CEER-S- 141

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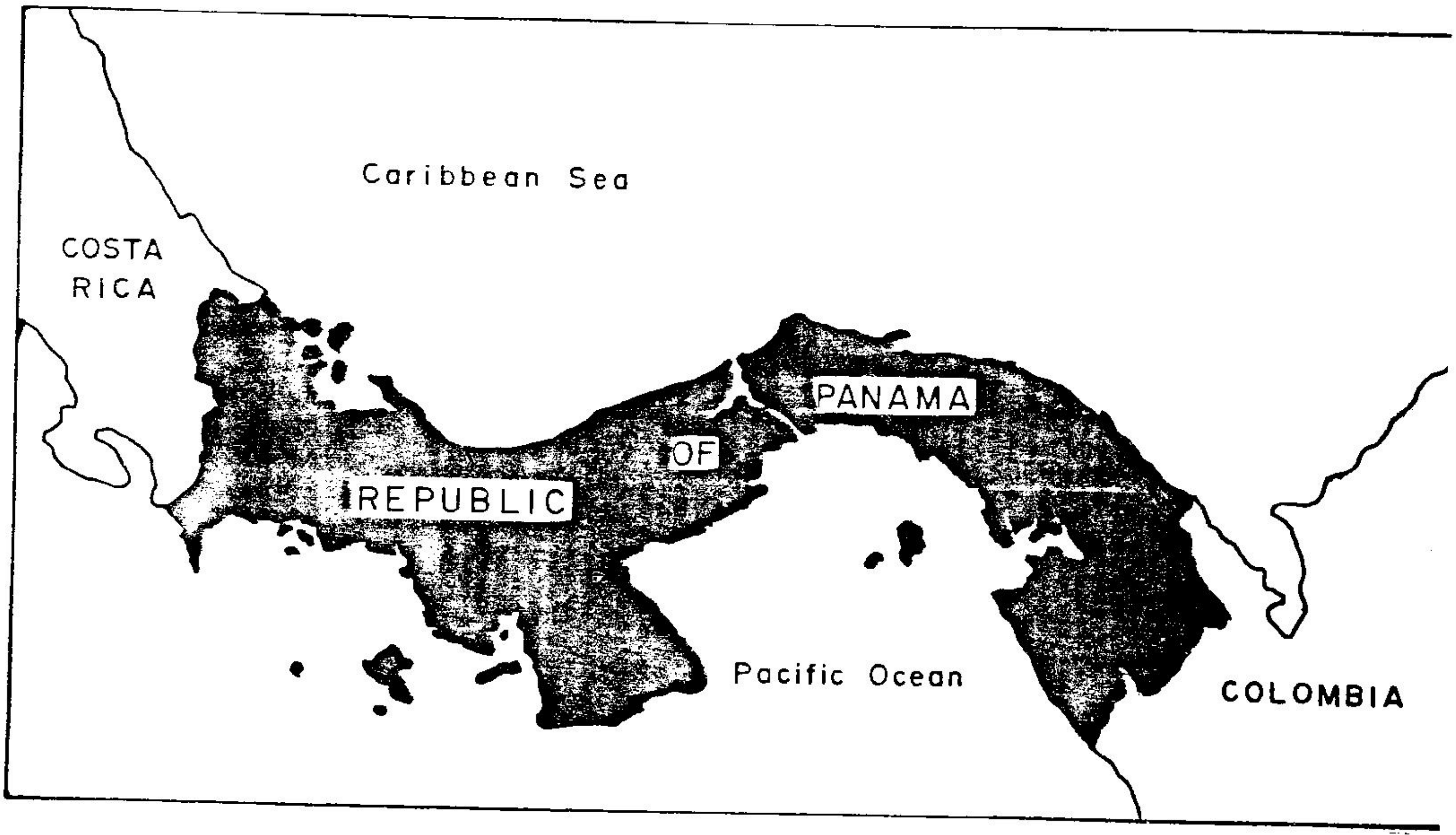

SEPTEMBER 1982

CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO - U.S. DEPARTMENT OF ENERGY

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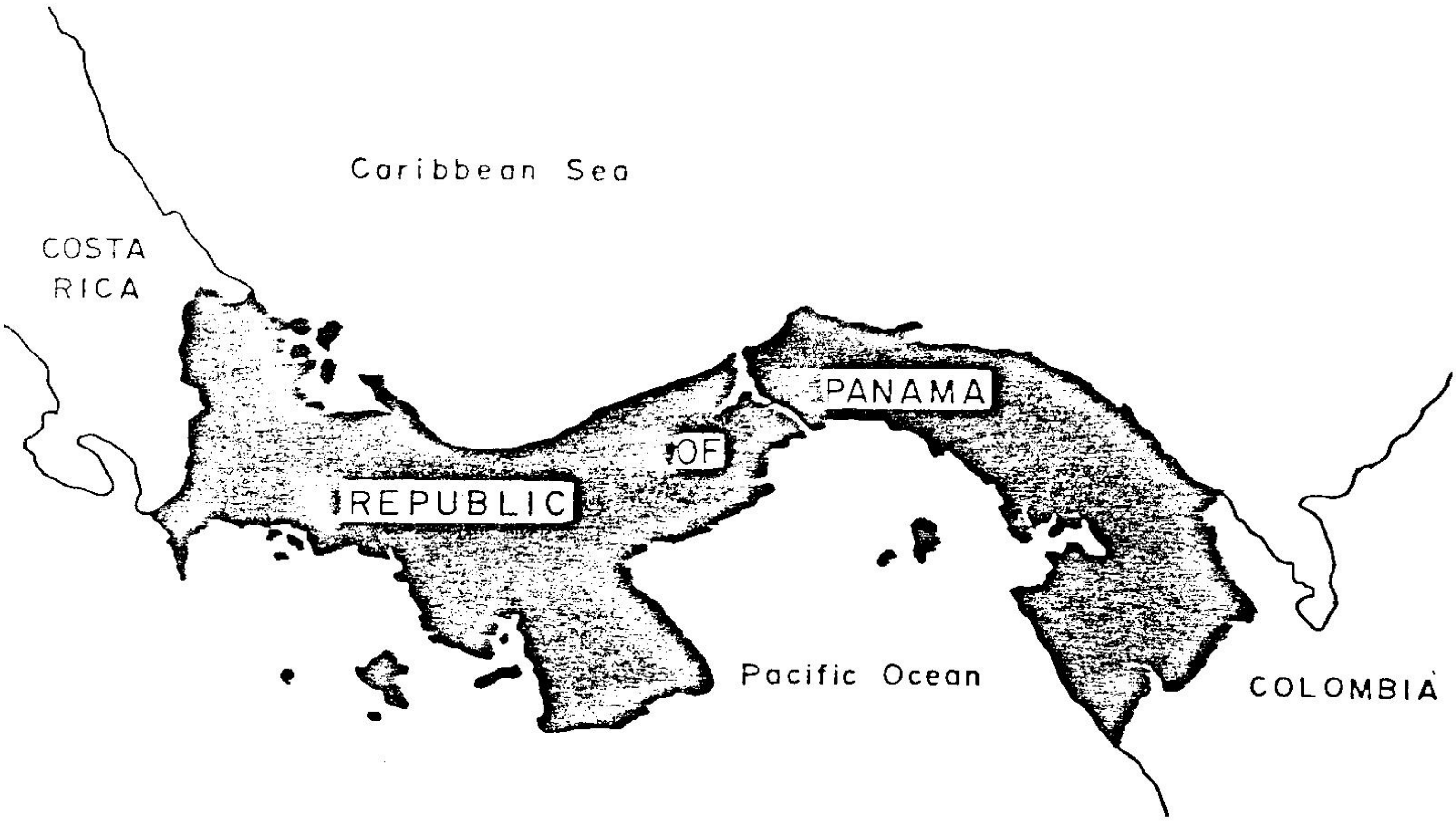

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INTRODUCTION

Energy is a basic resource needed to develop the economies of countries such as the Republic of Panamá successfully. The availability of energy in different forms is essential for most of the industrial and service activities, and the cost of delivered energy can be a critical factor in determining the economic competitiveness of industries and services and the ability of the general public to raise its standard of living.

The following are the principal products that are manufactured in the Republic of Panamá: matches, candies, crackers, ceramics, tiles, cement, cigarettes, dairy products, alcoholic beverages, soft drinks, canned fish, canned food, canned juices, flour, refined sugar, refined oil products, aluminum, and plastic products. The industrial sector requires energy for mining, manufacturing, transportation, air conditioning, agricultural production, and food processing and preservation. The agricultural industries include the raising of pigs, poultry and cattle. Providing energy for activities such as the above is a major problem facing all of the developing countries.

Like most developing countries, the Republic of Panamá is undergoing a rapid transition from an agrarian to an urban society. The Republic of Panamá consists of nine provinces which are Bocas del Toro, Cocle, Colón, Chiriqui, Darien, Herrera, Los Santos, Panamá, and Veraguas and a non

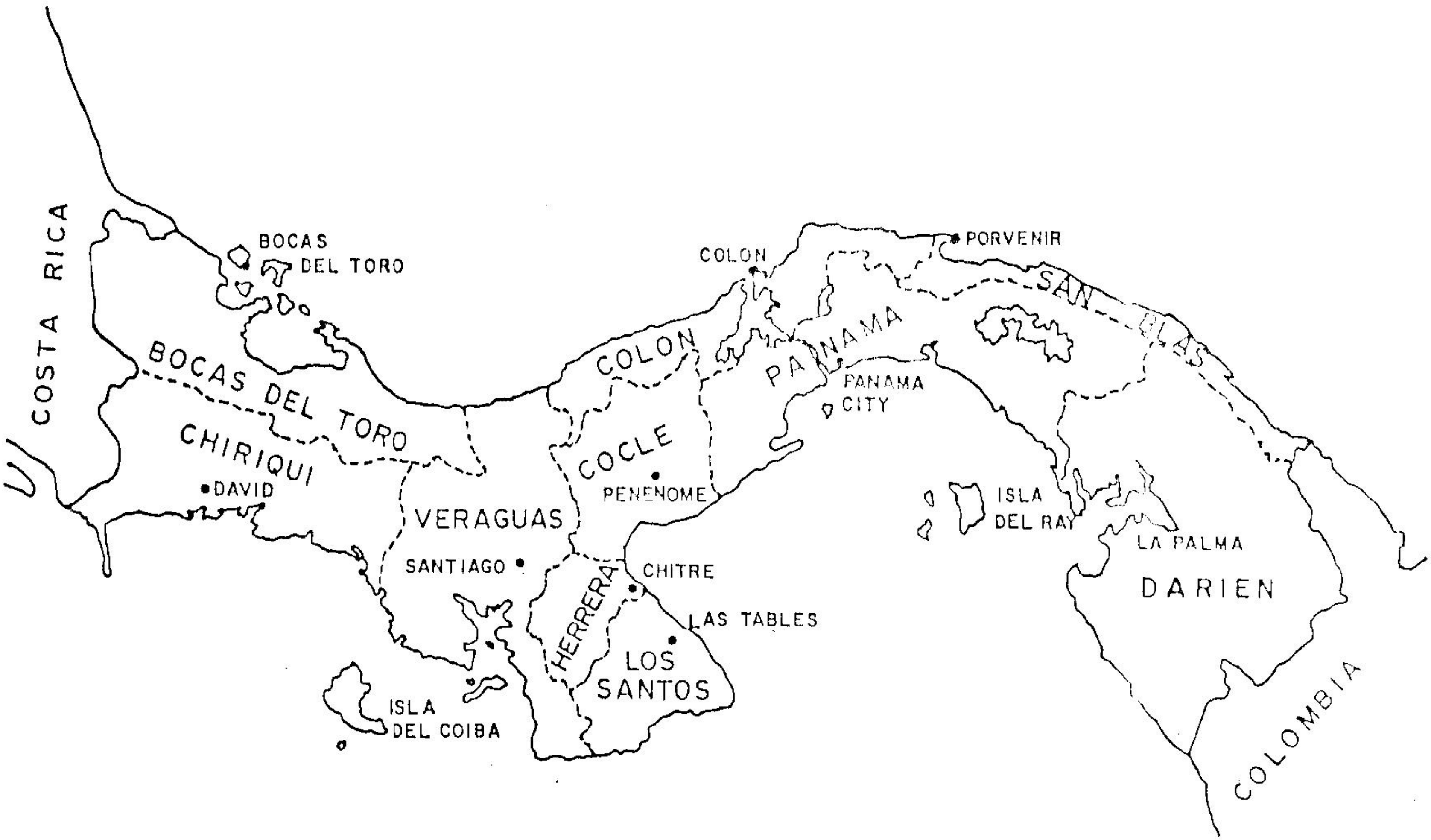

Fig. 1. Map of Provinces of the Republic of Panamá

provincial area known as Comarca de San Blás (see Fig. 1) About 46 percent of the population is concentrated in the urban areas; almost half of this urban population lives in Panamá City. The population density varies from 40 to 70 persons per square kilometer in Darien and Panamá, respectively. The urban metropolises have very active commerce and service industries. Yet the major exports, agricultural produce, sugar, rice and coffee, are produced mostly in the interior provinces of the Republic of Panamá: Chiriqui, Bocas del Toro, Veraguas, Darien. Therefore, the long term goal of the energy plan for the Republic of Panamá is to increase the country's economic growth by improving the energy consumption patterns and the energy distribution while diversifying the energy sources.

Because the Republic of Panamá depends totally on imported oil to sustain its economic activities, the sharp increases in oil prices present a major problem. By 1978 the cost of oil imports was equal to 73 percent of the total export earnings. For this reason, under financing from the World Bank in 1981, the Instituto de Recursos Hidráulicos y Electrificación (IRHE), e.g. Electric Power Authority of Panamá, assisted by the Center for Energy and Environment Research (CEER) of the University of Puerto Rico and the Institute of Energy Conversion of the University of Delaware, started work on a plan to use alternative energy sources to replace conventional fuels.

The development of alternative energy technologies, however, cannot proceed in isolation from the existing

TABLE I. ESTIMATED ENERGY CONSUMPTION IN THE REPUBLIC OF PANAMÁ* [1]

Energy Source	Use	Thousands of Equivalent Tons of Oil			
		Actual	Projected		
		1975	1980	1985	1990
Petroleum	Industry	202	299	525	791
	Transportation	441	572	750	945
	Electricity	514	703	778	511
	Domestic/Other	295	386	611	754
Hydro	Electricity	267	618	1,498	3,249
Wood Bagasse	Service Industry	113	147	188	128
	Other	201	225	157	138
	TOTAL	2,033	2,950	4,437	6,516

*Excluding the Canal Zone

TABLE II. REGIONAL DISTRIBUTION OF VARIOUS INDUSTRIAL AGRICULTURAL AND COMMERCIAL ACTIVITIES IN THE REPUBLIC OF PANAMÁ [2]

Type of Appl. / Province	Number of Units							
	Panamá City	Colón	Coclé	Herrera	Los Santos	Veraguas	Chiriquí	Bocas del Toro
Hotels	33	14	5	6	4	3	14	1
Restaurants and Cafeterias	212	35	9	6	2	4	11	-
Laundries	80	17	2	4	-	1	2	-
Hospitals	7	2	3	2	4	2	5	3
Breweries	3	-	-	-	-	-	2	-
Bottling Plants	9	1	-	-	-	-	5	-
Meat Packing	8	-	-	-	-	1	3	-
Supermarkets	86	4	5	2	2	-	11	2
Garment Manuf.	57	2	-	1	-	3	7	-
Vocational Schools with Cafeterias	3	-	-	-	-	-	2	-
Rice Mills	-	1	1	-	1	9	14	-
Sugar Mills	1	-	2	1	-	1	1	-
Coffee Drying Plants	3	1	1	-	1	-	4	-
Tabaco Drying Plants	2	-	-	-	-	-	-	-

patterns of energy use. Plans for alternative technologies and energy conservation should be integrated into the existing patterns of energy use in the various sectors of the Panamanian economy by taking into consideration the type of energy being used (see Tables I and II). Energy planning must be integrated with the overall economic plan. Future energy requirements must be interconnected with future energy economic activity such as industrial output and personal expenditures for energy consuming devices and fuels. Consequently, the assessment of the potential use of solar energy in the Republic of Panamá should be viewed as one part of an integrated energy plan.

1. SOLAR ENERGY ASSESSMENT PROGRAM

In recent years many countries have undertaken energy assessment studies which have included the use of alternative energy sources. The objectives of the Panamanian energy program were:

- to reduce dependence on imported fossil fuels (oil, coal, liquid gas, etc.), and thus limit the impact of world energy prices on the social and economic development plans of the Republic of Panamá;
- to encourage the use of decentralized, renewable resource technologies; and

- to introduce to the Republic of Panamá energy options other than fossil fuel or nuclear power.

A limited number of different applications of solar energy in the industrial, commercial and agricultural sectors of the Panamanian economy were selected for consideration. Site visits to fourteen plants including meat packing, food processing, garment manufacturing, refreshment bottling, tobacco drying and coffee drying plants as well as to a brewery, a hotel/restaurant, a hospital, a school cafeteria, a sugar mill, a rice mill, and a salt refinery were conducted in the four provinces of Cocle, Herrera, Veraquas and Chiriqui. The selection was made from the many types of industry and plants in the Republic of Panamá listed in Table II. Various solar energy applications such as water heating, hot air generation, solar assisted cooling, water pumping and other already demonstrated technologies were considered. The time and resources available limited the scope of the assessment, which should be viewed as a first step toward subsequent alternative energy planning and demonstration activities in the Republic of Panamá. This study, which is limited to solar thermal and photovoltaic systems, presents the potential for solar energy use based on only a limited number of possible applications and on the data collected during two subsequent visits of the assessment team in March and June 1981.[3,4]

It is anticipated that a detailed economic analysis and the policy studies which lie outside the limits of this project will be a natural extension of the present program. An analysis of advanced solar technologies such as central tower power units, stand-alone photovoltaic stations, salt-gradient ponds for electricity generation and high temperature process heat production would require the study of the availability of technology, the economics involved, and the industrial acceptance of a new energy source in the Republic. Moreover, the availability of manpower and materials for manufacturing, installing, operating and maintaining solar systems, the budget limitations, and the timetable of implementation would have to be determined.

By developing solar energy resources for manufacturing commodities in the Republic of Panamá, the foreign exchange component of the balance of payments problem could be reduced. Important social and economic benefits could also result from the establishing of an industrial base on solar energy technologies which could create jobs and products for internal and external markets. Several solar technologies have already been developed to the point where the Republic of Panamá could initiate a solar development plan which could be implemented in a reasonable period of time with a modest capital requirement. The factors stated above could provide the incentive for the Republic of Panamá to consider supporting a program for the widespread use of solar energy in appropriate applications.

Some solar technologies are sufficiently developed so that their selection for near-term applications could favorably influence the economy in the Republic of Panamá. Such applications include water heating and electric power generation for isolated rural areas. The number of economically attractive long-term options will increase as the cost of solar cooling and of process heat generation are reduced as a result of research and development programs in the United States, Europe, Australia and Japan and as larger scale commercial manufacturing capabilities are introduced.

2. SOLAR ENERGY RESOURCE BASE

The Republic of Panamá is located in the Western Hemisphere between the 6° and 10° latitudes and between the longitudes of 77° and 83°.

The Pacific Ocean borders on the south and the Caribbean Sea on the north; consequently, the weather in the narrow Isthmus of Panamá is dependent on oceanic conditions to a large extent. The climate in the Republic of Panamá is tropical with almost uniform temperatures all year. In the coastal areas temperatures range from 23°C to 27°C (73°F to 81°F). Nights are generally cool, and in the highlands the night temperatures range from 12°C to 19°C (52°F to 65°F). There are two seasons, rainy and dry. The rainy season lasts from April to December. The Republic of Panamá averages 165 cm (65 inches) of rain annually in the Pacific area and 305 cm (120 inches) in the Caribbean area. Cloudiness, fog and mist are the main meteorological factors which cause the diffusion of direct solar insolation in the Republic.

In order to achieve the greatest benefit-to-cost ratio, solar energy systems will have to be designed according to the solar radiation available and according to other local climatological characteristics. To design and evaluate the performance of simple solar systems such as solar water heaters, solar dryers, and solar stills, the following information is needed:

- Global solar radiation
- Dry-bulb temperature
- Wet-bulb temperature
- Wind speed and direction.

To size and operate more complex solar systems for industrial process heat, air conditioning and power generation, the direct component of the global solar radiation measurement is also required in the addition to the above data.

A solar radiation data base which provides accurate information for decisions about solar designs is needed in order to implement the cost-effective use of solar energy in the Republic of Panamá. A solar data base network, however, is not sufficient to develop solar energy applications. Research and testing facilities for assessment of components and for systems performance evaluation must also be available and equipped with the proper instrumentation.

The year-round availability of solar energy in the tropics is favorable when compared with areas in the northern and southern zones. Insolation measurements at a particular location on the earth's surface, however, are highly variable. The variations (at the same latitude) from one location to another are caused primarily by differences in local climatic conditions which cause the dispersion or reflection of the insolation incident on the earth's surrounding atmosphere. Local variance in the amount of air pollution also has an effect on the amount of insolation that penetrates through the atmosphere to ground level at any particular location.

The solar data recorded on a daily basis for the Republic of Panamá have been measured and compiled according to the available global insolation on a horizontal plane. This is the predominant method of measurement and reporting worldwide. The availability of diffuse data is rather sparce since only lately has an interest developed and corresponding effort been made to measure and record diffuse solar radiation. In the Republic of Panamá several years of solar data are available as daily totals for stations at David, Tocumen, Los Santos and Antón. Data are also available from the Panamá Canal Commission for several stations in the Canal Zone. The solar insolation measuring equipment and instruments at sites such as Tocumen Station and the Canal Zone undergo conditions of extreme rainfall and humidity almost all year long. The type of instruments used and the frequency of their calibration greatly affect the reliability of the data provided, especially at these sites.

Actonometers are being used at most stations. These solar instruments which are of the mechanical-bimetallicdrum recording type, are commonly used in remote stations where electrical power is not available. Installed in the early 1970's, these instruments have not been calibrated during their lifetimes in the field. Actonometers are designed as class III instruments in the World Meteorological Organization classification system in which class I is the highest quality rating. The recording chart which is driven mechanically by a spring must be first read and then manually interpolated to obtain the daily total values. The accuracy of the data from this instrument can vary widely depending on the care with which it is maintained and calibrated; the accuracy of even a well-maintained instrument could vary from ± 20 to ± 50 percent.

At least five years of data is required to establish the solar radiation climate patterns at a given location. Some of the data required to determine the solar energy resource base of the Republic of Panamá already exist and are presented in Tables III, and IV.

Table III shows the daily average values of the 1975 global solar insolation on a horizontal plane. Table IV shows a compilation of the monthly average of the daily global insolation, year by year, for the following stations: David (1972 to 1979), Los Santos (1973 to 1978), Antón (1971 to 1976), and Tocumen (1971 to 1974). A comprehensive summary and mapping of the solar energy resource of the Republic of Panamá does not exist and the accuracy of the existing data is questionable due to many possible sources of error. The solar data collected so far have to be

TABLE III. DAILY AVERAGE IN 1975 FOR GLOBAL SOLAR INSOLATION ON HORIZONTAL PLANE FOR THE REPUBLIC OF PANAMÁ [5]

Station	Solar Insolation		
	No. of hrs/month	No. of hrs/day	Langley/day*
Bocas del Toro	171	5.6	392
Santa Rosa	174	5.7	-
Icacal	165	5.4	370
Bajo Grande	125	4.1	385
David	184	6.0	381
El Real	117	3.8	-
Los Santos	186	6.1	421
Tocumen	146	4.8	380
Coiba	152	5.0	342
Roya	158	5.2	-

*1 Langley = $4.186 \times 10^4 J/m^2$

TABLE IV. MONTHLY AVERAGE OF DAILY SOLAR INSOLATION ON A HORIZONTAL PLANE, $\bar{I}_h$ (LANGLEYS/DAY) FOR THE REPUBLIC OF PANAMÁ [4]

Station	Month												Yearly Average of Daily Insolation
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	
David	431	488	491	438	393	351	369	372	373	347	344	388	399
Los Santos	466	486	506	497	411	328	351	335	353	337	314	384	397
Anton	444	483	514	493	392	338	369	350	360	346	345	408	403
Tocumen	432	486	455	487	420	394	397	383	416	396	379	450	424

validated and expanded to measure diffuse, direct and global solar radiation to determine in detail the potential of solar energy.

3. SCENARIO OF SOLAR ENERGY IMPLEMENTATION

The most realistic scenario for the near future assumes that government and international institutions promote the rapid and widespread implementation of renewable energy resources in developing countries, such as the Republic of Panamá. This could be done through a combination of subsidies, low-interest loans and regulations. Such action is valid in view of the beneficial foreign exchange, industrial development and employment market which can be associated with the implementation of alternative energy technologies. The further development of these alternative energy sources can be governed by private capital investment and market forces.

The solar energy implementation program could be composed of two phases:

Phase I - Installation and operation of demonstration/test systems, and

Phase II- Large scale manufacture and application programs.

The Phase I would consist of a limited number of installations which would be used to:

- Familiarize Panamanian technical and energy planning personnel with the technology options available;
- Identify potential applications and install small size systems to gain operating experience under Panamanian conditions;
- Indicate which systems are the best choice for manufacturing and use in the Republic of Panamá;
- Identify institutional and social issues which could significantly influence the choice of applications; and
- Set up an institutional network to direct the technical and administrative aspects of the various components of the program.

For advanced technologies such as photovoltaic power units, the demonstration systems should be installed at a limited number of carefully selected test sites which are under the direct control of trained personnel. The purpose of setting up small demonstration/test projects is to familiarize persons in various industries, in government and in the general public with the use of renewable energy technology. This type of demonstration also facilitates the transfer of technology from industrialized countries to the Republic of Panamá. The demonstration projects for the Phase I should satisfy the following criteria:

- Technology must be relevant;

- In general projects should not be site-specific;
- Projects should have wide applicability;
- Technology should be feasible, available and potentially economical;
- Demonstration must increase the knowledge of technology and provide response to a set of specific questions;
- Investment in the project should be in a budget range which will not financially preclude other demonstrations of similar applications;
- Maintenance by locally available manpower should be technically feasible.

This phase of the program requires little or no manufacturing capability in the Republic of Panamá.

During the Phase II of the program the following activities should be done:

- Set up local training and manufacturing centers at an early stage of implementation; vocational schools should be involved in this stage. Other human resources can be used; e.g. car mechanics can be trained to maintain wind machines.
- Make large-scale applications in various sectors of the Panamanian economy possible by arranging international loans and appropriate government incentives;

- Introduce education programs for persons in industry, agriculture, business, and for the general public;
- Introduce standards, regulations and guidelines for the thermal performance, installation and operation of systems.

Because the process of setting up standards, regulations and guidelines is long and tedious, an institutional structure responsible for handling these activites should be established at an early stage. The Comisión Panameña de Normas Industriales y Técnicas (COPANIT) is an advisory body for standards to the Ministry of Commerce and Industry. There are no standards at present in the Republic of Panamá for solar energy conversion and for conventional refrigeration. Regarding solar standards COPANIT is mainly concerned about capabilities to do testing, about availability of manpower, and about insufficient capabilities for developing standards for new industries. A competent institution such as the Instituto de Recursos Hidráulicos y Electrificación (IRHE) or a professional engineering organization could work with COPANIT to develop solar standards in the Republic of Panamá. These activities should be an integral part of the process of developing alternative energy sources in the Republic. Legislative action to create tax incentives for the use of alternative energy sources should accompany the development of solar standards.

Possible sources of international funds for programs in Panamá are the World Bank, Organization of American States, United States Agency for International Development, Overseas Private Investment Corporation, Canadian Development Funds, and European Common Market Development Funds. Such resources could be used to develop local manufacturing capabilites for alternative energy systems/equipment, and to use the available human resources and know-how through training and technology transfer.

An education program for managerial, professional and nonprofessional persons should be developed and implemented to make different groups aware of the energy situation. The newsmedia (newspapers, radio, TV), pamphlets, educational films, interviews, seminars, conferences and workshops could be used to direct the attention of the general public toward understanding the importance of energy issues. The workshops for the general public should make people aware of the status of solar technology, the role it can play in the Republic of Panamá and the benefits it can bring to the people and the country. Persons in industry should be informed about the demonstration systems which exist in other countries, the technological readiness of such systems, the government incentives which are available, and the other economical aspects which are pertinent to the use of solar energy in a developing country. The workshops for government officials should cover issues such as the status of solar technology, the feasibility of renewable resources, the integration of such resources into Panamá's economy, the financial support required, and the investment strategies which can be used. These activities should be a part of the overall political and economic process.

Although a more complete study which would fully analyze the factors mentioned above would be required to define an implementation plan in detail, the solar application scenario outlined above is suitable for the Republic of Panamá when one considers the prospects for solar technologies, the Panamanian resources, and the energy demands projections.

4. SOLAR TECHNOLOGY OPTIONS

Solar energy could be used for heating water for commercial, domestic, agricultural and industrial purposes, for producing process heat for commercial, agricultural and industrial applications, for assisting air conditioning systems, and for generating electricity by using photovoltaic cells. It is difficult to estimate the economic obstacles that still exist concerning the use of solar process heat systems, solar assisted air conditioning and photovoltaic cells. Because of technological readiness and the economics of solar water heating, this type of application has more potential to be used in the Republic of Panamá in the near future and, therefore, it should be treated in more detail.

There are many options available for utilizing solar energy resources in the Republic of Panamá. A combination of photovoltaic and solar thermal units could be used for industrial and agricultural processes. Wind turbines and photovoltaic systems could be used for pumping irrigation water; the former are already cost competitive as replacements for stand-alone diesel units and the latter may become cost effective by the end of the 1980's. Photovoltaic cells are economically advantageous at present whenever there is a need for electric power which cannot be supplied with conventional systems or only at high cost. In this category are such applications as: traffic signs, buoys, beacons, telecommunications, cathodic protection, emergency power supplies, etc. Future decisions regarding which system option is most appropriate will depend on the improvements made during the next five to ten years and on the technical and economical performance of these systems. Various technology options are in different states of development. The implementation programs call for using those technologies which have been proven to be effective and which show the greatest economic benefits. These technologies would include solar water heating and wind turbines. The widespread implementation of the more advanced technologies such as photovoltaic cells, solar aided air conditioning, and solar industrial process heat would be contingent upon a successful demonstration program and on further progress in improving the performance and lowering costs as a result of on going research and development programs in other countries.

In general, the feasibility of any technology or resource depends on the following factors:

- Energy conversion technology must be appropriate to the need;
- Technology should be simple and cost effective;
- Technology should be environmentally acceptable;
- Technology should be compatible with the existing social customs and structure;
- Maintenance demands must be low;
- Private and public institutions should be able to promote and maintain the resource;
- Capital requirements must be within the means of the country's financial resources.

The early installation of demonstration systems will involve purchasing most of the components outside of the Repubic of Panamá. But a significant advantage of solar technology for developing countries which have an existing industry and infrastructure base is that later on a large scale demonstration program can use fabrication and manpower resources available in the country. Solar systems could be installed on a large scale in residential, institutional and commercial buildings and in industrial plants which would result in reductions in the use of conventional fuels.

The operation of small scale (1 to 150 kW) solar thermal power units has been demonstrated. A number of units are operating in the United States, Mexico, Africa and Asia. These systems usually operate in a temperature range from 82°C to 149°C (180°F to 300°F) and convert heat generated by flat-plate or parabolic trough collectors into power by means of organic Rankine cycle engines. The most common application for these power units has been for pumping water.

Photovoltaic power units, which convert solar energy to electricity with no moving parts, are used throughout the world to supply small amounts of power to users located in remote areas which are not serviced by a utility grid. The effective performance of these systems has been demonstrated and efforts are now directed primarily toward lowering their cost, toward the improvement of the power conditioning subsystem, and toward the improvement of efficiency to make the cells competitive with conventional power systems.

The use of air conditioning in the Republic of Panamá is concentrated mainl in urban centers. As living standards improve and the electricity grid reaches more areas, the use of air conditioning is expected to spread to the rural regions of the country. Solar energy can be used to operate air conditioning systems, including those using absorption cycles which require heat, and conventional vapor compression cycles which use electrical or mechanical energy. The technical feasibility of solar air conditioning has been sufficiently demonstrated so that the near term introduction of solar air conditioning is judged to be a workable option for applications in the period of 1985-1990 if the economical aspects of these applications could be improved.

Solar refrigeration can often use the same basic technologies required for solar air conditioning. Solar refrigeration can advance the commercial activities related to agricultural produce and food. From the energy storage point of view the economics of solar refrigeration are more favorable since the storage can be in the form of cold or frozen produce.

A variety of systems with different requirements for manpower, finances and materials could be used to introduce each solar technology option. Solar related energy systems are fabricated primarily from basic construction materials such as steel, copper, wood, plastic, fiberglass, cement, glass and aluminum. The amount of these materials needed will depend on the projected use of solar energy as an alternative energy source in the Republic of Panamá.

In some cases the combination of materials required, could be modified to take advantage of resources in the Republic of Panamá. For example, aluminum could be substituted for steel, plastic pipes for steel pipes, and fiberglass and wood for metal. Creation of new employment markets will be indirectly associated with solar applications in the Republic because some of the basic materials used in the fabrication of subsystems will be manufactured within the country. It can generally be assumed that components which do not require specialized technology and manufacturing capabilities will be made in the country where the systems are installed. In the case of the Republic of Panamá such components would include towers for wind turbine units, collector array support structures, flat-plate solar collectors and some fiberglass shell parabolic trough collectors. Entire systems for solar ponds, both shallow and salt-gradient, could be made in the Republic. Although photovoltaic modules can be manufactured in the Republic of Panamá, sophisticated components for subsystems such as inverters, photovoltaic cells and blades for large wind turbines will have to be purchased abroad. Before making decisions about manufacturing or importing materials and subsystems, an analysis of the industrial capabilities of the Republic of Panamá in relation to the program of solar development needs to be made. Table V presents the cost of some materials in the Republic which would be used in solar applications.

4.1 Solar Thermal Power Systems

A number of solar thermal power systems are in various stages of development. It is expected that by the 1990's the ongoing development and demonstration program in various countries will lead to the commercial availability on the world market of solar thermal systems having a wide power range. A wide variety of solar thermal power systems for pumping irrigation water are already available. These systems consist of thermal collectors, reflectors, heat exchangers and prime movers coupled to water pumps. Conventional manufacturing techniques are used in assembling them,

TABLE V. COST OF SOME MATERIALS IN THE REPUBLIC OF PANAMÁ [2]

Material	Size/Quality	Thickness/Length Weight	Cost in U.S. $ (1981 Dollars)
Galvanized Steel Sheet	0.9 X 1.83 m (3X6ft)	0.20 mm (0.010 in)	5.15
Aluminum Sheet	0.9 X 3.05 m (3X10ft)	0.56 mm (0.022 in)	20.00
Stainless Steel Sheet	0.9 X 3.05 m (3X10ft)	0.46 mm (0.018 in)	57.00
Galvanized Corrugated Steel Sheet	0.3 X 11 m (1X36ft)	0.35 mm (0.014 in)	53.28
Copper Tubing	ϕ25.4 mm (1in)	linear foot	1.25
Copper Tubing	ϕ12.7 mm (1/2in)	linear foot	1.00
Polyethylene	-	136 kg (300 lbs)	400.00
Tedlar	-	136 kg (300 lbs)	400.00
NaCl	Commercial Purity	0.23 kg (0.5 lbs)	0.10
Paint	Anticorrosive	3.78 liters (1 gal)	12.30

and they are made of the common construction materials mentioned previously. For the most part these systems could be manufactured in the Republic of Panamá, thus providing an additonal incentive for their widespread use.

The economics of solar thermal power systems is influenced by their cost and the thermal performance of the solar collector and the prime mover subsystems. Most of the concentrating collectors considered for solar thermal power generation and several of the photovoltaic concentrator systems require highly concentrated direct solar radiation. Therefore, a high rate of diffusion of the global radiation available in the Republic of Panamá will reduce the effectiveness of these types of solar power systems.

Most solar applications which are appropriate for solar thermal power systems can be served by photovoltaic power units. In the future these two technology options could be used for applications including water pumping, air conditioning and refrigeration, village electrification, and eventually for large scale, grid-connected electric power generation. The kinds of systems implemented will depend, of course, on the progress made in lowering the cost and on the reliability and durability of the different systems in field operations.

Air conditioning and refrigeration can be provided by solar energy by means of mechanical power, electricity generation or the direct generation of thermal energy. Some cooling applications have an advantage over more generalized electric power applications since the storage requirements can be in the form of chilled water rather than batteries. If solar powered cooling proves to be reliable and economical, its adoption could result in substantial fuel and operating cost savings for a wide range of public and private users in the Republic of Panamá.

Although the technical feasibility of solar thermal power production is well established, the long-term reliability, low cost and technical performance required to justify a widespread implementation of solar thermal/electrical power conversion have not been demonstrated. More demonstration and development programs are required to identify the best system options for various applications in the Republic of Panamá. The high humidity and the corrosive environment of the oceans will also influence the kinds of systems selected for demonstrations.

The cost of power from a solar thermal power unit is a function of variables such as the initial cost, the annual power output, the operation and maintenance costs, the interest on loans and the depreciation rates. The cost of power usually decreases with an increase in a system's capacity. The cost of solar generated power is still significantly higher than power generated by large central utilities. Small diesel units, however, are often used for pumping water and power generation in remote areas with a cost of $0.14-$0.18/kWh for diesel units of 10 kW power capacity. This cost can be much higher in areas where the maintenance of systems is poor and the diesel fuel supply is expensive. Diesel engines are used in the Republic of Panamá for water pumping, at the La Victoria sugar mill in Santiago for example, and for power generation in remotely located plants, at the Setton coffee drying plant in Chiriqui, for example. It is difficult to estimate the capacity of the diesel pumps and generators installed in the Republic of Panamá and, therefore, it is also difficult to judge the extent to which stand alone solar energy systems can be used to displace diesel fuel there.

4.2 Photovoltaic Systems

An important aspect of the Panamanian government's policy is to improve living standards in rural areas and to develop sparsely populated areas. In many cases this process requires providing electric power for residential, agricultural and commercial aplications. At present, about 46 percent of Panamanian families are without electricity. In 1979, IRHE provided electrical service to a total of 220,000 customers. The distribution of residential, commercial and industrial users was 90.1, 9.5 and 0.4 percent respectively. The number of residential users were greatest in Panamá, Los Santos, Colón, and Herrera provinces and represented 76, 55, 53 and 49 percent of the total number of families within these provinces. Table VI shows the electrical power use in the Republic of Panamá.[6] Photovoltaic power units are well suited for providing power in remote areas where extending the utility grid or operating diesel engines/generators is particularly costly or

TABLE VI. ELECTRICAL POWER USE IN THE REPUBLIC OF PANAMÁ [6]

Province	Type of User			Residential families with electricity (%)	Residential families without electricity (%)
	Residential	Commercial	Industrial		
Bocas del Toro	441	59	-	4.10	95.90
Coclé	9236	798	44	32.78	67.22
Colón	17816	2162	6	53.31	46.69
Chiriquí	20573	2483	472	35.60	64.40
Darien	517	99	-	9.72	90.28
Herrera	8020	862	38	48.79	51.21
Los Santos	7708	828	17	54.68	45.32
Panamá	126474	12863	231	75.86	24.14
Veraguas	7531	712	68	21.65	78.35
TOTAL	198316	20866	876	-	-

impractical. The implementation of this option will depend on the cost of photovoltaic-generated electricity compared to the cost of operating diesel generators. The cost of a photovoltaic system depends mainly on how much energy storage and power conditioning is required and on the cost of the solar cell panels.

Photovoltaic systems will be the most attractive if no grid is available. It is highly probable that in power units under 100 KWh/day batteries will be used, in larger units a diesel generator will back-up the photovoltaic system. Due to a large component of the diffuse solar radiation a flat-panel type photovoltaic cells will be recommended for the Republic of Panamá. Today's advances in photovoltaic cells, however, have been considerably easier to foresee and achieve than those that will be required to make photovoltaic systems competitive with utilities in the future. At present a 20-Watt (no energy storage) module costs about $150-200 depending on quantity and the type of cells and would save approximately $4 per year in electricity in the Republic of Panamá. It is expected, however, that high efficiency photovoltaic cells will be made from relatively low-cost materials within a decade.

Several applications of photovoltaic demonstration units which use small systems, however, could be used locally to drive irrigation pumps and refrigeration units or to provide small amounts of power for use in villages. These systems would have to be located near the loads being served. For these applications land use requirements could be an important factor since such applications tend to be centered in areas of high population or extensive agricultural activities.* For larger applications of village electrification and residential use (assuming 2-1 kWh/day per dwelling) the land and grid interfacing requirements would have to be evaluated in more detail during the Phase II of the program.

Most regions of the Republic of Panamá are sparsely populated. Therefore, sufficient land areas are available for larger scale photovoltaic or solar thermal units that would tie in with the utility grid which is relatively extensively developed in urban areas.

4.2.1 Utility Interface

A large demonstration program of solar energy use should include the option of utility interfaced photovoltaic power. The displacement of a significant amount of electric generation capacity by photovoltaic power units will affect utility operations because the output of the solar power units will be highly variable and will depend on sunshine availability. The widespread use of photovoltaics will therefore require a study of the utility interface and of the impact of the use of photovoltaics on the optimum mix of conventional power systems, on the need for energy storage, and on the utility rate structure.

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*About 10 m^2 of collector panel area is required per peak kW of output capacity. The resultant land use required for a 10 hp pumping system would be about 240 m^2 of collector panel; spacing requirements to avoid shading are taken into account.

The optimization of the overall power generation and distribution system is an important part of the solar power and utility interface and should be analyzed during the demonstration phase. This optimization depends on factors such as electric power demand characteristics, cost of storage alternatives, mix of conventional generating facilities, and solar/wind resource dependability. If no storage is built into either the solar power units themselves (batteries, thermal storage, compressed air) or into the overall utility system (pumped hydro), the solar electricity generation systems function primarily as fuel savers and the requirements for conventional generator capacity are not significantly modified. From the technical and economical points of view, a few hours of energy storage to smooth out the clouds impact on electrity generation by solar energy may be recommended in the case of large, utility integrated solar power stations.

The solar generated electricity could be integrated into the country's distribution grid if the solar-electric plants capacity will not exceed up to 15 percent of existing capacity of electric plants in the Republic of Panamá. The IRHE expressed a willingness to buy solar-electric power at the rate of $0.065/kWh.* In the case of solar electricity generation at an isolated site, this rate could be increased to $0.085/kWh* according to IRHE. In addition, IRHE agreed that the present electric rate structure should be studied

*An industrial customer pays approximately $0.08-$0.12/kWh (1980 prices) to encourage energy conservation through financial incentives and through the use of alternative energy systems for electricity generation.

The IRHE uses five different electricity rates: one for the residential sector, one for public lighting, and three for commercial/industrial users. Customers are divided into small electricity users - below 5 kW, medium users - 6 to 29 kW, and large users - over 30 kW. Small and medium users are charged only for the electricity use in kWhrs. The large users pay according to the load factor and to the peak power energy use; Load Factor = kWhrs/8760 hrs x kW. This electricity rate structure was established in 1977. Persons interviewed in the Panamanian commerce/industry sector voice the opinion that the IRHE rate structure does not encourage energy conservation and hinders Panamanian national interest since a commercial/industrial customer using a lower number of electricity hours at the same capacity will have to pay higher rates.

4.3 Solar Water Heating Systems

The use of solar energy for hot water in the Republic of Panamá will depend largely on government policy and international loans. The government's desire to reduce imported oil, to alleviate the balance of payment problem, to improve the living standards in rural areas and to integrate the remote villages into the national life may positively affect the development of solar water heating industry and applications.

The government's commitment to improve life in the rural areas could suggest a commitment to support the installation of solar water heaters in rural areas. In addition to heating water for households and schools, water heating will be possible for institutional and commercial buildings such as hospitals and hotels and for industrial processes needed in textile and food processing industries, the refreshment making industry, and the coffee and tobacco industries. No solar systems supply process hot water or pre-heating boiler feed water in the Republic of Panamá. The pattern of market penetration by solar energy in other countries seems to indicate that institutional and commercial applications may increase the use of solar water heaters, in terms of area of collectors and energy savings, by roughly 20 percent over that used for residential applications.

Figure 2 shows the potential energy saving calculated on the base of the information received by the assessment team if solar heated and preheated water were used in various sectors of the Panamanian economy as shown in Table II.[3] Assuming 40 percent as the conversion efficiency of a solar system and the solar resource data of Table IV, this will result in an energy saving of $2.44 \times 10^9 J/m^2$-yr ($2.15 \times 10^5 Btu/ft^2$- yr) or $4.9 \times 10^{10} J/m^2$ ($4.32 \times 10^6 Btu/ft^2$-yr) in 20 years of a system's lifetime. For a typical solar water heating system which has a collector area of $3.6 m^2$ ($38.7 ft^2$), the energy saving will be 1.76×10^{11} Joules (1.67×10^8 Btu). This corresponds to the saving of 4561

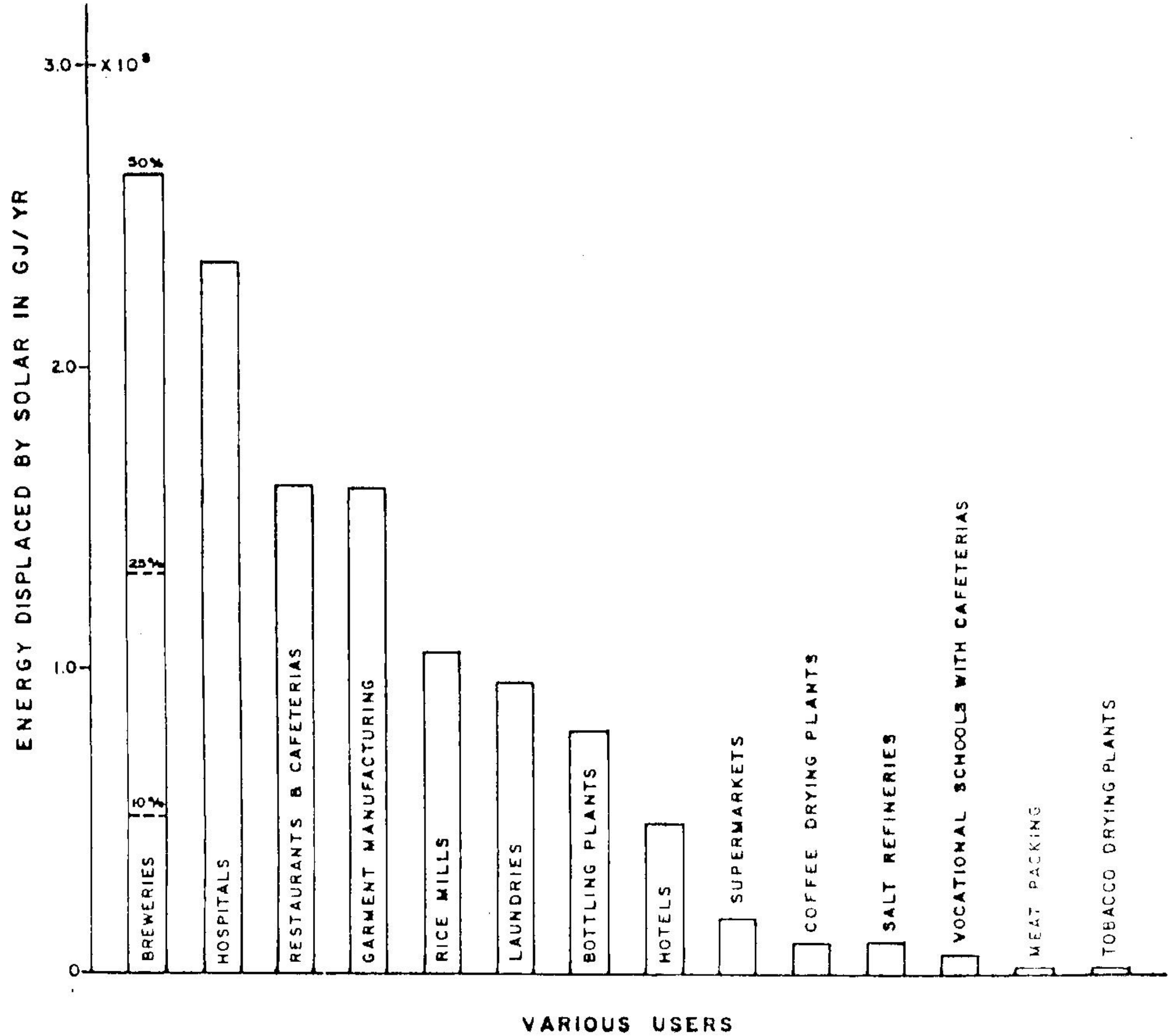

Fig. 2. Potential Energy Saving by Using Solar Heated Water in the Republic of Panamá.

liters (1205 gallons) of diesel fuel or fuel oil Nr. 2 for a single solar domestic water heating system during its twenty year lifetime.

For the applications listed in Table II, the overall energy saving in water heating will vary from 2.2×10^5 GJ/yr(2.0×10^{11} Btu/yr) for 10 percent of solar energy contribution to 1.7×10^6 GJ/yr(1.6×10^{12} Btu/yr) for 50 percent of solar energy contribution which corresponds to the savings of 1.1×10^8 gallons) of diesel fuel during 20 years of the solar systems' use respectively.

The rate at which solar water heaters are installed and consequently the potential energy saving which will result depends on the action taken by the Panamanian government and the assistance of international lending institutions. The effective and widespread implementation of solar water heating in the Republic of Panamá will depend on the development of solar hot water systems which are economical and appropriate. It is expected that the following kinds of solar hot water systems may be suitable for different applications in the Republic:

- Active systems
- Thermosyphon systems
- Refillable systems.

Active systems will be most appropriate in commercial buildings such as hospitals, hotels, restaurants, laundries, schools and appartment buildings where electricity, running water and a storage place are available.

Thermosyphon systems are suitable for the rural areas with non-freezing climates and where electricity is not available. These systems do not use pumps and controls. They are also very popular in the urban centers of many countries.

The refillable systems in which the collector and the storage are combined is a simple, low cost application of solar energy. Although they may not be used in situations where the refilling is considered an unacceptable inconvenience, the low cost of these systems make them a reasonable option for low income families in rural areas.

No significant technical constraints or human resources limitation exists concerning the production of solar water heating units in the Republic of Panamá. Most of the components of solar domestic water heating systems can be manufactured in the Republic of Panama. This kind of production can be incorporated into the present industrial infrastructure and can enhance industrial development. The requirements for labor, particularly technical labor for the assembling and installation, are within the Panamanian capabilities. Although the benefits of solar water heating are significant, it is evident that only with the government's commitment to overcome the existing capital cost barrier can solar energy provide a major contribution to the energy economics in the Republic. In a country where capital is in short supply and institutional barriers discourage capital investment in new energy systems, only the government and international aid to develop such systems can overcome the capital cost obstacles.

The foreign exchange losses and the desire to improve the standard of living of the Panamanian people should create a favorable political climate for solar water heating. Solar water heaters will primarily reduce the amount of energy required to heat water for bathing and laundering.

In view of the above factors, a demonstration of solar hot water heating by using flat-plate collectors was the technology selected by the IRHE for Phase 1 since it is suitable for all geographical areas of the Republic of Panamá and since it could be integrated into the present manufacturing infrastructure. A photovoltaic power unit demonstration/test project was also a selected technology because of its long term potential and the good perspectives for module manufacturing in the Republic.

4.3.1 Economics of Solar Water Heating

The economics of solar water heaters will be a primary determinant of their market acceptability. System economics will be influenced by the initial installed cost, operating and maintenance costs, financing costs (interest rates), system life (depreciation), cost of conventional energy, system performance (efficiency), and insolation levels. The initial installed cost depends mainly on the material cost and the labor cost. The principal components of an active solar hot water system are a solar collector panel, a structure for collector mounting, a storage tank, piping, and pumps and controllers.

TABLE VII. COST OF LABOR IN THE REPUBLIC OF PANAMÁ [2]

Trade	Qualifications	Cost of Labor/hr (1981 Dollars)
Mason	Qualified	$1.16
Carpenter	Qualified	1.16
Booster	Qualified	1.16
Plumber	Qualified	1.16
Painter	Qualified	1.16
Electrician	Qualified	1.16
Welder	First Class	2.30
Pipefitter	First Class	2.50
Operator	Light Equipment	1.55

The labor cost related to the economics of solar water heating systems if they were manufactured in the Republic of Panamã is shown in Table VII.

Readily available financing programs, tax credits or other financial means must be created to deal with the problem of the high first cost of solar systems. Stimulating the use of heated water, even if solar energy is used, involves a substantial initial commitment to import the equipment or at least some of the materials which will be required. The government and the business sectors should be made aware of the lifetime cost as opposed to the first cost of water heating systems in this situation.

Figure 3 shows the monthly savings of a solar hot water system assuming various electricity rates and the solar system costs. In the case of the Republic of Panamá, which has an electricity rate of \$0.08-\$0.12/kWhr, a solar system with a collector size of 3.6 m^2 (38.7 ft^2) having a 40 percent conversion efficiency would produce a monthly saving between \$17 to \$26. The solar produced heat cost will be \$8 to \$13 per 10^9 Joules (9.48 x 10^5 Btu) for the installed cost of solar domestic water heating systems in the range of \$150/m^2 to \$200/m^2 (14/ft^2 to \$18 ft^2). This solar heat cost includes the manufacturing of the systems in the Republic of Panamá, a twenty-year life of the solar system, an operating and maintenance charge of 2 percent of initial costs, and a government or international loan to subsidize the systems' introduction on the Panamanian market, and an 8 percent interest rate on the loan funds. It is clear that

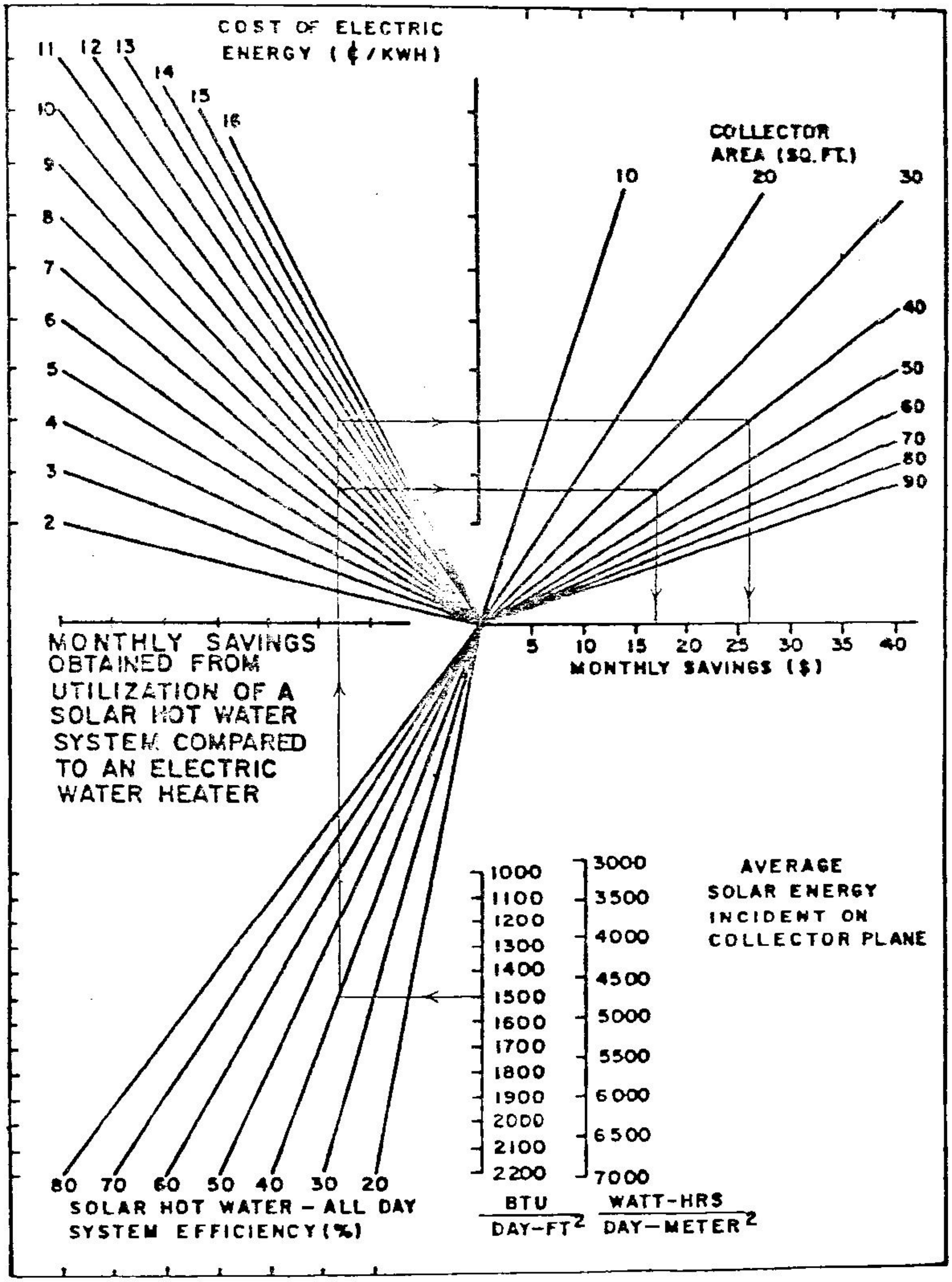

Fig. 3. Monthly Solar Hot Water Savings

the system cost per square meter has a significant influence on the cost of the solar generated heat and its reduction could accelerate the market penetration by solar water heaters.

It can be assumed that reductions in costs for solar water heating over the next few decades will be considerably less than those for solar photovoltaic or solar thermal power plants because the technical and engineering status of the latter systems are expected to improve greatly. Cost reductions on more developed technologies are brought about primarily by savings from volume production of the required equipment and engineering savings in equipment manufacture, installation, operation and maintenance activities. Cost reductions, however, will be limited because a large part of the cost is associated with conventional generators and controls.

4.3.2 Market Penetration

If the government does not strongly support solar water heating in the Republic of Panamá, the market penetration will depend on the economics of solar water heaters as established by the free market. Yet the foreign exchange and the industrial and social benefits of solar water heaters may induce the government to encourage their wide-spread implementation. In the latter case a broad range of actions is possible ranging from establishing standards to creating financial incentives (low-interest loans, tax credits, grants) to encourage the installation of solar water heaters. Such a solar program would create rural development, energy savings, favorable foreign exchange rates, the availability of capital, resource utilization and industrial development.

Market penetration will also depend on a number of variables such as fuel cost and supply, solar systems cost, market response, capital availability and the income levels of the consumers. The difference between the urban and rural areas is likely to have less of an effect on the market penetration of solar water heaters than on the type of solar systems which are installed. Nevertheless, the market resistance, the capital availability problems and the lack of government and international loan commitments would inhibit significantly the market penetration of solar water heaters.

The benefit to the foreign exchange and to the creation of jobs in relation to solar water heating would justify an additional 30 percent subsidy for water heaters. This would result in a decrease in the payback period and an increase in the market penetration. Without such an initiative, the present "wait and see" attitude of the market will continue since the transition to new fuels or systems usually takes from 30 to 50 years in the absence of any strong incentives.

The nature and the extent to which the manufacturing/marketing/installation/maintenance infrastructure develops to support the solar industry will be an important factor in achieving market acceptance. If the systems are appropriate, reliable and economical, are marketed and financed effectively, and are installed and maintained properly, the industry and the market penetration can be expected to develop rapidly and overcome the constraints that exist. In the case of solar water heaters, the rate of implementation can be estimated using the payback period versus the market penetration. It may be assumed that a six year payback period would result in a 1 percent penetration of new construction. Solar water heater market penetration will also depend on the rate of increase in the standard of living. In rural areas where hot water is a luxury and not a necessity, potential purchasers of solar water heaters may prefer other consumer items such as radios and television sets. Because no data exist on the hot water use in the various sectors of the Panamanian economy, the exact amount of the market which can be supplied by solar water heating is hard to determine. Nevertheless, a policy to encourage market penetration by solar water heaters should also be supported because of environmental considerations. Technology assessment studies prepared for other countries indicate that solar water heating has a net positive environmental impact in developing countries because it reduces the depletion of forests and other biomass resources.

4.3.3 Manpower Training

Educational institutions such as universities, high schools and vocational schools should introduce energy subject-matter into their curriculums and use their technical capabilities to initiate manufacturing of alternate energy devices (see Figures 4 and 5). In vocational schools solar collectors and solar water heaters could be produced and plumbers and contractors could be trained.

The training required for most of the fabrication, installation, and operation of solar systems is far less than that required for most conventional energy conversion facilities. It should not be difficult to train people to take advantage of the employment opportunities resulting from a solar implementation program. Solar water heating and certain other solar applications offer significant foreign exchange advantages. Over 50 percent of the installed system costs are labor-related and the Panamanian labor could readily be trained to perform these labor requirements. In addition, many of the basic materials and much of the equipment required could be manufactured in the Republic of Panamá.

The widespread implementation of the solar applications program will require the training of manpower skilled in management, science and engineering, manufacturing and production, installation and maintenance, and systems operations. One goal of Phase I is to provide a group of experienced personnel who can assist in initiating manpower training centers as part of the Phase II activities.

Many of the solar energy subsystems use components such as support structures, towers, piping/plumbing, and storage

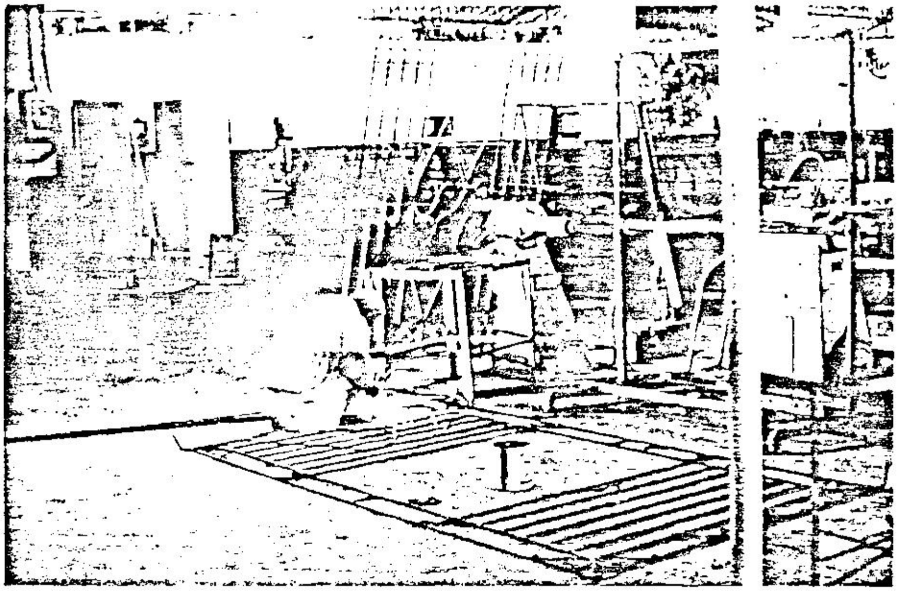

Fig. 4. Welding at Escuela de Artes y Oficios in Panamá City.

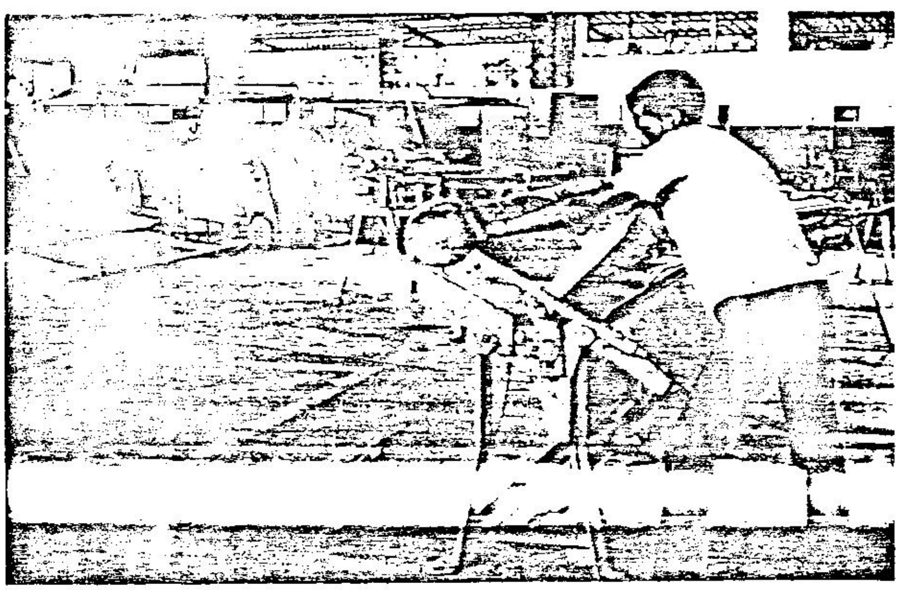

Fig. 5. Sheet Metal Cutting at Escuela de Artes y Oficios in Panamá City.

tanks which are similar in construction to conventional equipment. These subsystems require workers skilled in sheet metal forming, molding, plumbing, welding, mechanical assembly, carpentry, glass handling, site preparation, and concrete pouring as do conventional power systems.

A significant part of the manpower requirements involve basic skills similar to those already being provided by the existing manpower training/education infrastructure. Special training will be required, however, for many aspects of the solar related equipment design, manufacture and installation. For example, engineers will need to be trained in design and size solar water units, industrial process heat and photovoltaic power systems, and personnel will need to be trained to maintain wind turbine plants. The proper training of such personnel should take place at an early stage of the program to provide qualified manpower for the implementation of Phase II. Such training should include solar theory, design and layout instructions, system sizing methods, construction techniques and materials, building collectors and systems, and testing, maintaining, repairing and operating solar units.

4.3.4 Institutional and Social Considerations

In addition to the financial considerations and to governmental participation in the program, institutional factors influence the use of solar energy in a country. New products or systems must be introduced in the context of the established customs, social issues, political environment, existing industries and infrastructures. Solar energy in the Republic of Panamá may require some changes in living habits which call for a government or manufacturer sponsored education program. For example, the use of solar hot water systems may represent a significant departure from established habits in water collection, distribution and use.

5. EXPECTED IMPACT OF SOLAR TECHNOLOGIES

To determine accurately the extent to which solar energy technologies can be employed, a detailed market survey of issues such as technology availability, economics, consumer acceptance, and manufacturing capability needs to be done. In all cases, the widespread implementation of solar water heating, process heat generation, cooling and power systems will require positive action on the part of the government. It can be assumed, however, that government incentives can not be provided unless the basic economics of the solar option appear attractive when compared to more conventional options. In contrast to the individual decisions involved in the purchase and use of water heaters in the industrialized countries, most of the solar power systems in developing countries are purchased and installed by government agencies. The large grid-connected systems which would have a significant impact on the nationwide energy source will have to be purchased by a government backed-up loan in the Republic of Panamá.

The implementation rate for solar energy use would depend on the market development for solar systems if the economics of such systems proved favorable in Phase II. In general, the implementation rate for solar energy applications will be limited by materials, financing and available labor. The economics of internal resources such as labor and materials which would be used in the construction of solar power units would be compared to those of conventional power plants. The assumption is that the initial installations would be non-grid connected so that the relatively high cost of solar energy could be used to supplement or replace the energy produced conventionally by the diesel generators and diesel driven pumps which are costly to operate. Later applications would include installations which could be grid connected when improvements in the economics of solar energy systems would make such systems competitive with larger scale utility generators.

An accelerated solar implementation for power generators implies government action in the form of subsidies, standards and regulations to provide the base for the rapid build-up of the manufacturing capability during Phase II and in the future. It is anticipated that by the mid-1990's solar technology demonstrations will be used to indicate the type of technology, engineering, manufacturing and installation measures which will assure that solar energy systems are economically competitive when reasonable initial subsidies are provided. It can be projected that solar energy in its various forms can supply up to 15 percent of the electric energy needs in the Republic of Panamá. Such an increase in electric capacity could be absorbed by the present utility grid without causing any network disruption. Further increases in solar electric generating capacity could significantly influence utility operations and may require substantial additional energy storage capability in pumped storage or when integrated with the solar power systems, i.e. batteries which would adversely affect a system's economics. These factors do not limit the role of solar energy in the Republic of Panamá to the 15 percent range, but they do indicate the issues which need to be analyzed in the planning of a large scale solar applications program.

6. CONCLUSIONS

A general conclusion is that each of the plants visited in the Republic of Panamá could use solar energy in its direct form, or in the form of wind power, or in its biomass form. In some cases a company's interest may be strong enough to provide matching funds for a solar system pilot project. Various systems need to be evaluated and the demonstration of selected ones carried out. A technology demonstration program should be started to field-test some of the different concepts. Systems that could be tested include solar energy use for hot water generation and air conditioning (collector area of up to 1000 m^2), photovoltaic power units (0.5 to 5 kW), small (5 to 25 kW) and large (100 to 200 kW), wind machines and anaerobic digester systems similar to the 20 m^3 flexible, horizontal, plug-flow, semi-continuous anaerobic fermenter which was installed at a farming cooperative in the town of Santiago.

Almost all the plants visited could reduce their fossil fuel consumption by introducing energy conservation measures. An energy audit should indicate the areas which need improvement. Energy conservation measures should be implemented before the application of alternative energy sources is considered.

Future studies should be made to determine the direct, diffuse, and total solar components of solar availability in the Republic and how the ratio of direct to diffuse radiation varies at different locations throughout the country.

The development of an industrial base for solar water heating systems is important because of the current availability of proven technology and the wide range of possible solar applications in the Republic of Panamá. Organizational structures to manage the development of a solar water heating industry need to be established and government subsidies and a regulation policy determined. A financing mechanism with affordable interest rates must also be established to make possible the development of manufacturing and widespread applications of solar energy. In addition, the

Republic of Panamá should undertake a more systematic program to use solar energy by relating it to long-term integrated energy planning, economic sector planning, resource data and analytical methods development, and near-term infrastructure requirements.

The Panamanian government should support indigenous research on low cost solar technology development, provide consumers applications, make capital more accessible to those wishing to install solar systems, and identify and remove institutional barriers to the use of solar technologies.

Solar water heating in the residential, commercial, and industrial sectors has a good potential in a short term (Phase I and Phase II) and photovoltaic powered stand-alone electricity systems, industrial process heat generation and solar powered air conditioning in the commercial sector have some potential as solar energy applications in the Republic of Panamá in the long term, and they should be considered as potential candidates for the Phase II demonstrations.

Acknowledgement

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