10^9J (Foreign units)	L.E. 1.38/1/d (Egyptian) L.E. 2.6/1/d (Foreign)	10	2% of capital cost annually	Quotes obtained in response to GOE call for bids.	17.7% & 23.1%		As above; also Ag. Res. at L.E. 0.5/10^9J (local).
Solar Crop Drying	L.E. 15-100/Tonne	L.E. 1-5m^2 (Domestic) L.E. 6-24m^2 (Commercial)	10	L.E. 14-60/tonne	Brace Research Institute[20] Government of Pakistan[22]	17.7% & 23.1%		Fossil dryers at L.E. 100-300/Tonne (world costs); open air drying is free.
Rural Biogas Digesters	L.E. 1.7-3/10^9J	L.E. 150-260/unit of 10 m^3 size	20	L.E. 15-25/year excluding cost of dung	NAS[23]; University of Cairo (personal comm.)	17.7% & 23.1%	No credit taken for fertilizer slurry; assumed equal value to dung input.	Fossil L.E. 0.5-1.1/10^9J (local) or L.E. 3-9/10^9J; Ag. Res. L.E. 0.5/10^9J (local).
Wind-Irrigation	Competitive with diesel pumps	L.E. 800/unit (Egyptian) \$4,000/unit (U.S.)	20	5% of capital cost annually	Military factory U.S. team	17.7% & 23.1%		Diesel pumps.
Wind-Small Electric	L.E. 0.05-0.09/kWh * 15 mph wind L.E. 0.14-0.15/kWh * 12 mph wind	\$2,700/kW_e (U.S.)	20	5% of capital cost annually	U.S. team	17.7% & 23.1%	Costs highly dependent on average wind velocity. 12 mph average on northwest coast, 15 mph average on Red Sea coast. (Note: Large machines unlikely to be deployed on Red Sea. No load centers.)	Diesel electric L.E. 0.02/kWh (local), or L.E. 0.06/kWh (world).***
Wind-Large Electric	L.E. 0.03-0.06/kWh * 12 mph wind	\$1,000-1,200/kW_e (U.S.)	20	5% of capital cost annually	MITRE[19]	17.7% & 23.1%		Diesel (above), Grid L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world).****
Solar Refrigeration and Cooling	L.E. 4-5/10^9J	\$140-170/m^2 or \$20,000/kW (U.S.)	-	-	GOE/DOE[1]; U.S. team	-	Delivered energy cost estimated by GOE/DOE[1].	Fossil or electric; L.E. 0.7-12/10^9J (local), L.E. 5-19/10^9J (world) approximately.
Photovoltaics	L.E. 0.5-0.9/kWh (Present) L.E. 0.0[illegible]-0.15/kWh (1985)	\$10,600/kW_e (U.S. Present) \$1,800/kW_e (U.S. 1985)	10 to 20	1% of capital cost annually	U.S. team	17.7% & 23.1%		Batteries, diesel electric.
Options Not Selected:								
Solar Cooking	L.E. 2-11/10^9J	L.E. 60-140/unit	10	5% of capital cost annually	U.S. team	17.7% & 23.1%	Severe conflicts with Egyptian customs.	Fossil and Ag. Res. 0.5-1.1/10^9J (local), or L.E. 3-9/10^9J (world).
Solar Desalination	L.E. 0.002-0.005/litre	L.E. 10-20/m^2	10	5% of capital cost annually	NAS[18]	17.7% & 23.1%		Flash or reverse osmosis, wells, pipelines. Costs not known.
"Giant Tower"	L.E. 0.07-0.28/kWh (Egypt)	\$1,300-2,500/kW_e (U.S.) L.E. 2,000-4,000/kW_e (Egypt)	30	1.5% of capital cost annually	MITRE[19]; U.S. team	17.7% & 23.1%	Technology not yet proven.	Grid costs L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world).
Passive Solar Architecture	-	Small	30	Almost none	U.S. team; Egyptian sources	-	USAID/Cairo does not wish to pursue at this time.	Fossil fuels to small extent.
Improved Rural Stoves	Competitive*****	L.E. 10-20/unit	10	Almost none	U.S. team	17.7% & 23.1%	USAID/Cairo does not wish to pursue at this time.	Fossil and Ag. Res. 0.5-1.1/10^9J (local), or L.E. 3-9/10^9J (world).
Municipal Composting*	L.E. 4-11/Tonne compost	L.E. 3,400-9,300/TPD	30	L.E. 100-500/year/TPD	World Bank[27]	17.7% & 23.1%	World Bank has project underway.	
Tidal Generation	L.E. 0.002-0.01/kWh	L.E. 20,000/TPD	30	L.E. 800/yr/TPD	MITRE (Private comm.)	17.7% & 23.1%	Widespread Egyptian opposition.	Grid L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world).
Wind-Biogas	L.E. 5-9/10^9J	L.E. 22,000/TPD	30	4% of capital cost annually	Jones[28]	17.7% & 23.1%	Excludes distribution costs.	Fossil fuels L.E. 0.5-1.1/10^9J (local), or L.E. 3-9/10^9J (world).
Sewage-Biogas	L.E. 0.00[illegible]-0.009/kWh	L.E. 2.2/m^3/day	20 to 30	5% of capital cost annually	Jones[28]	17.7% & 23.1%	In-plant electricity use only; limited resource.	Grid L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world).
Large-Scale Hydro	Competitive	-	-	-	-	-	USAID/Cairo does not wish to pursue at this time.	Grid L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world).
Small-Scale Hydro	L.E. 0.0[illegible]-0.01/kWh	L.E. 700/kW_e	20 to 30	1.5% of capital cost annually	U.S. Corps of Engineers[10] NAS[18]	17.7% & 23.1%	Resource appears limited.	Grid L.E. 0.002-0.010/kWh (local), or L.E. 0.013-0.047/kWh (world). Diesel electric L.E. 0.02/kWh (local) or L.E. 0.06/kWh (world).
Geothermal	Unknown	Unknown	10 to 30	Unknown	-	-	Costs critically dependent upon resource quality which is unknown.	Competing sources depend upon resource location.

*Municipal solid waste.
**Egyptian Ministry of Petroleum (Private communication).
***Diesel electric costs assume capital cost of L.E. 300/kW_e, 25% efficiency, 40% capacity factor, 15 year life, operating and maintenance cost 5% of capital costs annually, world fuel price L.E. 5.2/10^6Btu, local fuel price L.E. 0.5/10^9J, fuel escalating 3.5% over inflation.
****Egyptian Electricity Authority[17].
*****Stoves could save significant proportion of agricultural residues now used as fuel at low cost.

TABLE B-1

CONSOLIDATED ECONOMIC DATA

(L.E. 1 = \$1.40)

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The cost ranges given in Table B-I reflect these and other uncertainties, such as the correct discount rate (see also Section B.3). Further data collection, engineering design, and cost estimating is needed before cost projections accurate enough for, e.g., Project Papers, can be developed.

The cost numbers have been calculated using a levelized life-cycle cost approach. This has the advantage of incorporating both capital costs and operating costs in a single number, thus easing comparison between alternatives with, for example, different capital intensities.

Where possible, costs have been presented as both the apparent user costs and also the real (world-price) costs. In the first case, the apparent user costs reflect the out-of-pocket expense to the user, after taking account of subsidies or other relevant factors. The real costs, on the other hand, reflect the costs from a national point of view (shadow prices, in economic terminology). The biggest discrepancy between apparent and user costs of energy in Egypt relates to petroleum fuels, which on the domestic market are subsidized to between 80 and 90% of their real (world-price) value, as shown in Table B-II.

The technique used to calculate the levelized life-cycle costs is based on discounted cash flow (DCF) analysis. This method takes account of the time value of money by discounting, or reducing,

TABLE B-II

FUEL SUBSIDY LEVELS IN EGYPT

FUEL	WORLD PRICE L.E./10^9 J*	LOCAL PRICE L.E./10^9 J	LOCAL PRICE EXPRESSED IN U.S. UNITS
Butagas	9.20	1.10	$1.30/Mcf
Kerosene	3.90	0.48	10¢/Gal
Mazout (Residual Fuel Oil)	2.95	0.17	3¢/Gal

* L.E. 1 = $1.40 U.S.

10^9 J = $0.95 x 10^6 Btu

Source: Egyptian Ministry of Petroleum[12]

future payments and receipts at some chosen rate, usually in the range of 10 to 20% per year.

In its simplest form, the cash flow in year i can be expressed:

Cash Flow (i) = Income (i) - Capital Investment (i)

- O&M* Costs (i) - Taxes (i) - Fuel (i) - Other Costs (i)..(1)

Note that this equation includes only real, tangible cash receipts and payments. Imaginary costs, such as depreciation, are excluded (although they will affect taxes, for example, as will tax credits and other adjustments). If the project life runs from year i = 1 through i = n, then at discount rate "r" the net value of the DCF (or Net Present Value, NPV) is:

$$NPV = \sum_{i=1}^{n} \text{cash flow (i)} * \frac{1}{(1+r)^i} \qquad ...(2)$$

The value of "r" which gives NPV=0 is called the discounted cash flow rate of return (dcfror). Generally, the more economically attractive a project is, the higher will be the dcfror, which represents the rate of return to capital invested. It often happens, however, that we wish to find the price (i.e., income) which will give a certain desired dcfror, and then to use this price as a basis for comparison with other sources. This is the approach used in this analysis. The energy prices which give dcfror's of 10% and 15% are calculated and compared with the prices (costs) of energy from other sources.

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*Operating and maintenance

An inflation rate of 7% has been assumed (see Section B.2). All calculations have been made in current value currency (as opposed to constant value currency).*

In the analyses performed here, taxes have been omitted; the rationale is that energy options studied are either small-scale non-commercial applications or options which would be applied by government-owned organizations. In either case, no taxes would be paid.

As an example, consider the cost of electricity from diesel-electric generators. The current (1980) capital cost is about $300/kWe, with a life of 15 years, and an O&M cost of $15/year, excluding fuel. At a capacity factor of 0.40 and a generating efficiency of 0.25, about 3506 kWh/yr. would be generated by 1 kW capacity, requiring about 8.3 barrels of fuel at a 1980 price of $30/bbl. We assume that the price of electricity and the cost of diesel fuel escalate at 3.5% in real terms. We choose a discount rate of 10%, net of inflation, or 17.7% including inflation and we wish to find the levelized life cycle unit price of electricity. This means that we want to find a price, p, per kWh, which will give NPV=0 at a discount rate r=0.177. This is equivalent to a 17.7% return to total invested capital. Equation (2) gives (in per-kW terms):

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*Constant value currency refers to currency of fixed purchasing power, while current value currency means the currency of purchasing power as affected by inflation. To take an example, one dollar in 1969 bought more than one dollar in 1979, so that a current dollar in 1979 was worth only some 60% of a current dollar in 1969. Alternatively, a constant 1969 dollar was worth about 1.7 1979 dollars.

$$0 = \sum_{i=1}^{15} 3506 * p * \left(\frac{1 + 0.107}{1 + 0.177}\right)^{i} - 300$$

$$- \sum_{i=1}^{15} 8.3 * 30 * \left(\frac{1 + 0.107}{1 + 0.177}\right)^{i}$$

$$- \sum_{i=1}^{15} 15 * \left(\frac{1 + 0.07}{1 + 0.177}\right)^{i}$$

$$0 = + p * 3506 * \left(\frac{1 - \frac{1.107}{1.177}^{15}}{1 - \frac{1.107}{1.177}}\right) * \frac{1.107}{1.177} - 300$$

$$- 8.3 * 30 * \left(\frac{1 - \frac{1.107}{1.177}^{15}}{1 - \frac{1.107}{1.177}}\right) * \frac{1.107}{1.177}$$

$$- 15 * \left(\frac{1 - \frac{1.070}{1.177}^{15}}{1 - \frac{1.107}{1.177}}\right) * \frac{1.070}{1.177}$$

$$0 = 33343p - 300 - 2368 - 126 \text{ or } p = 0.084$$

Thus, the levelized life-cycle cost under these assumptions is about 8 cents/kWh, or L.E. 0.06/kWh.

This methodology has been used to generate all per-unit energy costs in this study, except where noted.

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B.2 Assumptions

The major parameters affecting the delivered energy costs in the methodology used here are:

- capital costs
- O&M costs
- fuel costs
- project life
- discount rate
- inflation & escalation
- taxes

Of these, capital, O&M and fuel costs, and project life are case specific and are described in Appendix A for each option. The remaining parameters are discussed in turn:

Discount Rate

All options have been evaluated at net discount rates of 10% and 15% above inflation.* The current costs of loan capital in Egypt are 12% for individuals and 7% for businesses,** so that a 75:25 debt:equity ratio would lead to a return to equity in the range 4% to 39%, depending on which combination of discount and interest rates is chosen. An inflation rate of 7%, coupled with a discount rate of

*These are equivalent to 17.7% and 23.1% including inflation. The World Bank has used a net discount rate of 10% in evaluating natural gas distribution systems for Cairo.

**Personal communication from Dr. M. A. Salam, El Azhar University.

10%, implies a true return to capital of about 3%. This has been the historical real rate of return in industrialized countries for risk-free investments, such as government securities.

Inflation and Escalation

The underlying inflation rate has been assumed to be 7%. This figure is used in forward planning by the Ministry of Electricity.* Increasing inflation in the future would have the effect of making capital-intensive projects with low running costs, such as hydroelectric, wind, or direct solar, appear relatively cheaper when compared with other options. This is because capital-related costs are fixed at the beginning of the project and will not increase with inflation, while running and fuel costs will increase. In an environment of stable inflation (i.e., a constant rate) the discount rate will normally be high enough to equalize these effects unless, for example, fuel costs are increasing more rapidly than inflation. This latter eventuality is likely to be true, and the escalation rate for petroleum fuel has been assumed to be 3.5% above inflation, a very conservative assumption.**

Taxes

As noted above, taxes were not considered since it was felt that most projects were likely to be government-owned (and hence not liable for taxes), or intended for domestic use, i.e., not generating taxable income.

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*Personal communication from Dr. M. El Gazzar, Egyptian Electricity University.

**The World Bank has used this rate in evaluating natural gas distribution systems for Cairo.

B.3 Data Sources

The basic cost data for the triads analyzed in this report have been assembled from a number of different types of sources. Individual sources are given in Appendix A for each triad and are indicated in Table B-1. It is important to recognize, and in future analyses, account for, the respective strengths and weaknesses of the data sources used.

The main types of sources used are:

- North American published material
- Egyptian published material
- Joint Egypt/U.S. studies
- Egyptian private estimates

These are discussed individually:

North American published material. Examples of this type of material include various MITRE reports,[19,29,31] and other published material.[2,7] Costs given in these references are specific to North America, but have been used to represent world (i.e., real) costs, as opposed to Egyptian (subsidized) costs. However, it has been assumed that imported (advanced technology) U.S. systems would be more expensive in Egypt than in the U.S., due to transportation costs, and costs associated with lack of local infrastructure.

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(19) The MITRE Corporation, Systems Description and Engineering Costs for Solar-Related Technologies, MTR-7485, Vol. III, 1977.

(29) The MITRE Corporation, Silvicultural Biomass Farms, MTR-7347, 1977.

(31) The MITRE Corporation, Site-Specific Analysis of Geothermal Development, MTR-7586, 1978.

(2) Diffie and W.B. Eckman, Solar Energy Thermal Processes, Wiley & Sons, New York, 1974.

(7) World Bank, World Development Report, 1978.

Egyptian Published Material. This material comprises mainly official G.O.E. development reports and plans (e.g.[9,10,15]) and some background material (e.g.[5,17]). The material does not include much information on cost for the renewable energy sources, but contains information relating to costs of conventional competition, socio-economic background, likely market sizes, etc.

Joint Egypt/U.S. Studies. Examples include[1,3,4]. This material contains significant cost-related information, and is generally of high quality and specific to the Egyptian context. However, not enough data is available from this type of source to obviate the need for using purely U.S. data, or estimates by American or Egyptian individuals.

Team Members' Estimates. In some cases, published data sources did not contain sufficient information to estimate costs fully, and no Egyptian private sources existed (usually because the systems under consideraton were not or could not be manufactured in Egypt). In these circumstances, the teams made the best estimates possible based on their joint experience and judgment. In most cases, members had intimate knowledge of the systems involved (e.g., one member of the team had been involved in small windmill manufacture in the United States for several years).

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(9) Egyptian Ministry of Housing and Reconstruction, Regional Plan for Coastal Zone of the Western Desert, Final Report, 1979.

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(1) GOE/DOE, Joint Egypt/United States Report on Egypt/United States Cooperative Energy Assessment, Vol. IV, 1979.

(3) W.L. Hughes, Egyptian Wind Energy Resources Study, Final Report, Phase II, Oklahoma State University, 1979.

(4) W. L. Hughes, Egyptian Energy Resources Study Project Final Report, Oklahoma State University, 1975.

Egyptian Private Estimates. In cases where no published information was available from Egyptian sources, it often proved possible to obtain information privately from individuals in one of the Energy Ministries (Electricity, Petroleum) or from individuals involved in industry or commerce.

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APPENDIX C

CRITERIA FOR EVALUATING RESOURCE/TECHNOLOGY/ END USE TRIADS

To facilitate inter-comparison and selection among the set of triads, they were subjected to analysis under 11 assessment criteria. These comprise:

- real costs
- apparent user costs
- costs of competing energy sources
- potential market
- market penetration
- social impacts
- infrastructure
- critical resources
- environmental impacts
- Balance of Payments effects
- other donor activity

The factors included under each of these criteria were as follows:

Real Costs

The estimated levelized* cost per unit of energy produced by the type of systems under consideration. This cost is calculated using real, unsubsidized costs to the extent possible. Real costs are assumed to be reflected by U.S. prices or world market prices.** The cost includes both capital costs and operating and maintenance costs.

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*Appendix B contains a description of the levelized cost calculation method.

**This is not true for certain commodities, e.g., petroleum, but was felt to be the best overall assumption available.

Apparent User Costs

These costs reflect the effects of Egypt's widespread commodity subsidies and, hence, represent the estimated levelized cost to the end-user. The comparison of this cost with the apparent costs of competing energy sources determines the economic attractiveness of the system as seen by the user.

Costs of Competing Energy Sources

In Egypt the competing energy sources are petroleum fuels,* grid-provided electricity, or diesel-electric systems. The real and subsidized costs of selected petroleum fuels and marginal electricity generation costs in Egypt are discussed in Chapter 3.

Potential Market

Due to data limitations, potential markets have been usually specified in broad terms. Basically, the potential market represents all the energy usage which could technically be replaced by the triad under consideration.

Market Penetration

This represents the estimated market penetration potential taking into account all factors (e.g., economic competitiveness, speed of technology development, resource base, availability of infrastructure support, geographic restrictions, social impacts, etc.).

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*Coal is used only for metallurgical processes in Egypt.

Social Impacts

Evaluation of social impacts has occupied an important part of the analysis. Under the social impacts criterion are included characteristics of the energy source considered which would either help or hinder its acceptance. Generally, social impacts have been considered to be most significant at the village and domestic levels, where the life-style and habits of the people are intimately bound up with their methods of obtaining and using energy.

As an example, the use of solar cookers might require the main meal of the day to be prepared and eaten in the middle of the day. In an agricultural community where the men customarily, and in many cases the women and children, spend all day working in the fields at some distance from the village, lunching off a cold snack and eating their main meal after sunset, the use of solar cookers would require a major change in social behavior and organization. This would form a significant social impact requiring careful consideration.

Infrastructure

This criterion covers the extent to which existing institutions in Egypt would be capable of supporting the development and implementation of a given renewable energy option. Significant areas of infrastructure may include manufacturing, maintenance, education, management, technical development, financial and legal. This criterion deals with the infrastructure elements relevant to both commercialization/implementation and the management of the option when it is in place.

Critical Resources

Requirements for capital, skilled labor, management/personnel, water, land or other scarce resources which may create conflicts with other high-priority uses in Egypt, or which may impose particular constraints on development.

Environmental Impacts

This criterion covers qualitative estimates of environmental impacts compared with competing energy resources. Examples of impact areas include air and water pollution, availability of biomass for soil conditioning and fertilization, and noise levels.

Balance of Payments Effects

These represent qualitative or quantitative estimates of effects on the Balance of Payments (BOP) of implementation of the resource at the projected market penetration rate. A detailed analysis of BOP effects was felt to be outside the scope of this study, but the intent of this criterion is to distinguish between technologies having generally negative or generally positive impacts on Egypt's BOP deficit.

Other Donor Activity

From the point of view of USAID, an important criterion is the extent of activity by other international donors. The feeling of USAID was expressed as a reluctance to enter areas where significant programs of assistance from other donors were under way.

APPENDIX D

INSTITUTIONAL ANALYSIS

D.1 General Overview

Three cabinet ministries are primarily concerned with energy production, distribution, and research and development: the Ministry of Petroleum; the Ministry of Electric Power and Energy; and the Ministry of Atomic Energy and Scientific Research. In addition, three energy councils are functioning in a consultative role in energy policy: the High Council for Petroleum; the High Council for Electricity, and the High Council for the Utilization of Nuclear Energy. Recently, a Supreme Council for Renewable Energy was formed to handle the utilization of renewable energy technology in Egypt. The role of this Supreme Council* is the:

(1) Overall guidance and coordination of efforts of the Egyptian institutions involved in the field of renewable energy technology; and

(2) Study, development of plans, issuing of policies and generation of funds for the implementation of renewable energy products.

As part of its research mission the National Research Center (NCR) is involved in fostering the adaptation of renewable energy technology to the Egyptian environment. Training facilities in the Solar Energy Laboratory at the NRC, and in the Ministry of Industry

*See Prime Minister's Decree No. 1017, 1978.

Vocational Training Centers as well as in higher education institutions (e.g., Cairo University) could all be extended to handle the manpower training load requirement for renewable energy projects. This extension would require USAID to reinforce the existing training facilities in terms of hardware, software and organization capabilities. In particular, the selected trainees should be given adequate training in the proper U.S. institutions to update their experience in the selection, evaluation, testing, operations and maintenance of the various renewable energy systems of particular interest to Egypt.

In terms of hardware and software supply, it seems appropriate for USAID to arrange for a technology transfer program to help the NRC (and other research institutions that are now involved in renewable energy field) in the areas of mirror adjustment, mirror plating, photovoltaic cell manufacturing, black paint manufacturing and test proofing techniques.

Organizationally, the USAID may find it necessary to help articulate the now diffused organizational responsibilities for renewable energy technologies in the various Egyptian institutions involved.

At all urban levels, the implementation of renewable energy technologies will have to be coordinated between the Egyptian Industrialization Authority, the Supreme Council for Renewable Energy, the Ministry of Economy and Economic Cooperation and the end-users involved.

Existing rural, industrial and commercial banks can be used to extend loans to potential rural or urban end-users of renewable energy technology joint venture projects for technology transfer. Renewable energy manufacturing in Egypt can now be handled by the Ministry of Economy and Economic Cooperation under the provisions of the new foreign investment law #43 of 1974.

The Chairman of the Qattara Project Authority (QPA), Mr. Kamal Hamid, has been appointed to head the Supreme Council for Renewable Energy. It must be emphasized, however, that this appointment is in a personal capacity and does not extend to the QPA as such. The role of the QPA is limited to the management of a major renewable energy project--the hydroelectric project of the Qattara Depression.

In the renewable energy field, other institutions play peripheral or complementary roles to that of the Supreme Council of Renewable Energy. The Egyptian Electric Authority (EEA) has a leading role in the electric energy production and distribution field. In its endeavor to create other electric generation options for rural and remote areas, the EEA established the Solar Energy Commission (SEC) to look into various applications of solar energy in Egypt, and to coordinate the local solar technology research and development efforts. The EEA has also negotiated a number of international technology transfer agreements with the U.S., France, West Germany, and others in the field of renewable energy technology. In addition, the EEA contracted for the importation of one thousand solar water

heaters of different sizes and makes (Canadian, Italian, and Dutch) for local distribution and trial under different climatic conditions. This marketing and outreach effort is intended to determine performance and enhance public acceptance of solar water heaters.

D.2 Specific Roles in Recommended Options

D.2.1 Solar Water Heating and Solar Refrigeration and Cooling Demonstration Program

To demonstrate the potential of solar water heating in industrial applications and in refrigeration and cooling, USAID should consider working in cooperation with the Supreme Council for Renewable Energy (SCRE), the Ministry of Industry and the National Research Center. The Supreme Council for Renewable Energy and the Ministry of Industry would probably be responsible for selecting the demonstration sites and for later implementation and evaluation of the program together with USAID. The National Research Center (NRC) would be involved in the selection of the proper technology for the various demonstration sites and the adaptation of such technology to the Egyptian environment. For example, it is suggested that R&D be undertaken by NRC possibly with USAID assistance to determine suitable methods for drying phosphate slurry at El Hamrawain Mine using solar energy.

Infrastructure Development

Many of the renewable energy 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 and other labor skills common to a range of conventional power systems. There will be, however, special training required for many aspects of renewable energy related equipment design, manufacture, installation, operation and maintenance. This will range from training engineers to design and size solar water heaters, to training personnel to maintain wind turbine units. Training facilities in the Solar Energy Laboratory at the National Research Center, and in the Ministry of Industry Vocational Training Centers as well as in higher education institutions (e.g., Cairo University and Helwan Institute of Technology) could all be extended to handle this manpower training load.

Provision of Solar Water Heaters to Selected Target Groups

This marketing and outreach effort has already been initiated by the Egyptian Electric Authority (EEA) since 1978. It seems appropriate that any USAID extension of this effort to reach selected target groups (e.g., urban poor, health clinics and schools) would involve EEA as a counterpart who would help in the distribution of water heating systems and subsequent evaluation of the performance and public acceptance of these systems.

D.2.2 Solar Crop and Food Drying and Rural Biogas Digesters

Administratively, current responsibilities and organizational structure of the Egyptian Agriculture Extension Service could be

expanded to cover the requirements of all rural agricultural applications of renewable energy technology (e.g., training local craftsmen in solar crop drying equipment construction, operation and maintenance). The electric service bureau in each rural area can also be entrusted to look after the proper operation and maintenance of some applications in the villages.

Continued assistance to R&D efforts at the University of Cairo campus in Fayoum and the NRC is also necessary to help select and adapt the best from Indian and Chinese rural biogas digesters and to demonstrate the viability of rural biogas applications.

D.2.3 Wind Machines and Photovoltaic Remote Applications

It is suggested that any USAID programs for wind machines and photovoltaic for electric generation be undertaken as an extension of the current effort for rural electrification to cover areas which cannot now be economically supplied by conventional systems. The Rural Electrification Authority seems therefore to be the logical counterpart of USAID in the implementation of such programs.

In the implementation of wind machines for irrigation in coastal zone areas, USAID should consider working in cooperation with the Ministry of Housing and Urban Development. The Ministry of Housing and Urban Development would be involved in conducting studies on underground and surface water availability and other factors which determine the markets and impediments for wind-powered irrigation and

supporting the local manufacture, distribution and maintenance of such irrigation systems through the Ministry of Military Production or the local manufacturers or both.

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Department Approval: _____