DOE/NASA/0180-3
NASA CR-165441

Market Assessment of Photovoltaic Power Systems for Agricultural Applications in Mexico

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July 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-180

for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Division of Solar Thermal Energy Systems

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Washington, D.C. 20545
Under Interagency Agreement DE-AI01-79ET20485

ACKNOWLEDGEMENTS

The study team wishes to express its thanks to the many Mexican government officials, equipment distributors, farmers and others who generously contributed their time and effort to provide the data requested, and especially to Ing. Arturo Diaz Camacho, Director-General of Operations of COPLAMAR and Lic. Marco Antonio Morelos Chon, Director-General of PIDER, who wholeheartedly provided the resources of their staffs to assist the team in gathering the field information on which this report is largely based. Special thanks are also extended to Mr. Robert Wilcox, Science Attache at the U.S. Embassy in Mexico City, for his assistance and cooperation.

Abbreviations and Acronyms

BANRURAL - Banco Nacional de Credito Rural (National Rural Credit Bank)

BHP - brake horsepower

BORUCONSA - Bodegas Rurales de CONASUPO, S.A. (CONASUPO Rural Warehouses, Inc.)

CONASUPO - Compañía Nacional de Subsistencias Populares (National Basic Foodstuffs Co.)

CONACYT - Consejo Nacional de Ciencia y Tecnología (National Science and Technology Council)

COPLAMAR - Coordinación General del Plan Nacional de Zonas Deprimidas y Grupos Marginados (General Coordination of the National Plan for Economically Depressed Zones and Marginal Groups)

CFE - Comisión Federal de Electricidad (Federal Electricity Commission)

DIGAASES - Dirección General del Aprovechamiento de Aguas Salinas y Energía Solar (General Management for Saline Water and Solar Energy Development)

FIRA - Fondo de Garantía y Fomento para la Agricultura, Ganadería y Avicultura (Guarantee and Development Fund for Agriculture, Livestock and Poultry)

IIE - Instituto de Investigaciones Electricas (Electricity Research Institute)

IIM - Instituto de Investigaciones en Materiales (Materials Research Institute)

IPN - Instituto Politécnico Nacional (National Polytechnic Institute)

KVA - Kilovolt-ampere

KWH - Kilowatt-hour

KWp - Kilowatt-peak

l - liter

lcd - Liters per capita-day

PIDER - Programa Integrado de Desarrollo Rural (Integrated Rural Development Program)

SAHOP - Secretaria de Asentamientos Humanos y Obras Publicas (Ministry of Human Settlements and Public Works)

SARH - Secretaria de Agricultura y Recursos Hidráulicos (Ministry of Agriculture and Hydraulic Resources))

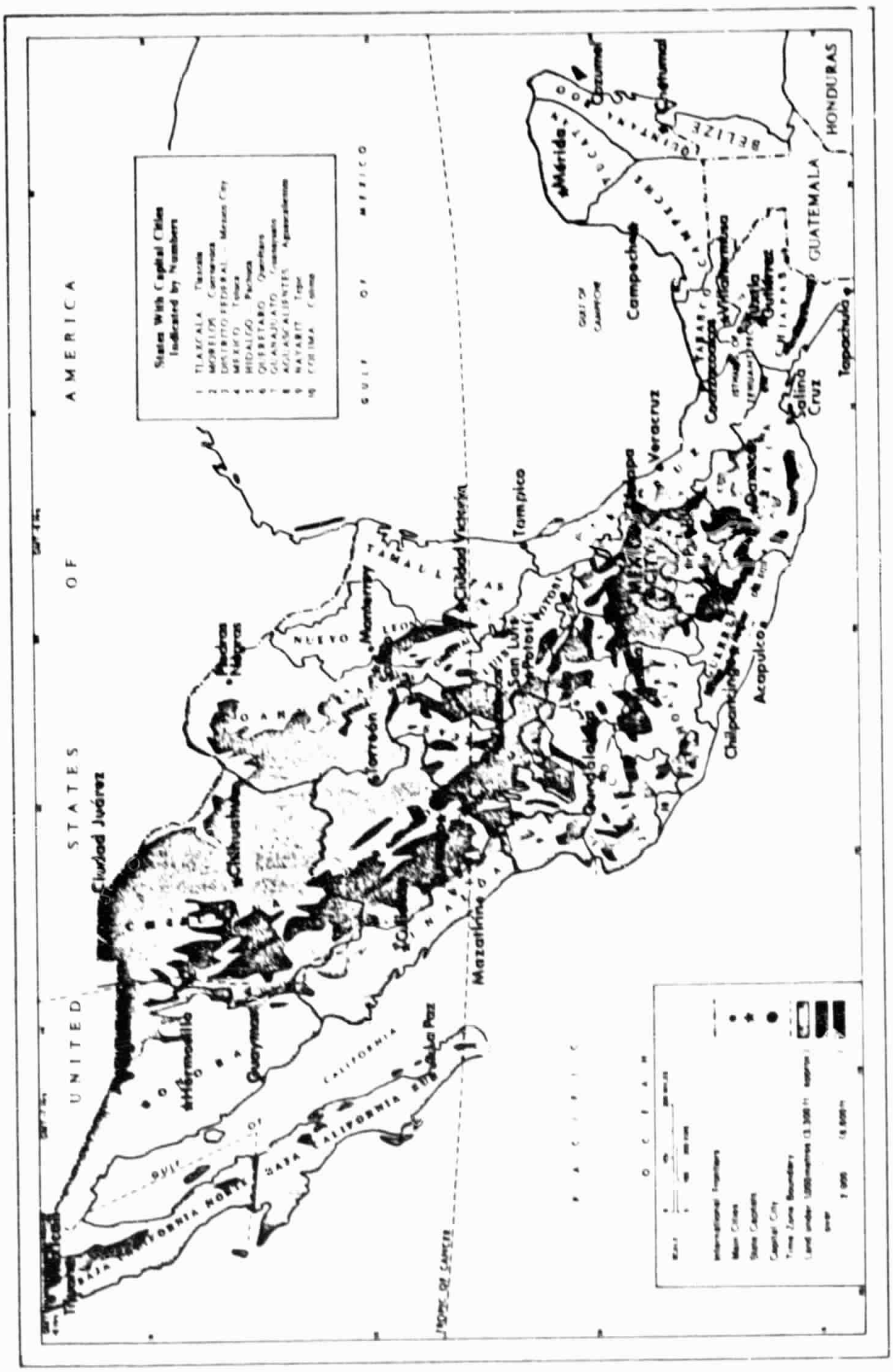
SPFI - Secretaria de Patrimonio y Fomento Industrial (Ministry of Patrimony and Industrial Development)

SPP - Secretaria de Programación y Presupuesto (Ministry of Planning and Budget)

WP - Peak watt

UNAM - Universidad Nacional Autónoma de Mexico (National Autonomous University of Mexico)

Exchange rate used in all conversions in this report - U.S. $1.00 = 23.5 Mexican pesos (prevailing exchange rate during March - April 1981)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Tapachula
Campeche
Mérida
Cozumel
Chetumal
BELIZE
GUATEMALA
HONDURAS
TROPIC OF CANCER

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

MARKET ASSESSMENT OF PHOTOVOLTAIC POWER SYSTEMS FOR AGRICULTURAL APPLICATIONS IN MEXICO

Executive Summary

Objectives

The Photovoltaic Stand-Alone Applications Project Office of NASA/Lewis Research Center, Cleveland, Ohio, is conducting an assessment of the market for remote photovoltaic (PV) power systems in worldwide agriculture for the U.S. Department of Energy. The study is to identify PV applications and countries with a high sales potential so that industry may develop appropriate market strategies. The applications considered are those requiring less than 15KW of power and operating in a stand-alone configuration without back-up power. In such applications, cost-competitiveness is based on a comparison with conventional gasoline and diesel power sources. This specific study assessed the market for PV in the Mexican agricultural sector and in rural services.

The objective of the study was to determine for each application the first year of cost-competitiveness, to estimate the market potential thereafter, and to discuss the environment in which PV systems would be marketed and employed. Emphasis is placed on stand-alone applications that are competitive prior to 1986; after this period with further cost reduction utility connected PV systems may become competitive.

The following market elements specific to Mexico are addressed in the report:

(a) Useful applications and estimates of the potential market for PV systems;

(b) power requirements and load profiles for applications compatible with PV usage;

(c) operating and cost characteristics of power systems that compete against PV;

(d) national development goals in rural electrification and rural services, technology programs and government policies that influence the demand for PV in Mexico;

(e) financing mechanisms and capital available for PV acquisition;

(f) channels for distribution, installation and maintenance of PV systems; and

(g) appropriate methods for conducting business in Mexico.

Study Approach

The market study for PV in worldwide agriculture was conducted by DHR, Incorporated, with Associates in Rural Development, Inc., as a subcontractor.

The present report is the third in a series of field studies, following studies in the Philippines (Oct.-Nov. 1980) and Nigeria (Jan.-Feb. 1981). The scope of these studies includes livestock, forestry, fisheries, crop production and rural services.

A study team composed of one DHR and one ARD specialist, accompanied by a NASA representative, arrived in Mexico on 3/8/81 for a 4-5 week field study. The team divided its activities between the Federal District and extensive field visits in the states of Zacatecas, Jalisco, Morelos, Oaxaca, Tabasco and Yucatan to study first hand the characteristics of Mexican stand-alone operations which might use PV as a power source. The team collected the data through meetings with Banrural, CFE, CONACYT, COPLAMAR, DIGAASES, FIRA, PIDER, SAHOP, SARH, and SPFI officials, IPN and UNAM-IIM scientists, U.S. Embassy officials, private sector representatives and farmers (see Abbreviations and Acronyms). A total of about 100 persons were interviewed, and appropriate sources of published information were consulted.

Various rural and agricultural power uses were investigated for applicability to PV. For the economically feasible applications based on projected PV costs, the present value of life-cycle cost was compared with that of an alternative power source to determine the first year of cost-competitiveness. The potential market for the following five years was estimated.

Status of PV in Energy Development Plans

The prime focus of Mexican energy policy in recent years has been the development of its vast petroleum and natural gas resources. Because it is self-sufficient in energy, Mexico is able to keep internal fuel prices below world prices as a means of encouraging industrial growth and of controlling inflation (recently at 30% per year). Presently, gasoline sells for $0.46 per gallon, kerosene for $0.24 and diesel for $0.16 per gallon.

About 88% of Mexico's primary energy is derived from its petroleum and natural gas resources. As a result of Mexican energy policy, growth in domestic demand for hydrocarbon fuel exceeded the growth rate in Gross Domestic Product (GDP) by 70% for the period 1975 to 1979.

The rapid rate at which Mexico is consuming its hydrocarbon resources is recognized in the present Energy Plan, Goals to 1990 and Projections through 2000*. Consequently, emphasis is being placed on the development of Mexico's coal, hydro, geothermal and uranium resources in order to decrease dependency on oil and gas in the long term. Fuel replacement by solar energy is less a goal than is the development of a solar technical capability.

The strategy of the Federal Electricity Commission (CFE) is to electrify larger rural communities (i.e., those with more than 500 inhabitants) first. Priority is given to villages which are no more than seven miles from the primary power distribution lines. Thus, they can be electrified using 20-30kVA transformers. Nearly all villages over 500 people will be electrified by 1982, according to the President's goal. For small remote communities, the CFE

*Energeticos, Boletin Informativo del Sector Energetico, Volume 4, Number 11. November, 1980.

generally provides electricity via diesel generators. Approximately 19,460 KW of diesel generators were installed by the CFE between 1978 and 1979. However, increased attention is now being given to alternate sources such as solar and small hydro. CFE officials expressed a reluctance towards applying solar systems because they cannot control their operation and do not consider most villagers capable of maintaining the equipment. However, when PV becomes cost competitive with large diesel generators, this large rural development market will hold potential for photovoltaics.

The Mexican government's policy of subsidizing energy costs to residential and industrial consumers makes it difficult for PV and other nonconventional energy systems to compete in the Mexican private sector market. The real (deflated) price of electricity has been steadily diminishing since 1962. Gasoline prices have been increasing at about the same rate as the cost of living, and recently at a lesser rate. As a major oil producer, Mexico can afford the policy of cheap internal energy prices, so this is likely to continue.

At current prices it is unrealistic to expect significant private sector interest in PV as an alternative to internal combustion engines. Private sector interest will be limited to applications for which internal combustion is not a practical alternative (mainly home TV in isolated locations). The primary market for PV in agriculture in the near term appears to be in the public sector.

<u>Implications of Mexican Agricultural Development Plans for PV Systems</u>

Mexico, with a population estimated at 68 million in 1980, has one of the highest demographic growth rates in the world, 3.4% per year. The per capita gross national product (GNP) is $1.090 (U.S.). Approximately 40% of the population is engaged in farming, fishing, and forestry, a percentage which has been declining due to migration from rural to urban areas. Agriculture's share of gross domestic product has declined to about 10%.

Mexico is the third largest country in size in Latin America. Mean daily solar insolation in Mexico ranges from about 375-540 langleys/day. Approximately 60% of the land is arid or semi-arid, and only about 15% is suitable for cultivation, a third of which is fallow. Due to varied climatic conditions, Mexico is able to produce both temperate and tropical foodstuffs. 50% of agricultural production is from the irrigated 25% of cultivated land.

In the central plateau region near Mexico City, maize, beans, soybeans and other crops are grown and dairy products and pork are also produced. Along the rainfed gulf coast, sugar cane, bananas, maize, and coffee are raised. In the southern semi-tropical state of Tabasco, beef, cocoa, bananas and sugar cane are the principal products. Maize, beans, sesame and cotton predominate, in Chiapas. In northwestern Mexico, cash crops such as fruits, vegetables and soybeans are grown.

The irrigated areas of northern and northwestern Mexico are characterized by large farm units, intensive mechanization, cash crop production and developed marketing facilities and government services. In the central plateau, farm units tend to be small, mechanization not widespread and traditional agriculture predominant. In the gulf coast lowlands, large farms produce commercial crops, but the level of mechanization is low. The poorest farming conditions in the country are along the southwest coast, where subsistence farmers cultivate small plots with primitive implements. In the Yucatan peninsula, traditional methods and subsistence crops also predominate but an attempt is underway to diversify the agricultural production with citrus and vegetable crops.

The total cost of the Mexican government's agricultural development program in 1980-81 will approximate U.S. $2.2 billion for production programs and U.S. $1.5 billion for consumption side activities.

The principal goals of the official Mexican Food System are to 1) maintain self-sufficiency in the production of corn and beans by 1982, 2) attain self-sufficiency in other staples by 1985, and 3) improve the nutrition levels of low-income Mexicans. The plan is composed of 12 program areas, one of the most important of which is the shared risk program, which guarantees a minimum income to farmers in rainfed areas who produce certain basic foodstuffs. By means of a price support policy, the government hopes to increase and diversify crop production. Under the system guaranteed prices will increase 6.3% for corn, 11.8% for beans and 3.6% for wheat between 1981 and 1982, in real terms, and the cost of inputs to producers will be subsidized.

The government optimistically has established a goal of 5.5 million additional hectares of land to be brought under cultivation by 1990 through a variety of irrigation schemes. The government also is attempting to modernize railroad transportation and improve port and handling facilities, particularly for agricultural commodities. Furthermore, a nationwide program for the construction of grain storage facilities at the major production and consumption centers was begun in 1980.

Agricultural operations which appear to hold promise for PV use in the near-term include cattle watering, rural potable water, small grain loaders, and rural refrigeration (see Potentially Feasible PV Applications for Market size estimates).

Availability of Long-Term Investment Funds for Photovoltaic Systems in Agriculture

Private venture capital in Mexico tends to be short-term and interest rates on short-term loans are high. Therefore, the principal sources of low-interest long-term loans will continue to be government development and agriculture banks and the multibancos. The low-interest loans only apply, however, to priority government activities, which photovoltaics at this point is not. If a PV project were to be funded by a domestic loan, it would likely be from NAFINSA, since that organization provides most financing for development projects, including irrigation and agricultural infrastructure, or by Banrural, which makes most long-term agricultural loans to ejidos and small farmers.

In interviews, public banking sector representatives indicated that it was unlikely that financing for PV use in irrigation or other agricultural projects would be approved unless it could be proved that such systems provided the most cost-effective power source when compared to currently available systems. The reluctance of these officials was based on the following factors:

- high initial capital cost of photovoltaic systems;
- widespread availability of electrified sites for agricultural development projects;
- belief that gasoline or diesel generators are more cost-effective power sources than PV;
- belief that other energy sources such as biogas and low-head hydro should be financed before photovoltaics; and
- reluctance to finance projects using unfamiliar technologies.

Representatives of private financial institutions noted that similar problems could be expected in obtaining private financing for PV systems since the technical evaluation staffs of private banks are often trained by the Guarantee and Development Fund for Agriculture Livestock and Poultry (FIRA) and use the same evaluation criteria as government banks. All sources agreed that the likelihood of PV financing would be improved by increased dissemination of information about photovoltaics use to financial institutions.

Barring a change in government policy, American photovoltaics manufacturers will have to focus their marketing efforts on convincing the private financial institutions that photovoltaics are economically and financially viable in order to gain long-term financing or to introduce innovative financial schemes which do not require domestic loans.

Major international sources of financing include the International Bank for Reconstruction and Development (IBRD), the Interamerican Development Bank (IDB), the International Fund for Agricultural Development, and the United States Export and Import Bank (EXIMBANK). Examples of loan terms on several international loans signed in 1979-1980 are presented in Table 1.

TABLE 1

LOAN TERMS FOR FOREIGN BORROWING
1979-80

Organization	Loan Amount (million US$)	Interest Rate	Loan Term
IBRD	175	7.9%	17 yrs. + 5 yr. grace period
IBRD	92	7.9%	17 yrs. + 5 yr. grace period
IDB	50	7.9%	20 yrs.
IDB	94	7.9%	25 yrs.
IDB	40	7.9%	20 yrs.
International Fund for Agricultural Development	22	8.0%	15 yrs. + 1 yr. grace period
US EXIMBANK	189.8	8.5%	11 yrs + 1 yr. grace period

SOURCE: Annual Report 1980, Nacional Financiera, S.A. Mexico, D.F., 1980

Potential PV Applications in Mexican Agriculture

During the visit to Mexico, a number of agricultural applications that could use PV power systems were identifed. The criteria used in the selection were:

- Level of production and importance of the product in Mexico
- Type of operation and its adaptability to use a PV power source.
- Extent of use of the operation in Mexico.
- Extent of the current level of mechanization of the operations (e.g., use of conventional energy systems).
- Size of the power unit required for a typical operation.

The feasibility analysis of individual applications included economic comparisons. PV systems costs were based on the PV cost projections of the Jet Propulsion Laboratory's "1980 Photovoltaic Systems Development Program Summary Documents," which were the most complete and up-to-date projections of stand-alone PV costs available (See Table 2).

TABLE 2

PV SYSTEM COST PROJECTIONS PER PEAK WATT (Wp) INSTALLED IN THE U.S.

	Cost of Solar Cells	System Cost w/o Battery Storage Capacity	Battery Storage Cost	System Cost With Battery Storage Capacity
July 1980, stand-alone system	10.60	17.17	3.68	20.85
1982 cost, stand-alone system	2.80	8.05	3.68	11.75
1984 cost, stand-alone system	0.70	3.87	2.68	6.55
1986 cost, residential system	0.70	1.60	-	-

Actual coventional (gas or diesel) system data for Mexico in 1981 were the basis for conventional system costs in the life-cycle comparisons. In cases where government agencies would be funding the power installations, international market prices for conventional fuels were used, since these fuels can be exported. The parameters used in the economic analysis of PV and conventional power systems in Mexico are listed below in Table 3.

TABLE 3

PARAMETERS USED IN ECONOMIC ANALYSIS OF PV AND CONVENTIONAL POWER SYSTEMS

Labor Cost in 1980$	$5/day
Fuel Cost in 1980$	
domestic market	gasoline $0.46/gallon diesel fuel $0.16/gallon butane $0.11/kg
international market	gasoline $2.38/gallon diesel fuel $1.15/gallon
Real Fuel Cost Escalation	3%
Inflation	all calculations done in real terms
Discount Rate	15%
Analysis Lifetime	20 years
Life of Conventional System	Equipment lifetimes ranged from 5-10 years

Based on the criteria cited above, cattle watering, rural water supply, and small grain loaders, and possibly rural refrigerators were the agricultural applications found to be feasible in Mexico. Other feasible rural sector applications were rural radio-telephones, schoolroom tape recorders, educational TV, private rural TV sets, and other appliances.

Cattle Watering

PV has several characteristics which make it ideally suited for cattle watering, namely:

(a) cattle water requirements increase in regions with greater solar radiation, and extended dry seasons match the capabilities of a PV pump;

(b) In rainy seasons, when it is cloudy and the PV system is required to supply least water, and the cattle can drink from surface depressions; thus the usual three-day reservoir capacity is also sufficient for a PV system and no extra investments in water storage capacity are required;

(c) cattle watering pumps are located at remote places where a diesel pump requires an operator's presence, fuel transport, and maintenance, which present continuing problems; and

(d) the pumping power requirements are small, so that a diesel motor (for which 6HP is usually the minimum size) is under-utilized.

On the other hand, the small windmill pump--which shares the above advantages--is being phased out owing to its high initial cost. Thus cost considerations are all-important. Cost comparison between PV and diesel systems (diesels are presently the power source of choice for new watering areas) shows that PV will be cost-competitive with diesel for livestock watering in Mexico by about 1984 for water depths of 50m and by about 1982 for water depths of 20m (typical in the center of Yucatan).

The cost advantage of PV relies on the inherent inefficiency of partly loaded diesel engines for low-power uses. The calculations are very sensitive to the pumping-jack efficiency assumed, which in this study was 0.35. PV is also expected to be more convenient and reliable than diesels. Note that PV would still be more expensive than windmill pumps, so that the fact that windmill pumps are being rapidly phased out should be a cause for concern to PV promoters.

The Directorate-General of Hydraulic Works and Agricultural Engineering for Rural Development is quite interested in PV livestock watering. However, due to the rapidly expanding nature of its activities and the delays associated with installing any new system, any market size figures would be purely a conjecture. Assuming that four pilot projects are installed in 1982, increasing to 40 per year in 1986, with an average size of 1.8KWp, the total demand for PV over the period would be about 200KWp.

Rural Potable Water

An estimated 100 publicly funded water supply projects will be installed annually in communities which do not have electricity and which average from 250 to 500 inhabitants. Economic comparison of PV and diesel costs reveals that for a community of 500 provided with public fountains, at a dynamic head of 50m, PV will be cost-competitive with diesel on a life-cycle basis starting in 1983. At this point, the front-end cost for a PV will be about $18,000 (descending to about $12,000 in 1986), compared with $2,400 for a diesel motor. Considering the fund availability in the Mexican accelerated program for rural water supply on the one hand, and the difficulties of operating and maintaining diesel engines in small communities on the other, a major shift to PV would be advantageous for communities of 500 inhabitants in Mexico about 1983 (or whenever installed array costs descend to about $7/Wp). For smaller communities or a a pumping depth of less than 50m, the break-even year will be even earlier.

If government agencies gradually introduce PV for rural potable water, the capacity installed during the period 1983-1986 might be on the order of 300KWp.

Small Grain Loaders

About 1000 small grain reception warehouses (25-500 MT capacity) are in rural locations which do not have electricity. Serious reliability problems have been encountered with the small (3HP) gasoline motors that power the small (5MT/hr. capacity) loaders for bulk loading of grain to bins or trucks. Only an estimated 50 of the 1000 motors are still operative. The loaders are not used during the rainy season (June through August) but work 4-6 hours per day the rest of the year.

Cost comparisons show that in 1986, a 2KWp PV system will cost 80% more than the comparable gasoline motor ($18,130 vs. $10,130). For grain elevating, however, the comparison is not this simple since because of gasoline engine maintenance difficulties grain handling in smaller warehouses must be carried out by hand. Assuming this entails employment of five laborers for 230 days/year at a minimum wage of $5/day, the annual cost is $5750, and the present value of 20-year operating cost (at 15% discount) is $41,400. Thus compared with manual grain handling, PV will be cost-competitive by 1982. Assuming satisfactory performance of a PV unit installed that year, as many as 40 units (80 KWp total array capacity) might be installed by 1986.

Rural Refrigeration

In rural areas without access to electricity, butane refrigerators can be found in households and on cattle ranches. These refrigerators are sturdy, require little maintenance, consume about 1kg of butane per day, and have a life cycle cost of $1980. The PV-powered alternative would cost more ($3400 by 1986, $4900 by 1982) but be more convenient. Total market size for PV-powered refrigerators would be at most 25 KWp from 1982-1986.

Other Feasible Rural Applications

Non-agricultural sectors will present the biggest market for PV in Mexico before 1986. The following non-agricultural applications of PV also have already been introduced in Mexico or have been mentioned by Mexican officials as appropriate for PV use.

Rural Services:

(a) Rural radio-telephone: The Ministry of Telecommunications and Transport has a pilot project in the mountains of Puebla.

(b) Tape recorders for rural schools: IPN has presented a project for introducing 4.5Wp solar battery chargers for tape recorders to 700 rural schools, showing this to be the most economic alternative.

(c) Educational TV: IPN has presented to PIDER a project for installing 100 PV-powered educational TV sets in rural schools.

Rural Appliances: There should be a significant demand for PV-powered TV sets for rural areas. Demand for PV-powered refrigerators, fans, lights, etc. would probably be minor in comparison.

Telecommunications: PV could be used to power TV and microwave relay stations, TV and radio repeaters, and other telecommunication equipment in remote locations.

Signalling: PV is advantageous for light buoys, small isolated lighthouses and offshore oil rigs, radio beacons for guiding aircraft, warning lights on isolated highway intersections and railway level crossings, etc.

Measuring: PV could be used in Mexico for unattended operation of weather stations, stream gages, traffic counters, seismic detectors and other measuring devices.

Cathodic Protection:	PV could be used to protect Mexico's rapidly expanding pipeline system from corrosion.

Pacific Northwest Laboratories* have estimated the market size for the following PV applications in Mexico:

Application	1982 Market (KWp)	1986 Market (KWp)
Communications Systems	50	100
Cathodic Protection Systems	20-100	100-400
Rural Potable Water Systems	30-100	300-1500
Village Power Systems	10-100	100-500
TOTAL	110-350	600-2500

Marginally Feasible PV Applications

A variety of agricultural applications were investigated by the team. Twenty-one applications were found generally unsuited to PV systems, usually for one of the following reasons:

- Demand is high during hours of low insolation (rainy, cloudy, or night hours) causing seasonal peak demand to be much higher than baseload, thus increasing array size and battery capacity.
- The remarkable extension of the Mexican electric power grid provides access to power where the application generally occurs; or,
- The size of the power requirement and/or storage requirements is too large for PV to be cost-effective when compared to large diesels.

The reasons for not considering PV use in the twenty-one applications are summarized in Table 4. Differences in local factors could result in exceptions where PV is well-suited.

Public and Private Sector Attitude Toward PV

Public and private sector groups who are unaware of PV have taken a wait-and-see attitude toward PV use. While very few private sector contacts were familiar with PV, public sector awareness was much higher, and a number of Mexican government agencies are considering PV use in the near term. Public sector contacts expressed the view that economic factors are the barrier to widespread PV use and that no social or cultural barriers exist. Private sector awareness of PV was largely through written communication. Many farmers contacted were skeptical about PV's appropriateness to their needs.

Since at present the Mexican government is the principal purchaser of PV equipment, it is important to note the policy of pluralism of technologies outlined by the National Solar Master Plan (PLANMAES). The plan advocates using a broad mix of solar technologies and suppliers. Therefore, it is unlikely that any one firm will dominate the Mexican PV market.

*Export Potential for Photovoltaic Systems, DOE/CS-0078, April 1979.

TABLE 4

MARGINALLY FEASIBLE PV APPLICATIONS

APPLICATION	Reasons for Not Considering PV Use: Timing of demand	Location near grid	High power demand	Other
Small-Scale Irrigation				1/
Auxiliary Irrigation and Drainage in High-Precipitation Areas	X			2/
Irrigation of Tree Nurseries		X		
Fish Reception Centers	X			
Cold Storage for Fruits and Vegetables		X		
Ice Production	X		X	
Veterinary Extension Centers		X		
Artificial Insemination Centers		X		
Grain Drying	X			
Maize Shelling	X		X	
Maize Dough Mills			X	
Copra Drying	X	X		
Sisal Stripping Plants		X		
Packing Sheds for Fruits and Vegetables		X		
Dairies		X		
Poultry Farms	X	X		
Pig Farms	X	X		
Production of Fish Fingerlings		X		
Aquaculture				3/
Projectors for Extension Agents [4]	X			

1/ Groundwater depth too great for economic use of PV.

2/ Requirements for mobility and large amounts of power make internal combustion engines particularly suitable.

3/ No power demand.

4/ Due to constant travel over rough roads, sturdy and durable PV panels are essential.

Current PV Activity

Photovoltaics research and development is being carried out at several Mexican universities and research institutes. The National Polytechnic Institute (IPN) is currently producing single crystal silicon cells and flat panels with capacity for 1982 estimated at 40 KW/year. Negotiations for a commercial production plant (300 KW/year) are ongoing; the systems cost goal for the project is U.S. $12-15 per installed watt. While the government agency in charge of solar demonstrations is under no restrictions to buy domestic systems, it is likely that the government in general will buy Mexican systems first.

Presently, three American firms and five European firms compete in the Mexican photovoltaics market. This market now is almost exclusively comprised of various government agencies, with rural telephones and televisions as the major applications.

Business Environment for Marketing PV Systems

U.S. manufacturers face both advantages and disadvantages in developing the Mexican market. The principal advantages are that American photovoltaic technology is regarded as the best available, and several American firms are already active in the market establishing a favorable reputation.

Against these advantages, several disadvantages must be measured. First, no incentives currently exist for using PV in Mexico. Second, U.S. PV firms will have to compete with both domestic Mexican PV production and non-U.S. imports. Third, U.S. firms are not likely to have access to either Mexican private capital or government financing of direct investments. Fourth, American photovoltaic systems containing parts which are not manufactured in Mexico face high tariffs.

In order to realize the photovoltaics market potential U.S. firms should:

1) perform as much as possible of the production and assembly of PV systems at plants in Mexico in order to avoid high tariffs charged against imported complete systems;

2) enter into joint-venture agreements with Mexican partners in order to facilitate government approval for establishing business in Mexico and in order to qualify for financial incentives offered to domestic businesses; and

3) offer complete systems (e.g., PV powered television sets and irrigation and potable water pumps requiring low power ratings).

Table 5 summarizes the advantages and disadvantages of the present business climate for marketing American PV systems

TABLE 5

CHARACTERISTICS OF THE MEXICAN BUSINESS CLIMATE

Area	Present Status
Level of Public Awareness	• Little awareness of PV, except in public energy sectors.
Competition	• In-country competition from Phillips Mexicana and the National Polytechnic Institute • Strong competition from French and German PV suppliers. • Supply diversification recommended for public purchases.
Investment Climate	• Positive climate for investments. • Preferance for payback much sooner than possible with PV. • No government investment incentives for PV; DIGASSES is encouraging such incentives.
Standards and Regulations	• Generally all U.S. electrical standards are acceptable. • High tariff rates for imported systems and components.

Conclusions

PV was found to be cost-competitive, at international fuel prices in the next five years, for cattle watering, rural water supply, and small grain loaders, and possibly rural refrigerators. This translates into a maximum probable effective demand of 605 kilowatts peak through 1986 for the agricultural sector (see table below) with sales to the public sector. In comparison, a U.S. DOE study of four non-agricultural applications revealed maximum potential of 2600 KWp in 1986 alone.

TABLE 6

MARKET POTENTIAL OF FEASIBLE PV APPLICATIONS

Application	Year of Cost Competitiveness	Maximum Probable Effective Demand Thru 1986
Livestock watering	1982 to 1984	200 kwp
Rural water supply	1983	300 kwp
Small grain loaders	1982	80 kwp
Rural refrigerators	----	25 kwp
Total		605 kwp

Appropriate, non-agricultural, rural applications found to be cost-competitive in this study include rural radio-telephones, schoolroom tape recorders, educational TV, private rural TV sets and other appliances.

Largely because of the wide extent of the Mexican rural electrification system or high power requirements (when economies of scale of diesel makes its use cheaper) short-term market potential for twenty-one other agricultural applications investigated was found to be poor.

The potential value of the short-term agricultural sector market for PV is about $3.6 million. The predominant buyer is the Mexican government, which has a strong rural presence, has a strong indigenous PV development program, and is likely to purchase PV systems from the IPN. Non-Mexican suppliers are likely to be limited to:

(a) supplying raw materials and machinery to the IPN production;

(b) filling the gap where public sector demand exceeds IPN production;

(c) furnishing PV modules as a part of complete systems (e.g., for telecommunication equipment or measuring devices); and,

(d) providing PV kits for operating rural appliances.

PV manufacturers who want to realize this potential should:

(a) perform as much as possible of the production and assembly in Mexico to avoid the higher tariffs on imported complete PV systems;

(b) enter into joint-venture agreements with Mexican companies to facilitate government approval and to benefit from financial incentives; and,

(c) offer complete systems (e.g., a TV set, PV array and battery which are matched to each other and adjusted to local isolation levels).

MARKET ASSESSMENT OF PHOTOVOLTAIC POWER SYSTEMS FOR AGRICULTURAL APPLICATIONS IN MEXICO

1.0 INTRODUCTION

Study Objectives: The Photovoltaic Stand-Alone Applications Project Office of NASA/Lewis Research Center, Cleveland, Ohio, has issued a contract to conduct an assessment of the market for remote photovoltaic (PV) power systems in worldwide agriculture. The prime purpose of this study was to provide a data base and an analysis of the potential market for PV in worldwide agriculture. The study identifies applications with high PV sales potential and provides information to assist industry in developing appropriate market strategies.

Development of the Study: The market study for PV applications in worldwide agriculture was contracted to DHR, Incorporated, with Associates in Rural Development, Inc. as a subcontractor. The present report is the third in a series of field studies, following visits to the Philippines (Oct-Nov. 1980) and to Nigeria (Jan-Feb. 1981). The subject of these studies, namely the agricultural sector, was broadly defined to include livestock, forestry and fisheries and rural services.

Time horizon of the study: The motivation for the study is that solar cell costs have been coming down dramatically due to the improved cell technology and mass-production methods, and further cost reductions are projected which will make PV price-competitive in applications where at present it is not. The objective of the analysis was to determine for each application the first year of cost-competitiveness and the market potential thereafter. For the economic comparison, the analysis was based on the PV cost projections made at JPL[1/], which are the most complete and up-to-date projections of PV costs available. JPL has projected PV system cost goals as follows:

1/ "1980 Photovoltaic Systems Development Program Summary Documents." Jet Propulsion Laboratory, Pasedena.

PROJECTED COST GOALS OF PV POWER SYSTEMS

INSTALLED IN THE U.S., IN 1980 DOLLARS PER PEAK WATT (Wp)

	Cost of Solar Cells	System Cost w/o Battery Storage Capacity	Battery Storage Cost	System Cost With Battery Storage Capacity
July 1980, stand-alone system (Table 1.1)	10.60	17.17	3.68	20.85
1982 cost, stand-alone system (Table 1.2)	2.80	8.05	3.68	11.73
1986 cost, stand-alone system (Table 1.3)	0.70	3.87	2.68	6.55
1986 cost, residential system (Table 1.4)	0.70	1.60	-	-

The above table shows that an enormous cost reduction is projected for the solar cells, while the cost of balance-of-system (BOS) elements--in particular the storage batteries--will descend a lot more slowly and thus form an increasing share of the total cost. In 1986 electricity produced by a residential PV system is projected to be cost-competitive with conventional grid electricity as a day-time energy saver. At that point large markets will be opened for PV arrays in grid-connected domestic and industrial systems. Whenever this happens, the market for PV in remote stand-alone applications will be dwarfed in comparison. Thus the main interest in stand-alone applications, from the PV manufacturers point of view, lies in their market potential up to 1986. (Note that if the year of PV costs-competiteness for residential systems arrives later than projected, PV cost-competitiveness in remote stand-alone systems will be similarly delayed). Furthermore, prediction of the market beyond 1986 on the basis of production technologies which are still at the laboratory stage or not yet in existence can only be a speculation. Note moreover that by 1986 the cell cost is projected to be only $0.70/Wp out of total stand-alone system cost of $3.87-6.55 per peak watt and no large further cost reductions are projected for the balance-of-system elements, so that even a very large reduction of PV cell costs after 1986 will not make PV cost-competitive in most stand-alone applications in which it is not cost-competitive by 1986. Based on these considerations, the present study has concentrated on investigation of the market for PV in agricultural and rural applications over the period 1981-1986.

Topics of the study: The study provides information on the following subjects, which are essential to developing a market strategy:

TABLE 1.1: 1980 COST OF A 20KWp REMOTE STAND-ALONE PV SYSTEM (IN JULY 1980 DOLLARS)

	System Price Element	Initial Price $/Wp (1980$): FOB Manufactured	Initial Price: Marketing & Distribution	Initial Price: Installation	Initial Price: Subtotal	Energy Price Elements $/Wp (1980$): Initial Installed System Price	Energy Price Elements: Life Cycle Operation & Maintenance	Levelized Energy Price, ¢/kWh (1980$): 2350 kWh/kWp	1770 kWh/kWp	1400 kWh/kWp
ARRAY	• Collector	10.60	INCL.	0.81	11.41	13.60	0.13	109.4	145.[illegible]	183.6
	• Structures & Foundations	0.60	0.12	0.40	1.12					
	• Site & Preparation	-	-	0.56	0.56					
	• Field Wiring	-	-	0.44	0.44					
	• Lightning Protection	-	-	0.07	0.07					
POWER PROCESSOR	• Power Conditioner	0.49	INCL.	0.05	0.54	0.86	0.13	7.7	10.2	12.9
	• Electrical Switchgear & Wiring	0.11	0.06	0.05	0.22					
	• Control Building	-	-	0.10	0.10					
STORAGE	• Battery	2.60	0.52	0.08	3.20	3.68	2.80	48.0	63.7	80.6
	• Charger	0.10	0.03	0.04	0.17					
	• Battery Building	-	-	0.31	0.31					
INDIRECTS	• Design & Project Management Fee				2.71	2.71		21.6	28.7	36.3
	• Sales Fee				0					
	• Interest During Construction									
TOTAL, COMPLETE SYSTEM		14.50	0.73	2.91		20.85	3.06	186.7	247.8	313.4
TOTAL, w/o BATTERY STORAGE		11.80	0.18	2.48		17.17	0.26	-	-	-

Assumptions

- 8% Collector Area Efficiency
- Marketing & Distribution: Collector -%, Structure 20%, Electrical 50%, Storage & Equipment, 20%.
- Fees: Design and Project Management, 15% Sales: 0%.
- Lifetimes: System 20 years, Economic 20 years.
- Operation & Maintenance: \$16/kWp/yr.
- Utilization Factor (U): 0.64
- Fixed Charge Rate: 0.12
- Discount Rate: After taxes (k) 8%
- Battery: \$170/kWh Initial FOB Price; 10 year Life; 3 days Storage (15kWh/kWp)
- Inflation Rate(i) 6%
- Capital Recovery Factor: 0.10

Source: JPL, "1980 Photovoltaic Systems Development Program Summary Document" (Draft)

TABLE 1.2: 1982 COST PROJECTIONS OF A 20 Kwp REMOTE STAND-ALONE PV SYSTEM
(IN JULY 1980 DOLLARS)

	SYSTEM PRICE ELEMENT	INITIAL PRICE $/Wp (1980$)				ENERGY PRICE ELEMENTS $/Wp (1980$)		LEVELIZED ENERGY PRICE, ¢/kWh (1980$)		
		PV MANUFACTURER	MARKETING & DISTRIBUTION	INSTALLATION	SUBTOTAL	INITIAL INSTALLED SYSTEM PRICE	LIFE CYCLE OPERATION & MAINTENANCE	2350 kWh/kWp	1770 kWh/kWp	1400 kWh/kWp
ARRAY	• COLLECTOR	2.80	0.84	0.40	4.04	5.84	0.13	47.5	63.1	79.7
	• STRUCTURES & FOUNDATIONS	0.50	0.10	0.30	0.90					
	• SITE & PREPARATION	-	-	0.50	0.50					
	• FIELD WIRING	-	-	0.35	0.35					
	• LIGHTNING PROTECTION	-	-	0.50	0.05					
POWER PROCESSOR	• POWER CONDITIONER	0.22	0.11	0.05	0.38	0.70	0.13	6.4	8.6	10.7
	• ELECTRICAL SWITCHGEAR & WIRING	0.11	0.06	0.05	0.22					
	• CONTROL BUILDING	-	-	0.10	0.10					
STORAGE	• BATTERY	2.60	0.52	0.08	3.20	3.68	2.80	48.0	63.7	80.6
	• CHARGER	0.10	0.03	0.04	0.17					
	• BATTERY BUILDING	-	-	0.31	0.31					
INDIRECTS	• DESIGN & PROJECT MANAGEMENT FEE	X	X	X	1.51	1.51	X	12.0	15.9	20.1
	• SALES FEE				0					
	• INTEREST DURING CONSTRUCTION				-					
TOTAL, COMPLETE SYSTEM		6.33	1.66	2.23	X	11.73	3.06	113.9	151.3	191.1
TOTAL, w/o BATTERY STORAGE		3.63	1.11	1.80		8.05	0.26	-	-	-

Assumptions

- 10% Collector Area Efficiency
- Marketing & Distribution: Collector 30% Structure 20%, Power Conditioning & Electrical 50%, Storage & Equipment 20%
- Fees: Design and Project Management 15% Sales, 10%.
- Lifetimes: System 20 years, Economic 20 yrs.
- Operation & Maintenance: $16/kWp/yrs.
- Utilization Factor (U): 0.64
- Fixed Charge Rate: 0.12
- Discount Rate: After taxes (%) 8%
- Battery Storage: 3 days (15 kWh/kWp) $170 kwh Initial Price, 10 year Life
- Inflation Rate(%): 6%
- Capital Recovery Factor: 0.10

Source: JPL, "1980 Photovoltaic Systems Development Program Summary Document" (Draft)

TABLE 1.3: 1986 COST PROJECTIONS OF A 100 Kwp REMOTE STAND-ALONE PV SYSTEM
(IN JULY 1980 DOLLARS)

SYSTEM PRICE ELEMENT		INITIAL PRICE $/W$_p$ (1980$): FOB MANUFACTURER	MARKETING & DISTRIBUTION	INSTALLATION	SUBTOTAL	ENERGY PRICE ELEMENTS $/W$_p$ (1980$): INITIAL INSTALLED SYSTEM PRICE	LIFE CYCLE OPERATION & MAINTENANCE	LEVELIZED ENERGY PRICE, ¢/kWh (1980$): 2350 kWh/kW$_p$	1770 kWh/kW$_p$	1400 kWh/kW$_p$
ARRAY	• COLLECTOR	0.70	0.21	0.20	1.11	2.49	0.13	19.0	25.2	31.9
	• STRUCTURES & FOUNDATIONS	0.40	0.08	0.20	0.68					
	• SITE & PREPARATION	-	-	0.40	0.40					
	• FIELD WIRING	-	-	0.25	0.25					
	• LIGHTNING PROTECTION	-	-	0.05	0.05					
POWER PROCESSOR	• POWER CONDITIONER	0.11	0.06	0.05	0.22	0.54	0.13	4.7	6.2	7.9
	• ELECTRICAL SWITCHGEAR & WIRING	0.11	0.06	0.05	0.22					
	• CONTROL BUILDING	-	-	0.10	0.10					
STORAGE	• BATTERY	1.83	0.37	0.08	2.28	2.68	2.04	32.0	42.5	53.7
	• CHARGER	0.10	0.03	0.04	0.17					
	• BATTERY BUILDING	-	-	0.23	0.23					
INDIRECTS	• DESIGN & PROJECT MANAGEMENT FEE				0.84	0.84		6.1	8.1	10.2
	• SALES FEE				0					
	• INTEREST DURING CONSTRUCTION									
TOTAL, COMPLETE SYSTEM		3.25	0.81	1.65		6.55	2.30	61.8	82.0	105.7
TOTAL, w/o BATTERY STORAGE		1.32	0.41	1.30		3.87	0.26	-	-	-

Assumptions

- 10% Collector Area Efficiency
- Marketing & Distribution: Collector 30% Structure 20%, Power Conditioning & Electrical 50%, Storage & Equipment 20%
- Fees: Design and Project Management 15% Sales, 0%
- Lifetimes: System 20 years, Economic 20 yrs.
- Operation & Maintenance: $16/kW$_p$/year
- Utilization Factor (U): 0.70
- Fixed Charge Rate: 0.12
- Discount Rate: After Taxes (k) 8%
- Battery Storage: 3 days (15 kWh/kW$_p$), $120/kWh Initial Price, 10 years
- Inflation Rate(g): 6%
- Capital Recovery Factor: 0.10

Source: JPL, "1980 Photovoltaic Systems Development Program Summary Document" (Draft)

TABLE 1.4: 1986 COST PROJECTIONS OF A 10Kwp RESIDENTIAL P/V SYSTEM
(IN JULY 1980 DOLLARS)

	SYSTEM PRICE ELEMENT	INITIAL PRICE W_I$, (1980$)				ENERGY PRICE ELEMENTS W_p$, (1980$)		LEVELIZED ENERGY PRICE, ¢/kWh (1980$)		
		FOB MANUFACTURER	MARKETING & DISTRIBUTION	INSTALLATION	SUBTOTAL	INITIAL INSTALLED SYSTEM PRICE	LIFE CYCLE OPERATION + MAINTENANCE	2350 kWh/kW$_p$	1770 kWh/kW$_p$	1400 kWh/kW$_p$
ARRAY	• COLLECTOR	0.70	0.21	0.17	1.08	1.12	0.22	3.3	4.4	5.5
	• STRUCTURES & FOUNDATIONS	-	-	-	-					
	• SITE & PREPARATION	-	-	-	-					
	• FIELD WIRING	-	-	0.04	0.04					
	• LIGHTNING PROTECTION	-	-	-	-					
POWER PROCESSOR	• POWER CONDITIONER	0.20	0.10	0.04	0.34	0.34	0.22	1.4	1.9	2.3
	• ELECTRICAL SWITCHGEAR & WIRING	-	-	-	INCL. IN POWER COND.					
	• CONTROL BUILDING	-	-	-	-					
STORAGE	• BATTERY	-	-	-	-	-	-	-	-	-
	• CHARGER	-	-	-	-					
	• BATTERY BUILDING	-	-	-	-					
INDIRECTS	• DESIGN & PROJECT MANAGEMENT FEE	X	X	X	0.07	0.14	X	0.4	0.5	0.7
	• SALES FEE				0.07					
	• INTEREST DURING CONSTRUCTION				-					
TOTAL		0.90	0.31	0.25	X	1.60	0.44	5.1	6.8	8.5

Assumptions

- 10% Collector Area Efficiency
- Marketing & Distribution: Collector 30% Structure -%, Power Conditioning & Electrical 50%, Storage & Equipment -%
- Fees: Design and Project Management 5% Sales 5%
- Lifetimes: System 30 years, Economic 30 yrs.
- Operation & Maintenance: $16/Kw$_p$/year
- Utilization Factor (U): 0.63
- Fixed Charge Rate: 0.08
- Discount Rate: Before Taxes 10%, After Taxes (k) 6.5%
- Solar Availability (kwh/kw$_p$/yr): Phoenix 2350, Miami 1770, Boston 1400
- Inflation Rate(g): 6%
- Capital Recovery Factor: 0.077
- Factor to Convert From Levelized Normal To Real Energy Price(F): 2.10
- Tract House

Source: JPL, "1980 Photovoltaic Systems Development Program Summary Document" (Draft)

(a) the potential market for PV sales;

(b) power requirements and usage time profiles for applications which are compatible with PV use;

(c) operating and cost characteristics of power systems which will compete against PV;

(d) national development goals in rural electrification and rural services, other programs and government policies which will influence the demand for PV in Mexico;

(e) appropriate financing mechanisms and capital available for PV acquisition;

(f) channels for distribution, installation and maintenance for PV systems; and

(g) appropriate methods for conducting business in Mexico.

Conduct of the study: A study team composed of one DHR and one ARD specialist, accompanied by a NASA representative, arrived in Mexico on 3/8/81 for a 4-5 week field study. The team divided its activities between the Federal District and extensive field visits in the states of Zacatecas, Jalisco, Morelos, Oaxaca, Tabasco and Yuctan to study first hand the characteristics of Mexican stand-alone operations which might use PV as a power sources. The team collected the data through meetings with Banrural, CFE, CONACYT, COPLAMAR, DIGAASES, FIRA, PIDER, SAHOP, SARH and SPFI officials, IPN and UNAM-IIM scientists, U.S. Embassy officials, private sector representatives and farmers. A total of about 100 persons were interviewed; the list of contacts is given in Appendix A. Appropriate sources of published information were consulted, as detailed in Appendix E, the Bibliography.

Data Analysis and Market Evaluation: Agricultural and rural services applications data collected during the field visits and interviews included the following: power and energy use, time profile of use, current practices, type of equipment and power sources used, cost of energy, extent of use and trends. The load profile and competing system data were used to compare the present value life cycle costs of PV systems with that of competing gasoline or diesel engines. It was assumed that PV systems will begin penetrating the market when its life cycle costs were less than or equal to that of the competing system. Initially the rate of penetration is very small due to greater familiarity with, and the infrastructure available for conventional power sources. However, as the costs of PV systems keep decreasing relative to conventional systems, the market penetration rate begins increasing. The market for PV systems in the 1982-86 time frame is based on: extent of use of the particular application; equipment replacement rates; trends; and our estimates as to rate at which users gain familiarity with PV systems, and the rate at which a suitable infrastructure would be developed.

Summary of results: Various rural and agricultural power uses were investigated for the applicability of PV. Out of twenty-five potential agricultural PV uses which were investigated, no less than twenty-one were found inappropriate for PV use in the near future. The reasons were usually either (a) cost considerations, which would make PV less competitive than the lowest cost conventional energy alternative, or (b) the remarkable extent of the Mexican rural electrification system, which is scheduled to reach almost all communities of over 500 inhabitants by 1982 and is available in locations where most agricultural operations are carried out. PV was found to be cost-competitive over the next five years for cattle watering, rural water supply and small grain loaders, and possibly rural refrigerators. To this should be added other rural applications such as rural radio-telephones, schoolroom tape recorders, educational TV, private rural TV sets and other appliances for which PV is likely to fill rural power demands. These were not included in the scope of the present study.

Report organization: Chapter 2 gives an overview of the demographic, agricultural, and energy situation in Mexico, Mexican PV capabilities and the key institutions in PV development. Chapter 3 discusses the Mexican economic, agricultural and rural electrification development plans. Chapter 4 covers financial institutions in Mexico which fund energy, agriculture and development projects. Chapter 5 describes the business environment in Mexico as it relates to photovoltaics. Chapter 6 discusses the feasible applications of PV in the Mexican agricultural sector over the next five years. Chapter 7 describes those applications for which PV was found to be marginally feasible over that period. Chapter 8 summarizes the conclusions of the study.

2.0 DEMOGRAPHIC OVERVIEW

With a population estimated at 68 million in 1980, the United States of Mexico is the most populous nation in the Spanish-speaking world. Its demographic growth rate is one of the highest in the world, 3.4% per year. The per capita gross national product (GNP) is $1,090 (U.S.). Approximately 40% of the population is engaged in farming, fishing, and forestry, a percentage which has been declining due to migration from rural to urban areas. Agriculture's share of gross domestic product has declined to the point where its present contribution is about 10%.

Mexico's land area of 760,000 square miles makes it the third largest country in size in Latin America, after Brazil and Argentina. The greater part of the country is a highland plateau bordered on the east, west, and south by mountains. Approximately 60% of the land is arid or semi-arid and only about 15% is suitable for cultivation. Nevertheless, due to varied climatic conditions, Mexico is able to produce both temperate and tropical foodstuffs.

In the central plateau region near Mexico City, maize, beans, soybeans and other crops are grown for domestic consumption and dairy products and pork are also produced. Along the rainfed gulf coast, sugar cane and bananas are raised in the lowlands and maize and coffee at higher elevations. In the southern semi-tropical state of Tabasco, beef, cocoa, bananas and sugar cane are the principal products. Maize, beans, sesame and cotton predominate in Chiapas. In northwestern Mexico, cash crops such as fruits, vegetables and soybeans are grown for export.

While average farm size is 7 hectares, there is considerable variation in farm size and cropping methods in Mexico, even within regions. In general, however, the irrigated areas of northern and northwestern Mexico are characterized by large farm units, intensive mechanization, cash crop production and developed marketing facilities and government services. In the central plateau, traditional agriculture predominates with farm units tending to be small and unmechanized. In the gulf coast lowlands, large farms produce commercial crops, but the level of mechanization is also low. The poorest farming conditions in the country are along the southwest coast, where subsistence farmers cultivate small plots with primitive implements. In the Yucatan peninsula, traditional methods and subsistence crops also predominate but an attempt is underway to diversify the agricultural production with citrus and vegetable crops.

According to the Fifth Agricultural Census, of the 35 million hectares classified as arable and permanent cropland only about 23 million hectares, or two-thirds, is under cultivation. The remainder is generally left fallow. Approximately 6 million hectares are irrigated. Most of the irrigated land is located in the arid and semi-arid states of Chihuahua, Sinaloa and Sonora. Irrigated land accounts for 50% of Mexico's agricultural production. Nearly one-fourth of the irrigated land is under private ownership.

Farmers can be divided into three groupings; ejidatarios (those who farm collectively, usually on government-redistributed lands called ejidos, where groups of families have joint tenure rights to land), private farmers, and landless farmers. The three million farmers are divided equally among these categories. Land holdings, capital and services are skewed with the result that 6% of the farms account for 85% of product sales.

2.1 Energy Situation Overview

The prime focus of Mexican energy policy in recent years has been the development of its vast petroleum and natural gas resources. Because it is self-sufficient in energy, Mexico is able to keep internal fuel prices below world prices as a means of encouraging industrial growth and of controlling inflation (recently increasing at 30% per year). Presently, gasoline sells for $0.46 per gallon, kerosene for $0.24 and diesel for $0.16 per gallon.

About 88% of Mexico's primary energy is currently derived from its petroleum and natural gas resources. Growth in domestic demand for hydrocarbon fuel exceeded the growth rate in Gross Domestic Product (GDP) by 70% for the period 1975 to 1979.

The rapid rate at which Mexico is consuming its hydrocarbon resources is recognized in the Ministry of Patrimony and Industrial Development's recent Energy Plan, Goals to 1990 and Projections through 2000. As a consequence, emphasis is being placed on the development of Mexico's coal, hydro, geothermal and uranium resources in order to decrease dependency on oil and gas in the long term as seen in Figure 2.1. Key energy sources are outlined below:

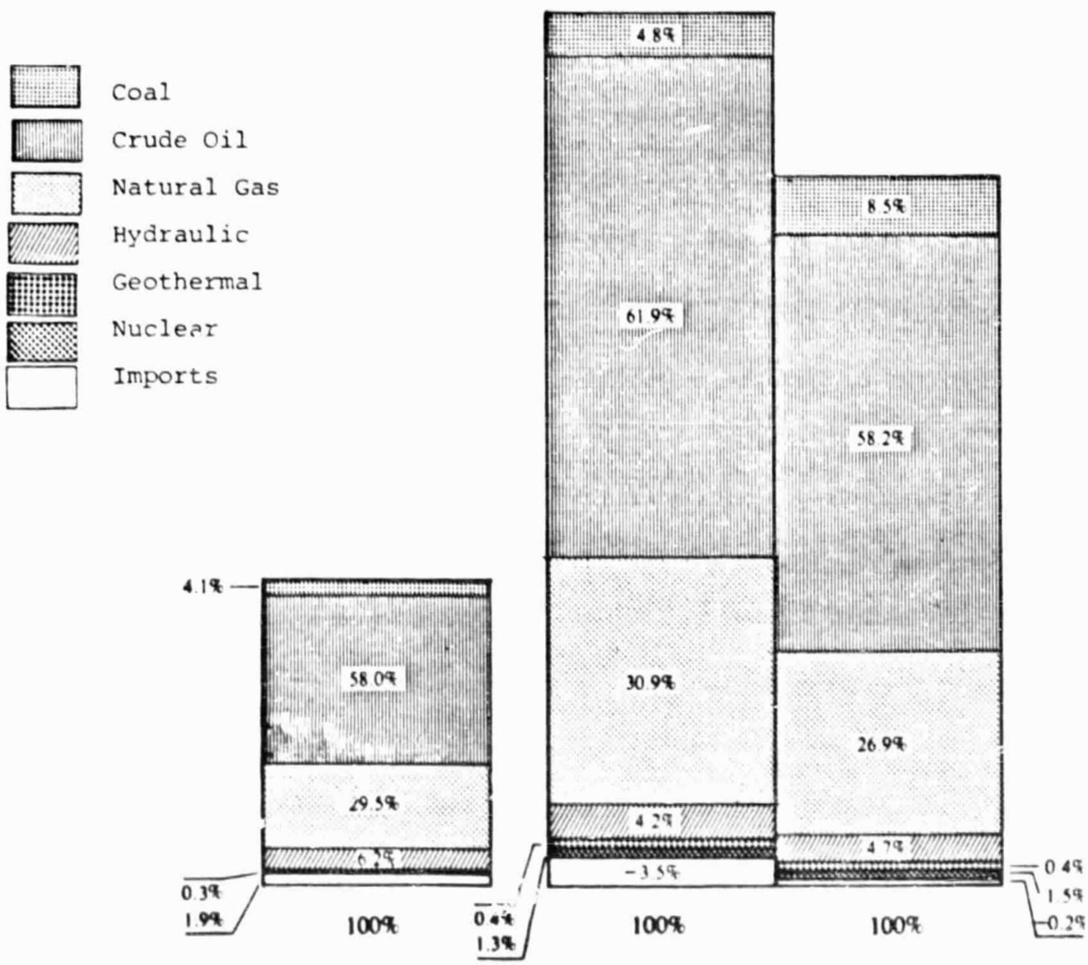
- Natural gas - Mexico has massive natural gas reserves. Daily production in 1980 totalled 65.5 million cubic meters of associated gas and 18 million cubic meters of unassociated gas, a 34% increase over 1978 figures. Domestic consumption has increased due to government subsidies and coal-to-gas conversion programs for large utilities. The National Energy Plan establishes a limit of 300 million cubic feet per day on natural gas exports through 1982.

FIGURE 2.1

SUPPLY STRUCTURE OF PRIMARY ENERGY FOR DOMESTIC USE, BY PRINCIPAL SOURCES, 1979-1990

1979	1990 Base Projection	1990 Projection of Energy Program
1.8	5.4	4.4

(Millions of daily barrels of crude oil equivalent)

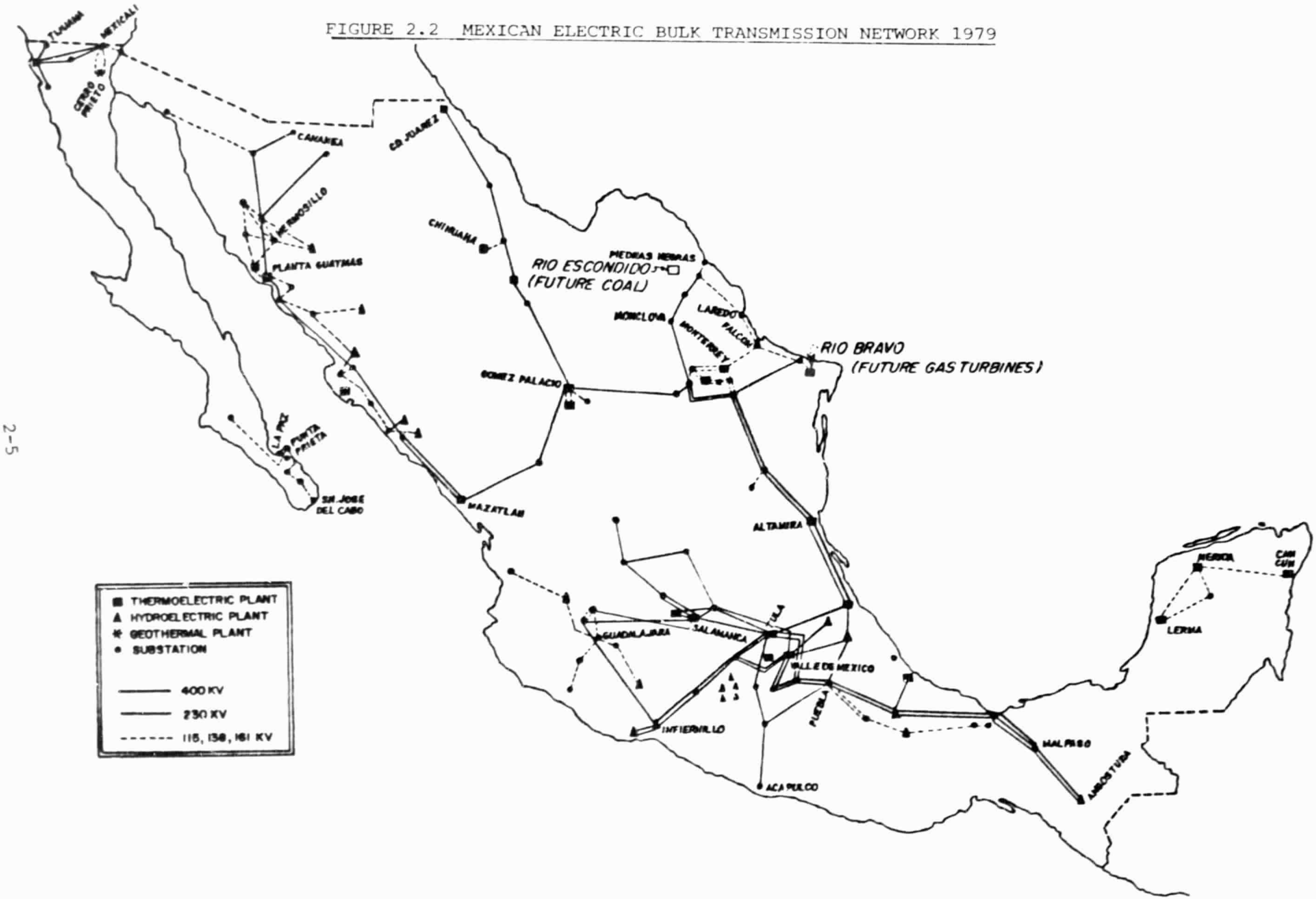


SOURCE: "Programa de Energia, Metas a 1990 y proyecciones al ano 2000." Energeticos, Boletin Informativo del Sector Energetico, Noviembre, 1980

- Petroleum - Mexico's proven petroleum reserves total 40 billion barrels, with potential reserves estimated at 200 billion barrels. Current production is at about 2.6 million barrels per day. The National Energy Plan establishes a limit on petroleum exports of 1.5 million barrels per day. Mexico is currently the largest non-OPEC oil exporter.
- Coal - Mexico has two billion tons in proven coal reserves, 650 million tons of which are concentrated in three states. Coal production in 1979 was about 8.9 million tons. Although coal currently supplies only about 6% of Mexico's energy, it is projected to supply 12% by the year 2000. A coal burning plant comprised of four 300MW units is currently under construction in Rio Escondido, Coahuila. The first unit will be in service in 1982, the other units will follow in six month intervals.
- Hydro - Installed hydroelectric capacity was 4.8 GW in 1975, representing about 40% of installed electric capacity. By 1983 installed hydroelectric capacity is scheduled to reach 10 GW. Thus far, only about 25% of Mexico's hydroelectric potential has been exploited.
- Geothermal - Mexico has 310 thermal zones and 20 geothermal fields located chiefly in the states of Jalisco, Sonora, Queretaro, Colima and Michoacan. While geothermal currently provides only 0.65% of total electric generating capacity, this is expected to increase to 7% by the year 2000 according to the National Energy Plan. The Cerro Prieto plant in Baja California Norte, the only geothermal unit in operation, generates about 75MW from 50 wells. It is being enlarged to attain a capacity of 500MW in the near future.
- Nuclear - Mexico's proven uranium reserves total some 136,000 tons, among the largest in Latin America. Mexico plans to develop nuclear power to provide energy for the future when its hydrocarbon resources are depleted. The Laguna Verde plant in Veracruz, begun in 1973, is scheduled to begin operation in 1983. The plant is composed of two 654 MW boiling water reactor units which will account for nearly 6% of Mexico's installed generating capacity when completed.
- Renewable Energy - The Mexican government is interested in developing decentralized energy sources for those areas which are not connected to the electric grid for reasons of distance from power source or low demand. The Master Plan for Use of Solar Energy (PLANMAES) establishes a goal of substituting six percent of electrical consumption with solar energy by the year 2000. Consequently, Mexico has initiated several solar water pumping, irrigation and electrification projects for use in remote villages. Solar energy holds promise in Mexico because more than 40% of the country receives insolation in excess of 500 cal/cm^2/day. The Northwest of Mexico, including Baja California, receives the highest daily insolation levels and therefore holds the greatest solar potential.

The CFE national electric transmission network, shown in Figure 2.2, is operated as a single synchronized system with the exception of the Baja California and Yucatan areas, which are operated on an isolated basis. The 400 KV backbone transmission system covers most of the nation. Significant additional transmission at 230 KV and 115 KV also exists. Due to the great distances

FIGURE 2.2 MEXICAN ELECTRIC BULK TRANSMISSION NETWORK 1979



SOURCE: Electricity Exchanges United States/Mexico, U.S. DOE and CFE, May 1980.

between load center and substations, transmission capacity is generally limited by steady-state stability. The CFE national network is divided into nine regions for administration of generation, transmission and distribution, as seen in Figure 2.3.

National peak load and energy requirements for 1979, and 1990 are presented in Table 2.1. The forecasted annual peak load growth is 9.8 percent. In order to meet this growth an additional 18,700 MW of generating capacity is planned by 1990. This amounts to more than a doubling of existing system capacity. The high growth rate in electrical energy demand reflects the energy needs of the Industrial Development Plan.

Table 2.2 indicates likely trends in fuel sources for electrical generation through 1986. Mexico originally planned to product most of its electricity from nuclear power by the year 2000. However, due to rising costs associated with nuclear power plants, this program is being modified and now projects 20,000 MWe nuclear capacity by 2000.

2.2 Key Public Sector Organizations in the Energy Area

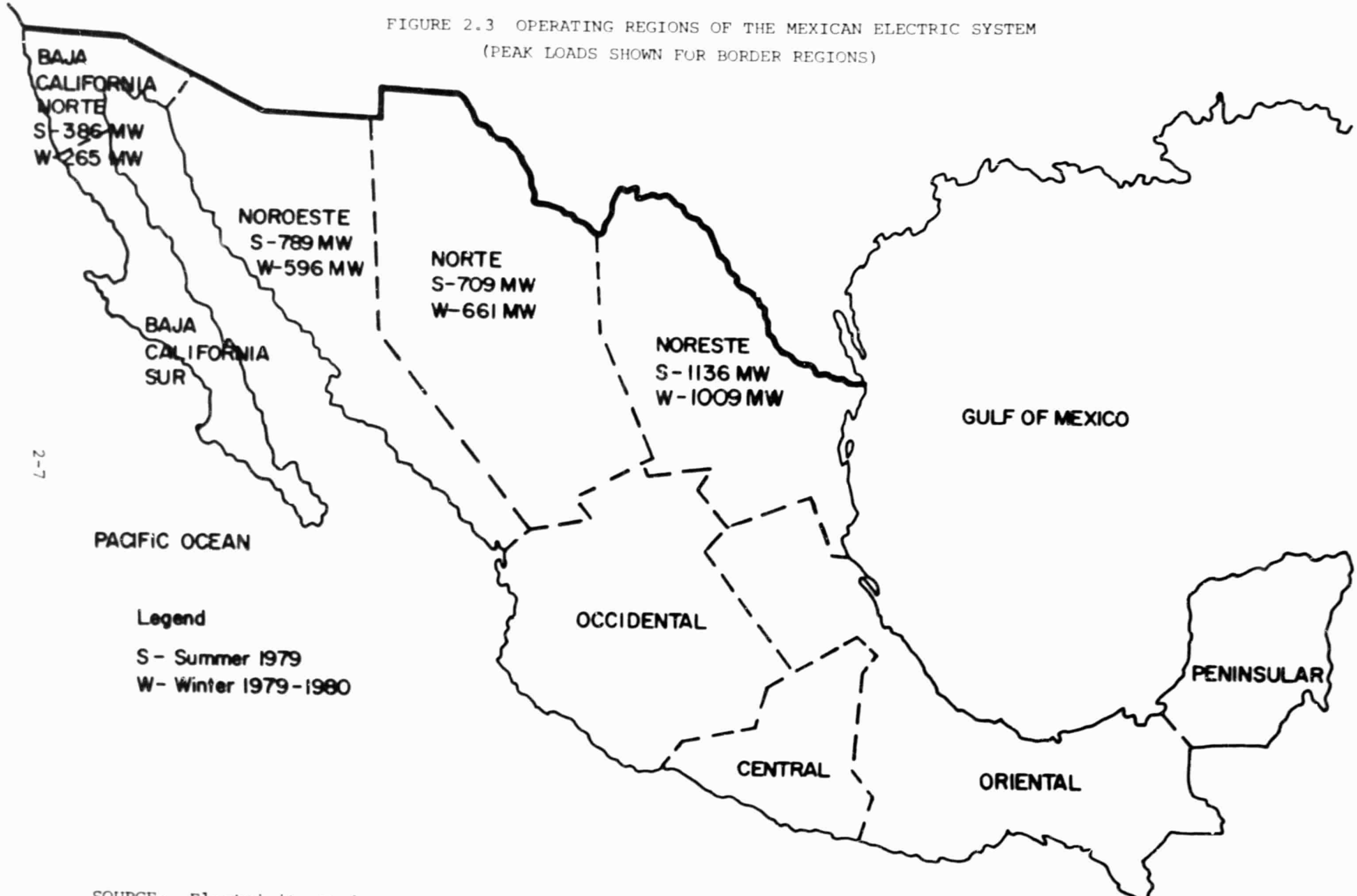
There is no single cabinet level position within the Mexican government where energy matters are centralized. Rather, ultimate responsibility for the formulation of national energy policy rests with the President of the Republic. The National Energy Commission (CNE), within the Ministry of Patrimony and Industrial Promotion has the task of coordinating the energy policy with the various federal agencies listed below which are charged with carrying out its component parts.

- PEMEX - Petroleos Mexicanos, the government-owned petroleum company. It has sole responsibility for exploration, production, refining, transportation and marketing of oil, natural gas and petrochemical products;
- CFE - Federal Electricity Commission, an autonomous governmental agency that organizes and directs the generation, transmission and distribution of electric energy;
- IIE - Institute of Electricity Research, conducts research in electrical generation, develops new technologies and advises the Federal Electricity Commission and the electrical manufacturing industry;
- CONACYT - National Science and Technology Council, funds energy research and development in national universities and government laboratories;
- DIGAASES - General Management for Saline Water and Solar Energy Development, division of SAHOP, Ministry of Human Settlements and Public Works, promotes solar energy demonstration and commercialization and carries out PLANMAES, (National Solar Energy Plan), published in 1979.

2.3 Mexican PV Capability

Photovoltaics research and development in Mexico is being carried out at present at several universities and research institutes under various programs.

FIGURE 2.3 OPERATING REGIONS OF THE MEXICAN ELECTRIC SYSTEM
(PEAK LOADS SHOWN FOR BORDER REGIONS)



SOURCE: Electricity Exchanges United States/Mexico, U.S. DOE and CFE, May 1980.

TABLE 2.1 ELECTRIC ENERGY FORECASTS

MEXICAN PEAK LOAD FORECAST (MW)

National	1979	1985	1990	Growth Rate %
Low	-	17,600	26,500	8.5
Most Likely	9,633	19,400	30,600	9.8
High	-	19,750	32,300	10.3

MEXICAN ENERGY FORECAST (GWH)

National	1979	1985	1990	Growth Rate %
Low	-	96,500	145,800	8.8
Most Likely	58,070	106,300	168,500	10.1
High	-	108,300	177,600	10.6

SOURCE: Electricity Exchanges United States/Mexico, U.S. DOE and CFE, May 1980.

TABLE 2.2

GENERATING CAPACITY BY PLANT FUEL TYPE 1977-1986

(in megawatts and as percentage of total)

FUEL TYPE	1977		1982		1986	
Hydro	4609.78	(39.64%)	6649.78	(36.83%)	8617.80	(35.48%)
Oil	5148.55	(44.50%)	8218.20	(45.52%)	9913.70	(40.85%)
Diesel	301.35	(2.60%)	290.78	(1.61%)	290.78	(1.20%)
Gas	1436.20	(12.41%)	1460.20	(8.09%)	1460.20	(6.01%)
Coal	-	-	600.00	(3.33%)	2400.00	(9.89%)
Geothermal	75.00	(.65%)	180.00	(1.00%)	290.00	(1.19%)
Nuclear	-	-	654.00	(3.62%)	1308.00	(5.38%)
TOTAL	11570.88	(100.00%)	18052.96	(100.00%)	24290.46	(100.00%)

SOURCE: Office of Preliminary Studies and Engineering, Program Planning Dept., CFE, in Mexico Solar Energy Country Notebook, PRC Energy Analysis Company, March 21, 1979.

The principal sponsors are CONACYT and DIGAASES. The government's objective seems to be the creation of a national solar technology and solar capability, rather than fossil fuel replacement capacity in the short term. The dominant attitude, expressed by Juan Eibenschutz of the National Energy Commission, at the Seventh Energy Technology Conference in Washington, D.C. in March, 1980, is that solar energy technology is presently too expensive to be applied on a wide scale by developing countries.

Nevertheless, much progress has already been made in developing a national expertise in photovoltaics. The National Polytechnic Institute (IPN) is currently producing single crystal silicon cells and flat panel modules in a laboratory process. Although production in 1980 was about 5 KW, a pilot plant is now being installed which will increase production capacity to 10-20 kw/year by 1982. CONACYT, which along with the OAS and the UNDP funds IPN PV work, is currently negotiating with the Inter-American Development Bank for a U.S. $1.2 million loan for the construction of a commercial scale photovoltaic plant. The systems cost goal for the project is U.S. $12-15 per installed watt. The IPN is also researching thin film GaAs and SnOx solar cells. Reportedly, the IPN has also established a trust fund to promote PV commercialization.

The Materials Research Institute (IIM) and the Engineering Department of the National Autonomous University of Mexico (UNAM) have also been active in fundamental photovoltaics research and development. The Engineering Department has developed detailed solar insolation maps for Mexico based on data compiled in 38 locations (See Appendix B). Economic evaluations of photovoltaic systems for rural areas in Mexico have been investigated by the IIM. In addition, the CIM is conducting research on Cu_2S/CdS, Cu/CuO_2 and amorphous silicon cells.

Research into photovoltaics and other solar technologies is also carried out at the Non-Conventional Energy Department of the Electrical Research Institute (IIE). Most funding for biogas, wind, photovoltaics and other renewable energy research is provided by the CFE. The IIE has submitted a proposal to CONACYT for the design of a 30 KW modular photovoltaic power station. The IIE's primary interest in photovoltaics is the development of systems design and balance of system construction capability and not PV cell production.

DIGAASES was put in charge of solar energy demonstration and commercialization in 1977. Since that time it has installed about 20 KW of photovoltaics in demonstrations for applications such as telecommunications, refrigerators, pumps, televisions and marine and air signals in remote areas. DIGAASES officials estimate that the initial demand for photovoltaics for rural projects of various Mexican government agencies is on the order of 250 KW. These officials state that photovoltaics are probably more cost-effective than solar thermal systems for rural applications requiring less than 1.5 KW. DIGAASES has followed the US DOE's Photovoltaic Systems Development Program closely in developing its PV commercialization strategy. Although DIGAASES shares with the IPN the long-range goal of developing an indigenous Mexican photovoltaics industry, it follows a policy of using the best available equipment, foreign or domestic, for its demonstrations. Therefore, there are no restrictions on American firms supplying PV equipment to DIGAASES.

2.4 PV Related International Agreements

The French Ministry of Foreign Affairs signed the first international solar agreement with Mexico, the TONATIUH program, in 1969. Under this agreement, sixteen solar thermal water pumping units were installed in Mexican villages by the French firm SOFRETES. The program is under the management of DIGAASES.

The Mexican government and the West Germany Federal Ministry for Research and Technology, in 1978 entered into a joint program called SONNTLAN for solar energy utilization. Under one part of the agreement, Las Barrancas, a fishing village of 250 people in Baja California, will be equipped with an integrated solar system. This includes a 5KW peak photovoltaic system for water pumping provided by AEG - Telefunken. The total cost of the project will be about $16 million, $9 million of which will be provided by West Germany. Construction has been completed, and a two-year testing and operation period is currently underway.

Under the auspices of the 1972 Science and Technology Agreement between Mexico and the United States, a Memorandum for Understanding for cooperative research and development projects in renewable energy technologies was signed in February 1978. The participating government agencies are the Mexican CONACYT and the U.S. Department of Energy. One project involves cooperative research in amorphous silicon between the Center for Materials Research (CIM) of the UNAM, and the University of Delaware. Previous plans for a solar village project called SUNCALLI have been abandoned.

2.5 Implications of the Energy Situation and Government Energy Plans for PV Systems

The Mexican government's policy of subsidizing energy costs to residential and industrial consumers makes it difficult for P/V and other nonconventional energy systems to compete in the Mexican market. The real (deflated) price of electricity has been steadily diminishing since 1962. Gasoline prices have been increasing at about the same rate as the cost of living and recently, at a lesser rate. As a major oil producer, Mexico can afford the policy of cheap internal energy prices, so it is likely to continue.

At current prices it is unrealistic to expect private sector interest in P/V as an alternative to internal combustion engines. Private sector interest will be limited to applications for which internal combustion is not a practical alternative, e.g. home TV in isolated locations. The primary market for P/V in agriculture in the near term appears to be in the public sector, as will be discussed in Chapter 6 on Feasible Agricultural P/V Applications.

3.0 MEXICAN DEVELOPMENT PLANS

3.1 Economic Development Plans

The Mexican government's overall economic growth and development strategy is outlined in the Plan Global de Desarrollo 1980-1982, or Overall Development Plan, published in April 1980. The Plan coordinates objectives and policies in thirteen different sectoral areas including the National Industrial Development Plan, the Mexican Food Supply System (SAM), the National Agriculture, Livestock and Forest Development plan, the National Employment Plan and the National Energy Plan. Mexico's petroleum revenues will be used to finance the expansion of Mexico's industrial base and increase agricultural investment.

PEMEX, the National Petroleum Corporation, is scheduled to receive 32% of the estimated forty billion dollars in anticipated oil and natural gas earnings for reinvestment purposes. The remaining $27.2 billion will be divided between agriculture, stock-raising and rural development (25%), social services and education (24%), communications and transportation (20%), industry (16%), and support to state and local governments (15%).

The present Mexican Administration views exploitation of Mexico's petroleum reserves as a means to maintain a high economic growth-rate and create jobs. The government has targeted a GDP growth rate of 7.5 to 8% for 1981 and 1982 hoping thereby to achieve a growth rate in employment of 4.2%, or 750,000 jobs per year. Indeed, job creation has been given a higher priority under the present Portillo Administration than controlling inflation, which is currently at a 30% annual level. The anti-inflation policy is centered around increasing supply by removing bottlenecks, keeping the prices of fuel and food staples at artificially low levels and controlling imports.

3.2 Rural Electrification in Mexico

The Federal Electricity Commission (CFE) is charged with carrying out the program outlined in the Plan Nacional de Electrificacion Rural 1979-1982. The Mexican government views rural electrification as a means of improving the quality of life in the rural sector, increasing agricultural production and reducing migration to crowded urban areas. The Plan delineates three separate programs of electrification: Population Centers, targeted at rural communities and suburban neighorhoods; Production, directed towards agriculture, irrigation wells and rural industries, and Public Services, including schools, potable water wells, and medical clinics. During the period 1979-1982 approximately 410 million dollars will be spent on the rural electrification program.

The strategy of the CFE is to electrify the larger communities (i.e., those with more than 500 inhabitants) first. Priority is given to villages which are no more than seven miles from the grid or the distribution lines and can therefore be electrified using 20-30kw transformers. For small remote communities, the CFE generally provides electricity via diesel generators. Approximately 19,460 KW diesel were installed by the CFE between 1978 and 1979. However, increased attention is now being given to alternate sources such as solar and small hydro. CFE officials expressed a reluctance towards solar because they cannot control its operation and do not consider most villagers capable of maintaining the equipment.

Figure 3.1 shows the distribution of unelectrified communities by state in 1977. It indicates that six states, Chiapas, Chihuahua, Jalisco, Michoacan, Tampaulipas, and Veracruz each have more than 4500 unelectrified rural communities. Within these communities live 4,138,000 people.

As can be seen in Table 3.1, rural electrification in Mexico is already quite advanced. The table shows that electricity is available in practically all communities of over 2500 inhabitants, 85% of those between 1000 and 2500 inhabitants, 65% of those between 500 and 1000 inhabitants and 45% of those between 250 and 500 inhabitants. Nonetheless, the table also indicates that in 1977 some 10 million Mexicans living in 78,668 rural communities lacked electricity. However, by 1982, 2,275,955 of them will be covered since electricity will be available in nearly all villages of 500 or more inhabitants. Table 3.2 presents an estimate of the likely distribution of electrified rural communities assuming completion of the Plan's goal of electrifying 5892 rural communities by 1982.

The production program of the CFE aims to increase agricultural production and rural employment in accord with the objectives established by the National Agricultural, Livestock and Forest Development Plan. The CFE serves these goals by fulfilling the electrification requirements for the programs of the Ministry of Agriculture and Hydraulic Resources (SARH), the National Rural Credit Bank (BANRURAL), PIDER and the state governments. Preferential financing is given to low and medium income producers who participate in the programs of these organizations. The Plan Nacional de Electrificacion Rural states that between 1979 and 1982 some 8645 agricultural pumps will be electrified under the Production program, irrigating 270,400 hectares. Approximately 42% of the demand for rural electrification derives from SARH projects, 41% from PIDER development projects, 13% from BANRURAL projects, and the remainder from State governments, Banco de Mexico (FIRA), and other agencies.

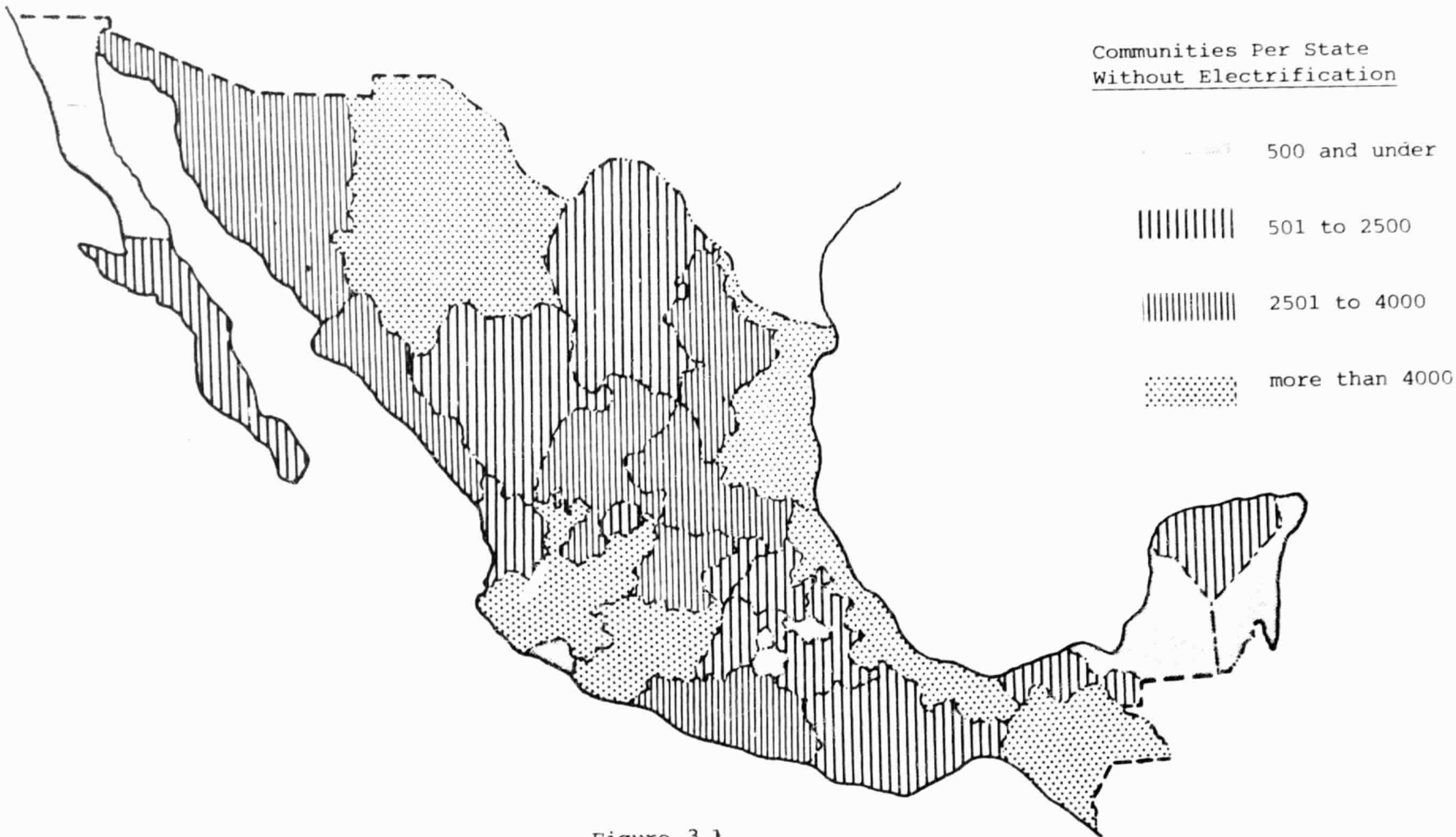


Figure 3.1

DISTRIBUTION OF UNELECTRIFIED COMMUNITIES (1977)

SOURCE: Plan Nacional de Electrificacion Rural 1979-1982

Table 3.1

EXTENT OF ELECTRIFICATION IN MEXICO, DECEMBER, 1977

Number of Inhabitants Per Rural Community	Communities			Inhabitants		
	Number	Number Electrified	Percentage Electrified	Number	Number w/ Electricity	Percentage w/ Electricity
1 to 99	57,176	1,457	2.5%	1,786,311	79,442	4.4%
100 to 249	16,582	3,481	21%	3,212,258	719,499	22%
250 to 499	12,150	5,483	45%	4,857,809	2,167,178	45%
500 to 999	7,384	4,766	65%	5,696,437	3,633,391	64%
1000 to 2499	4,073	3,525	87%	6,920,598	5,905,369	85%
2500 to 9999	1,544	1,529	99%	9,039,417	8,949,793	99%
Total Rural (56%)	98,909	20,241	20%	31,512,830	21,454,672	68%
Urban 1/ (44%)	393	393	100%	24,680,131	24,680,131	100%
Total Population (100%) 1/	99,302	20,634	21%	56,192,961	46,134,803	82%

1/ Not including the population of the Federal District (Mexico City), estimated in December 1977 at 8,785,236 inhabitants, bringing the total national population to 64,978,197.

SOURCE: Gerencia General de Electrificacion Rural, CFE

Table 3.2

ESTIMATED EXTENT OF RURAL ELECTRIFICATION IN MEXICO, 1982

Number of Inhabitants Per Rural Community	Communities: Number	Communities: Number Electrified 1982	Percentage Electrified 1982	Increment Electrified Over 1977
1 to 99	57,176	1,600	2.8%	143
100 to 249	16,582	4,000	24%	519
250 to 499	12,150	7,619	63%	2,136
500 to 999	7,384	7,300	98%	2,534
1000 to 2499	4,073	4,070	99%	545
2500 to 9999	1,544	1,544	100%	15
TOTAL RURAL	98,909	26,133	26%	5,892

As seen in Figure 3.2, about 28% of the 23 million hectares of cultivated land in Mexico are irrigated. Gravity-fed irrigation accounts for 80% and pumped systems account for 20%. 85% of the pumping systems are powered by electricity and about 15% by internal combustion engines. CFE estimates there are 3,691 internal combustion engine pumps serving an area of 171,086 hectares. About 69% of these IC pumps are concentrated in six states, as follows:

State	Internal Combustion Driven Pumping Units	Hectares Irrigated
Sonora	787	55,090
Guanajuato	554	16,620
Zacatecas	514	20,560
San Luis Potosi	349	6,282
Baja California Sur	263	19,725
Durango	259	9,324
TOTAL	2,726 (69%)	127,601 (75%)

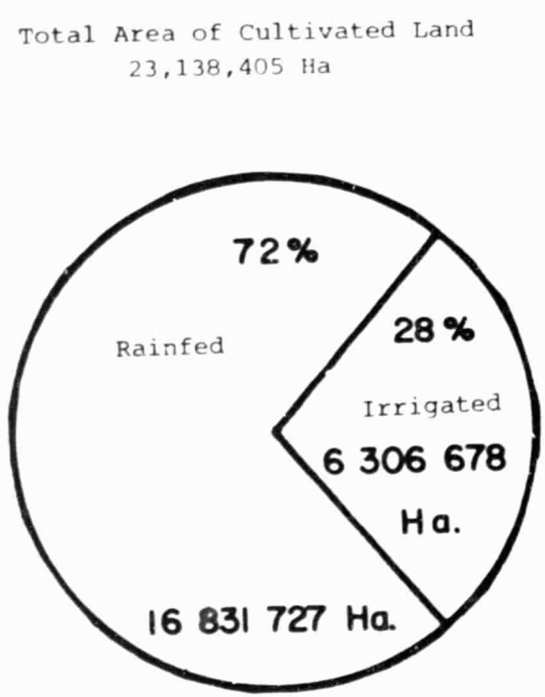
The remaining 31% of the internal combustion driven pumping units identified by the CFE are dispersed between the remaining 25 states and the Federal District. Because electric motors display better efficiency and lower maintenance costs, they are preferred by the SARH and PIDER. PIDER has embarked on a program to substitute 630 electric motors for existing internal combustion engines.

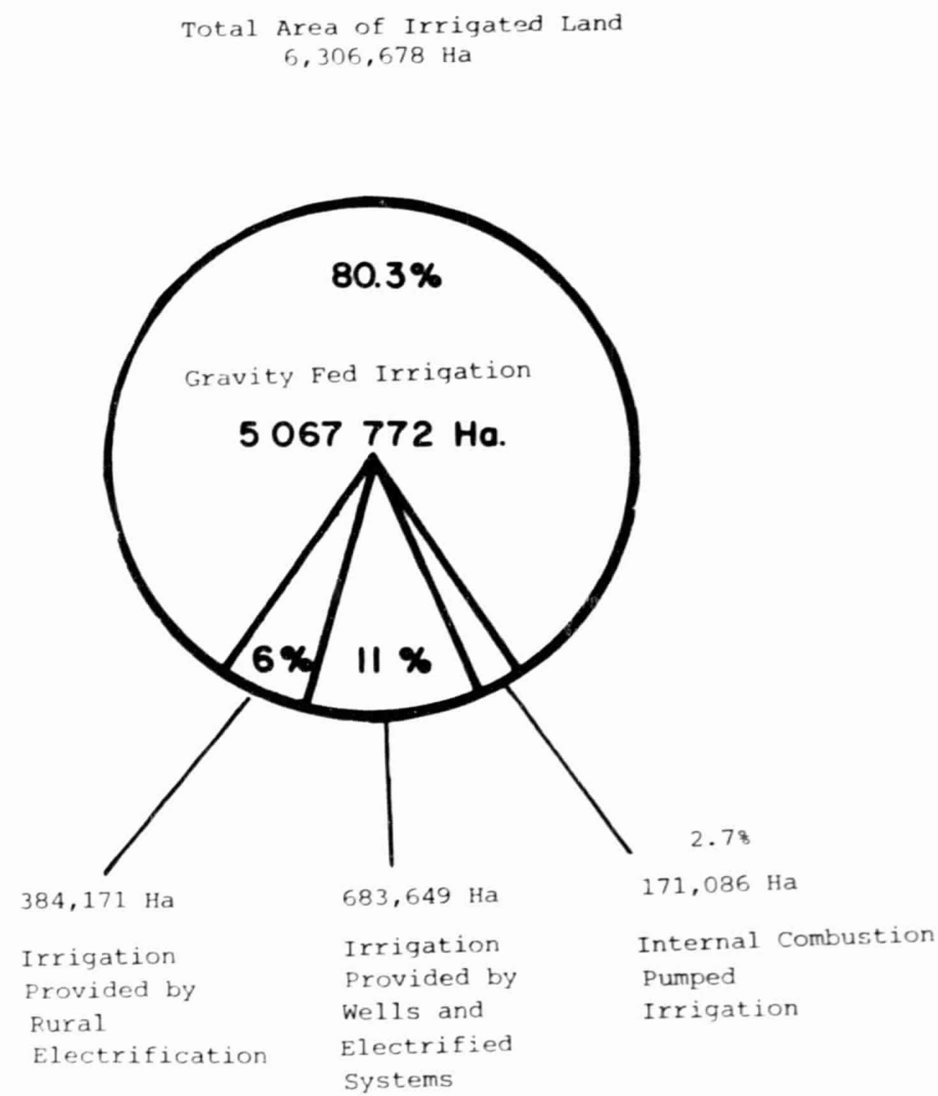
3.3 Agricultural Development Plans

The Mexican government's agricultural development policy is outlined in the Sistema Alimentario Mexicano, or Mexican Food System (SAM), announced in March 1980. The principal goals of the SAM are 1) to attain self-sufficiency in the production of corn and beans by 1982, 2) to attain self-sufficiency in other staples by 1985, and 3) to improve the nutrition levels of low-income Mexicans. The SAM is composed of 12 program areas, one of the most important of which is the shared risk program, which guarantees a minimum income to farmers in rainfed areas who produce certain basic foodstuffs. Be means of a price support policy, the government hopes to increase and diversify crop production. Under the SAM guaranteed prices will increase 6.3% for corn, 11.8% for beans and 3.6% for wheat between 1981 and 1982, in real terms. Furthermore, the cost of inputs such as fertilizer and seeds to these producers will be subsidized.

The Plan Nacional de Desarollo Agropecuario has established a goal of 5.5 additional hectares of land to be brought under cultivation by 1990 through a

FIGURE 3.2 DISTRIBUTION OF CULTIVATED LAND





SOURCE: Plan Nacional de Electrificacion Rural variety of irrigation schemes. The distribution of this future farmland is shown in Figure 3.3. About 59% of the farmland will be added in the rainfed areas of the Gulf and Southeast through the construction of dams and drainage of marshes. An additional 27% is to be opened for cultivation in the North and Central Pacific Coast region via extension of existing irrigation facilities. The remaining farmland will be situated in the North and North Central region (4%) and the Central West (10%). The goal of 550,000 additional hectares per year may be viewed as optimistic given that during the period 1976-1981 additional cultivated land increased at about 260,000 hectares per year.

Some of the chief problems in Mexican agriculture have been transportation bottlenecks, inadequate storage facilities and underutilization of land. In recognition of these problems the Mexican government in 1981 began to invest heavily in projects designed to modernize railroad transportation and improve port and handling facilities, particularly for agricultural commodities. Furthermore, a nationwide program for the construction of grain storage facilities around the major production and consumption centers was begun in 1980.

The total cost of the agricultural development program in 1980-81 will approximate U.S. $2.2 billion for production programs and U.S. $1.5 billion for consumption side activities.

In addition the Law for Agricultural and Livestock Development, which took effect in February 1981, seeks to improve the productivity of Mexican farmland. It encourages communal farmers, such as ejidatarios, whose ejidos are often characterized by low levels of productivity, to form "units of production" with small landowners in order to take advantage of modern farming techniques and available capital. Other features of the law penalize owners of idle land, encourage production of crops on grazing land and discourage the fractionalization of farm property into units of less than five hectares.

The Lopez Portillo Administration has increased funding for rural development projects directed towards the poor and landless farmers. Several programs have been initiated to give improved extension services and to provide seeds and fertilizer to low income farmers in selected areas. These Mexican government efforts in the agricultural sector since 1970 and especially since 1976 have been directed toward stemming urban migration by making enormous investments in the rural areas, especially in the rainfed ejido sector. Public investments in rural areas are channeled to the executing ministries such as SARH, SAHOP, and CONASUPO, mainly through COPLAMAR (Coordination of the Plan for Marginal Zones) and PIDER (Program for Integrated Rural Development).

FIGURE 3.3

DISTRIBUTION OF THE 5.5 MILLION HECTARES THAT WILL BE MADE AVAILABLE DURING THE NEXT TEN YEARS FOR ADDITIONAL FARMLAND

SOURCE: International Harvester of Mexico

COPLAMAR reports directly to the President's office and is involved mainly in financing rural infrastructure such as roads, bridges, rural potable water, electrification, rural clinics and stores, etc. Its approach is sectoral, financing action in each of those fields through the appropriate executing agency. The COPLAMAR budget for 1980 was about U.S. $1500 million, and it is strongly supported by the President.

PIDER is involved more in productive investments such as poultry and pig farms, dairies, small-scale irrigation, fruit orchards, agro-industries, etc., although it also finances rural infrastructure of the types mentioned above. Its approach is integrated, working in some 140 geographically-defined micro-regions in which it finances integrated rural development programs. The PIDER budget has grown from about U.S. $200 million in 1977 to U.S. $640 million in 1980, and the scope of its activities has increased considerably.

COPLAMAR and PIDER planners used financial criteria such as net present value and cost-benefit ratio, along with social criteria such as employment generation and basic human needs in their project approval process. Therefore a large potential market for photovoltaics in rural development projects, particularly in the rainfed ejido sector, will exist when PV becomes economically competitive with diesel generators.

4.0 FINANCING OF AGRICULTURE, ENERGY AND DEVELOPMENT PROJECTS

4.1 Overview of the Mexican Banking/Investment System

The Mexican banking system includes public, private, and mixed financial institutions. The Banco de Mexico, S.A., the country's central bank, regulates currency in circulation, credit, interest rates, bank reserves, exchange rates, and loan and investment transactions. Financial transactions are closely supervised by the National Banking and Insurance Commission. The Mexican government has established a number of other banks geared to investments in specific sectors. One of the most important of these is Nacional Financiera, S.A., which is 51% government-owned, and whose main objective is Mexico's industrial development. Other such institutions include Banrural (agricultural credit), Banobras (public works project), and Banco Nacional de Comercio Exterior (export financing).

Nacional Financiera also operates a number of trust funds (fideicomisos) which make below-market rate funds available for specific purposes of interest to the Mexican government. These funds are not generally available to foreign-owned companies. Among these funds are FIRA (agriculture and agro-industry), FOGAIN (medium and small-scale industry), FONATUR (tourism development), FOMIN (industrial development) and FONEP (special preinvestment studies and projects).

For many years, the Mexican banking system consisted of institutions offering a limited number of specific services (e.g., deposits, savings, mortgage operations, etc.). In March 1976, Mexico's General Law on Credit Institutions and Auxiliary Organizations was amended to permit a single institution to include commercial, investment, and mortgage banking. This action was taken to encourage a more efficient banking system through economies of scale. Currently, these multiple-service banks, or "multibancos", such as Bancomer, Banamex, Comermex, and Banca Serfin provide most of the non-government finance available to private enterprise. Insurance and bonding companies also contribute to the supply of funds available for loans and investments.

The main sources of short-term credit are the commercial banks. Short-term bank credit is limited by law to 180 days. Usually, short-term loans can be renewed for up to 360 days, after which a new loan agreement must be made. The interest rates on short-term credit vary according to application, from 16% for a few industrial uses to 22% for commercial uses. Most banks charge a higher effective rate by imposing an up-front charge of 1% as a commission for credit opening or renewal.

The principle sources of medium and long-term credit are finance companies (financieros) and multiple-service banks (multibancos). These institutions offer two types of credit, each with its own characteristics. "Prestamos de habitacion o avio" are loans guaranteed by a company's (or farm's) current assets. These loans must be used to purchase raw materials which serve as security for the loans as the materials are processed into finished products. In the case of farmers, the crop itself may serve as collateral. The usual term of these loans in the agricultural sector is one or two years, depending on the production cycle. "Credito refaccionario" consists of loans guaranteed by a company's (or farmer's) fixed assets. These loans are granted for the purchase of machinery or equipment for which a chattel mortgage serves as collateral. Terms on these loans range from five to fifteen years. In recent years, the Banco de Mexico has limited considerably the amount of credit available to private industry and commerce, both by increasing reserve requirements and by directing the banks to invest substantial portions of their available loan funds in other fields. For instance, private banks and "multibancos" must direct a minimum of from 0.7 to 3.0% of their loans, short or long term, to low income ejidatarios, and to agro-industries. For agriculture, livestock, poultry, apiculture (beekeeping) and fishing, the required minimum ranges from 3.9% for private banks in metropolitan areas to 25% for private banks in rural areas, and to 4.7% for multibancos.

4.2 Agricultural Financing

A major source of medium and long-term loans to the agricultural sector in Mexico is the Banco Nacional de Credito Rural, or Banrural. Banrural's principle clients are the ejidatarios and small farmers who might otherwise have difficulty in obtaining loans from private banks. Banrural's principal sources of funding include federal revenues, direct loans from the private sector, both foreign and domestic, and the FIRA, (Guarantee and Development Fund for Agriculture, Livestock and Poultry).

Loan terms and interest rates on Banrural loans vary according to borrower and end use. The Special Program for Low Income Producers, established by the federal government, authorizes the FIRA to discount low-interest, long-term loans granted by Banrural, FINASA (National Sugar Finance Company) and private banks to low income farmers for activities such as:

a) Opening of new land to cultivation,
b) Small irrigation projects,
c) Permanent plantations,
d) Digging of wells,
e) Construction, and
f) Acquisition of breeding stock, machinery and equipment.

The program is aimed at assisting ejidatarios and small landowners (minifundistas). Interest rates for farmers engaged in primary activities range from 11.0 to 13.5% depending on the size of the loan. For agroindustries which qualify under the program the rate is 14%. For established operations with prior credit, 15.5% is charged. However, for producers of corn and beans, which the SAM has established as priority foodstuffs, a rate of 12% has been set.

Repayment terms are established by Banrural officials as a function of the borrower's ability to pay. For each loan request received, Banrural technicians perform a credit study which establishes loan terms and makes recommendations to the farmer. The maximum repayment term allowed by law is 15 years for "credito refaccionario." Penalty for late payment is an additional 2% above set interest rate, calculated on the balance due and time elapsed. "Credito de avio" is normally repaid when the crop is harvested and sold.

Banrural offers several types of collateral arrangements as well. Farmers with sufficient resources are required to put up a percentage of the investment in cash themselves as determined by Banrural. Low income farmers who own their property provide a mortgage guarantee of up to 70% of the value of their house, land, equipment, etc. For ejidatarios who do not own their land, capital goods, crops, and even moral guarantees are accepted, depending on the circumstances.

The average size of loans granted to ejidatarios is 250,000 pesos ($10,638). The maximum amount allowed by law is 400,000 pesos ($17,021) per ejidatario, multiplied by the number of farmers in the ejido. For small property owners, the usual size of loans is 1.5 to 2 million pesos ($63,830 - $85,100) per farmer, multiplied by the number of farmers in the farming unit.

In 1979, Banrural loans discounted by the FIRA totalled U.S. $160 million. Table 4.1 below shows the distribution of Banrural financing by end use sector.

TABLE 4.1 BANRURAL FINANCING

Agriculture	63.8%
Livestock	26.3
Agroindustry	7.5
Poultry	1.1
Apiculture (beekeeping)	0.8
Other	0.5
	100.0%

SOURCE: Ing. Isidro Comacho, General Subdirectorate for Credit, Banrural

Banrural officials estimated that approximately 18% of the bank's loans are used for irrigation purposes, and 29% for farm mechanization.

As seen in Table 4.2, the private banks, and especially a few of the large multibancos, (e.g., Bancomer, Banamex, and Comermex), lent large volumes of money to the agricultural sector in 1979. However, this table tends to understate the importance of Banrural in agricultural lending because not all of Banrural's activities are discounted by the FIRA.

Table 4.3 shows the distribution of medium and long-term loans for the establishment and expansion of agroindustries in 1979. The agroindustries which received the largest aggregate investment were oilseed milling, feed mixers, fruit and vegetable sorting and packing, and grain driers.

TABLE 4.2 CREDIT DISCOUNTED BY FIRA 1979

BY FINANCIAL INSTITUTIONS

FINANCIAL INSTITUTION	1-2 Year Loans (credito de avio)		5-15 Year Loans (credito refaccionario)		TOTAL	
	Millions of U.S.$*	%	Millions of U.S.$*	%	Millions of U.S.$*	%
Private Banks (including multibancos)	486.2	42.9	359.6	31.7	845.8	74.6
Bancomer	143.7	12.7	110.1	9.7	253.8	22.4
Banamex	116.8	10.3	101.1	8.9	217.9	19.2
Comermex	64.2	5.7	46.7	4.1	110.9	9.8
Banpacifico	33.2	2.9	12.6	1.1	45.8	4.0
Serfin	31.7	2.8	18.9	1.8	50.5	4.6
Alianza Intebancaria Regional	42.4	3.7	34.8	3.1	77.2	6.8
Bancos Regionales Asociados	32.7	2.9	19.8	1.7	52.5	4.6
Confia	3.1	0.3	1.6	0.1	4.7	0.4
Non-Affiliated Independent Banks	18.4	1.6	13.9	1.2	32.3	2.8
Mixed Banks	48.5	4.2	42.8	3.8	91.3	8.0
Financiero Internacional	24.3	2.1	18.4	1.6	42.7	3.7
Banco Mexicano, S.A. Somex	23.2	2.0	13.7	1.2	36.9	3.2
Non-Affiliated Independents	.9	0.1	10.7	1.0	11.7	1.1
Government Banks	--	--	197.3	17.4	197.3	17.4
Banrural	--	--	159.9	14.1	159.9	14.1
Finasa	--	--	37.8	3.3	37.8	3.3
TOTAL	534.7	47.1	599.7	52.9	1,134.4	100.0

* At exchange rate of 23.5 pesos/U.S.$

SOURCE: Informe Anual 1979, Banco de Mexico, S.A. FIRA, Mexico, D.F., 1980.

TABLE 4.3 MEDIUM AND LONG TERM LOANS[1/] FOR THE ESTABLISHMENT AND EXPANSION OF AGROINDUSTRIES

1979

	Type of Agroindustry	Number of Loans	Aggregate Investment* (U.S. $)	Average Loan Size* (U.S. $)
1.	Slaughterhouses and Beef packing	21	$ 7,699,791	$ 366,657
2.	Milk pasteurizers and dairy processing	21	3,972,868	189,184
3.	Poultry processing	7	1,597,966	228,281
4.	Feed Mixers	58	22,359,034	385,501
5.	Grain driers and storage	36	14,120,778	392,244
6.	Dehydrators	15	4,366,417	291,094
7.	Gins and fiber extraction	9	1,595,906	177,323
8.	Oilseed milling	14	31,912,468	2,279,462
9.	Fertilizer and insecticide mixers	9	2,030,911	225,657
10.	Fruit and vegetable sorting and packing	94	15,869,038	168,820
11.	Fruit and vegetable refrigeration	44	8,650,809	196,609
12.	Fruit and vegetable processing	16	8,331,557	520,722
13.	Grain milling	16	8,176,677	511,042
14.	Vintners and distilleries	11	4,934,979	448,634
15.	General processing	33	3,374,919	102,270
16	Extractive industry	1	10,638	10,638
17.	Forestry	31	3,318,962	107,063
18.	Inputs and services	18	5,033,200	279,622
19.	Fishing and fish processing	8	1,016,681	127,085
20.	Agricultural machinery	5	632,174	126,435
	TOTAL	467	$149,005,770	$ 319,070

1/ The exact distribution between medium and long-term loans for agroindustry is not known. However, for FIRA discounted loans as a whole in 1979, long term loans (credito refaccionario) accounted for 53%, and medium-term loans (credito de avio) accounted for 47%.

* Assuming conversion rate of 23.5 pesos/U.S. $.

SOURCE: Informe Anual 1979, Banco de Mexico, S.A. FIRA, Mexico, D.F., 1980.

4.3 Energy and Industrial Development Financing

The principal industrial development bank in Mexico is the Nacional Financiera, S.A. (NAFINSA). Funds managed by NAFINSA in financial fiduciaries and guarantee and endorsement operations totalled US$15.0 billion as of June 30, 1980. Total credits made available during the 1979-1980 financial year amounted to US$ 2.5 billion. This represented a 37.6% increase over the previous year.

Of this total, US$428.8 million was directed to the energy sector. Petroleos Mexicano (PEMEX) received US$204.2 million which enabled the company to continue its production programs and to conduct research and development into new technologies. Support of US$224.6 million was provided for the Federal Electricity Commission (CFE), for expansion of generating capacity transmission and distribution. Private sector capital invested in the energy sector in 1980 totalled some US $469.2 million. An additional US$357.2 million was provided for agriculture, hunting, forestry, and fisheries through specialized banks, SARH, and the various trust funds (e.g. FIRA) set up by the federal government to support these activities. Private and mixed sector credit devoted to agriculture and livestock in 1979 totalled US$2.25 billion.

Diversification of NAFINSA's portfolio was achieved by offering support to basic industrial activities, such as iron and steel (US$350.2 million), as well as transportation (US$269.9 million), agriculture, forestry and fisheries (US$357.2 million), tourism (US$58.9 million) and other priority fields such as mineral extraction. A significant portion of these funds were channeled through development trust funds such as FOGAIN, FOMEX, FONEI and others.

Approximately 51% of the financing provided by NAFINSA in 1979-1930 came from internal sources. In its role as financial agent to the Mexican government, NAFINSA contracted new loans totalling US$473 million with international organizations and foreign government agencies during the financial year. In addition, it initiated negotiations for loans in the amount of US$2.033 billion which will be channeled into:

1) irrigation programs
2) pre-investment studies
3) support to agro-industrial projects
4) the steel industry
5) fertilizers

6) agricultural credit programs
7) the mining industry
8) support programs for small and medium scale industry
9) rural development, and
10) the importation of needed capital goods.

Major international sources of financing include the International Bank for Reconstruction and Development (IBRD), the Interamerican Development Bank (IDB), the International Fund for Agricultural Development, and the United States Export and Import Bank (EXIMBANK). Loans to Mexico through Nacional Financiera, S.A. approved by the IBRD and the IDB during 1979-1980 are shown in Table 4.4. Examples of loan terms on several international loans signed in 1979-1980 are presented in Table 4.5.

4.4 Attitudes of Financial Institutions Towards Photovoltaics

Interviews with several private and government financial institution representatives were held to assess the attitudes of the financial community towards photovoltaic systems. In the financial sector awareness of photovoltaics was generally low, specifically regarding possible applications. While these individuals were willing to consider loans for photovoltaic systems, they did not exhibit any great enthusiasm. Representatives of Banural and the FIRA felt that it was unlikely that financing for PV use in irrigation or other agricultural profits would be approved unless it could be proved that such systems provided the most cost-effective power source when compared to existing systems. The reluctance of these officials was based on the following factors:

- high initial capital cost of photovoltaic systems
- widespread availability of electrified sites for agricultural development projects
- belief that gasoline or diesel generators are more cost-effective power sources than PV
- belief that other energy sources such as biogas and low-head hydro should be financed before photovoltaics
- reluctance to finance projects using unfamiliar technologies.

Representatives of private financial institutions noted that similar problems could be expected in obtaining private financing for PV systems since the technical evaluation staffs of private banks are often trained by the FIRA and use the same evaluation criteria as government banks. All sources agreed that the likelihood of PV financing would be improved by increased dissemination of information about photovoltaics use to financial institutions. A representative of the FIRA expressed interest in publishing information about PV

TABLE 4.4

IBRD and IDB FINANCING AS OF JUNE 30, 1980
(Thousands of U.S.$)

Application	IBRD Amount Approved	IBRD Structure (%)	IDB Amount Approved	IDB Structure (%)
Total	3,927,100	100.0	2,058,596	100.0
Industry	812,000	20.7	0	0.0
Electricity	704,800	17.9	0	0.0
Irrigation	682,500	17.4	685,042	33.8
Agricultural Credit	600,000	15.3	441,604	21.4
Roads & Highways	266,800	6.8	243,981	11.9
Mining	40,000	1.0	158,250	7.7
Rural Development	336,000	8.6	40,939	2.0
Railroads	235,700	6.0	0	0.0
Credits to Small & Medium-Scale In-	0	0.0	113,392	5.5
Tourism	114,000	2.9	80,488	3.9
Higher Education	0	0.0	63,144	3.1
Iron and Steel	0	0.0	60,553	2.9
Export credits	0	0.0	52,433	2.5
Drinking Water	90,000	2.3	14,024	0.7
Fisheries	0	0.0	47,692	2.3
Pre-Investment Studies	0	0.0	37,054	1.8
Airports	25,000	0.6	0	0.0
Ports	20,300	0.5	0	0.0
Housing	0	0.0	10,000	0.5

SOURCE: Annual Report, 1980, Nacional Financiera, S.A., Mexico, D.F., 1980.

TABLE 4.5

LOAN TERMS FOR FOREIGN BORROWING

Organization	Loan Amount (million US$)	Interest Rate	Loan Term
IBRD	175	7.9%	17 yrs. + 5 yr. grace period
IBRD	92	7.9%	17 yrs. + 5 yr. grace period
IDB	50	7.9%	20 years
IDB	94	7.9%	25 years
IDB	40	7.9%	20 years
International Fund for Agricultural Development	22	8.0%	15 yrs. + 1 yr. grace period
US EXIMBANK	189.8	8.5%	11 years + 1 grace period

SOURCE: Annual Report 1980, Nacional Financiera, S.A. Mexico, D.F., 1980 applications in agriculture in the FIRA newsletter.

4.5 Availability of Long-Term Investment Funds for Photovoltaic Systems in Agriculture

Due to their high initial capital costs, photovoltaic systems will require long-term financing. As indicated in previous sections, long-term agricultural loans in 1979 totalled US$599.7 million and NAFINSA loans to the energy sector US$428.8 million. Although these are large sums, the fact that photovoltaics is not a priority for the Mexican government makes it extremely unlikely that long-term financing would be available for large purchases of photovoltaics systems. It is probable, however, that if a PV project were to be funded by a domestic loan, it would likely be from NAFINSA, since that organization provides most financing for development projects, including irrigation and agricultural infrastructure, or by Banrural, which makes most long-term agricultural loans to ejidos and small farmers.

Another possibility is that a PV project could be financed with international funding. As indicated in Section 2.3, the IPN is currently soliciting financing from the IDB for construction of a commercial-scale PV plant. International agencies have shown interest in financing renewable energy projects in other countries and therefore might be receptive to a PV project in Mexico. Much depends however, on the outcome of PV projects proposed or under consideration by Mexican government agencies (see Section 5.1). If these projects, particularly in the area of telecommunications, become priority items, then financing, whether through banks or federal funding will not be a problem.

For the time being, however, the initial amount of capital that would be available for photovoltaic systems would be very small. Consequently, American PV manufacturers may have to develop innovative financing schemes in order to sell PV products in Mexico.

4.6 Conclusions

Mexico has an extensive financial system composed of private, mixed and government-owned financial institutions. Most long-term financing is provided by the multiple-service banks (multibancos) and the government banks, such as Banrural and Nacional Financiera. Long-term loans to the agricultural sector in 1979 totalled US$599.7 million. Only a small part of this capital is estimated to be available for financing photovoltaic systems in the near term. This lack of capital may be a significant barrier to the marketing of photovoltaic systems in Mexico.

Private venture capital in Mexico tends to be short-term and with high interest rates. Therefore, the principal sources of low-interest long-term loans will continue to be government development and agriculture banks, and the multibancos. Since the low-interest loans apply to priority government activities, low priority photovoltaics would not be eligible. Barring a change in government policy, American photovoltaics manufacturers will have to focus their marketing efforts on convincing the private financial institutions that photovoltaics are economically and financially viable in order to gain long-term financing or introduce innovative financial schemes which do not require domestic loans.

5.0 BUSINESS ENVIRONMENT

5.1 Level of Awareness

An estimated 25% of the individuals contacted had any substantial knowledge of PV systems. Among energy sector organizations the level of awareness was much higher, reflecting the advanced stage of photovoltaic development in Mexico. SARH, PIDER and COPLAMAR officials involved in irrigation, water pumping and rural development were aware of possible PV applications in these areas. However, these individuals felt that the cost of PV precluded its adoption except in certain low power uses. They felt, however, that when PV costs decline to a level competitive with internal combustion engine power any cultural or social barriers that may hamper its widespread implementation could be overcome.

Despite these expressed reservations about PV applicability several government agencies are considering PV use in the near term. These include:

- Ministry of Education - 17.5 Wp PV systems to power black and white television and/or tape recorders for rural education in 700 rural villages.
- Department of Fishing - portable PV powered television units (24 watts) to provide technical training for fishermen; small icemaking plants; fish refrigeration.
- PEMEX - cathodic protection for off-shore oil rigs and pipeline.
- SARH - PV powered water pumps (714 Wp) for irrigation.
- Ministry of Transportation and Communications - Solar-powered buoys for navigation; Plan Nacional de Telefonia Rural (National Rural Telephonic Communications Plan) - installation of 1,000 PV powered rural telephones in 10 years.
- Ministry of Defense - military radio.
- Mexican Social Security Institute (IMSS) - rural hospital units equipped with flourescent lamps, refrigerator units, and radios.

Only a few of the private sector contacts who were not energy related were familiar with photovoltaics. A few contacts indicated they had seen photovoltaics advertised on television, but the majority of those who were aware of PV had read about it. Among farmers, awareness of PV was generally low and many were skeptical about its appropriateness to their needs. High first cost seemed to be the principal inhibitor to PV use in the rural sector; most farmers without access to electricity lack the financial resources to purchase PV systems. Like the public sector, the private sector in Mexico is adopting a wait-and-see attitude towards PV.

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1. J.L. Del Valle, C. Flores and A. Urbano, "Estudio Preliminar de las Alternativias Para Suministro de Electricidad a Aulas Rurales Programa "Primaria para Todos;" Reporte Interno IEES-10480, Centro de Invesitgación y Estudios Avanzados del Instituto Politécnico Nacional, Mexico, D.F. Agosto 1980.
2. E.J. Perez, S. Noyola and L. Hernandez, "Diseño y Operación de un Sistema Motobomba Solar Fotovoltaico Para Agua, Reporte Les-Clp-Cn07-80-01, IPN. Mexico, D.F., Septiembre, 1980.

5.2 PV Business Activity

While the indigenous photovoltaics industry in Mexico is in a formulating stage, it is important to recognize that several international firms, both Mexican and non-Mexican, are already active in the PV market. Probably the first PV firm to enter the market was Phillips Holland in 1972-73. Until recently, Phillips marketed its imported PV system through a Mexican agent. Phillips arrays were installed in the first solar house (La Cosa Solar 1) constructed in Ajusco, outside Mexico City in 1976. It is reputed that the Solar Division of Phillips Mexicana, S.A. de C.V. will begin assembling PV modules in Mexico in the near future.

Several French firms are also active in the Mexican market. Thomson CSF sells PV-powered rural telephone station systems, and Guinard and Briau both market water pumping stations equipped with PV modules. The German firm AEG-Telefunken, in addition to providing arrays for the SONNTLAN project, has expressed to the Mexican government interest in establishing an assembly plant in Mexico.

While in Mexico the team contacted three firms which market American photovoltaic systems. Of these firms only one (SOLVIMEX) assembles PV modules in-country with imported cells. This is done to avoid the higher tariffs on imported systems (See Section 5.6). SOLVIMEX tentatively plans to begin cell manufacture in Mexico in two or three years, depending on market development. A company representative indicated that the major PV market in the near term will be in rural telephones and televisions, with the Mexican government being the principal client.

The two other firms contacted, Productos Lorain de Mexico, S.A. de C.V., and Motorola de Mexico, S.A. de C.V. concurred in the judgement that the principal client for PV equipment will be the Mexican government. Both stressed the advantage in converting to in-country assembly and/or manufacture should the market for PV expand further. A Productos Lorain de Mexico sales manager estimated that the Mexican PV market had increased 100% between 1978 and 1980 and predicted that rural telephones will constitute the major market in the short-term. Neither company had directed its marketing efforts towards rural or agricultural areas although they were aware of possible applications in the sector.

It bears repeating that the IPN is presently expanding its installed capacity to 20 kw by 1982 and is seeking funding for a commercial-scale (300 kw/year) plant. Therefore, locally produced photovoltaics are likely to play an increasing part in the Mexican market. Furthermore, another U.S. manufacturer has reportedly asked for Mexican government approval to establish a PV assembly factory in an in-bound border zone to secure preferential tax allowances (see Section 7.5).

Given the fact that at present the Mexican government is the principal purchaser of PV equipment, it is important to note the policy of pluralism of technologies outlined in the National Solar Master Plan (PLANMAES). The Plan advocates using a broad mix of solar technologies and suppliers. Therefore, it is unlikely that any one firm will dominate the Mexican PV market.

5.3 Current Generation Equipment Competition

Mexico represents a significant market for American diesel generator set suppliers. U.S. Department of Commerce data indicate that in 1980 the United States exported $3,376,327 in diesel generator sets of less than 400 kw. The leading U.S. suppliers of diesel engines and generator sets are Caterpillar, Cummins, Detroit Diesel Allison (General Motors) and Briggs and Stratton. Several American firms manufacture internal combustion generator sets in Mexico through subsidiaries. These include Manufacturer a Fairbanks Morse, S.A. (subsidiary of Fairbanks Morse) and Kohler de Mexico (subsidiary of Kohler). In addition, International Harvester de Mexico, S.A. de C.V. manufactures a limited number of 78 and 123 h.p. diesel engines for water pumping applications. These U.S. firms benefit from name recognition, good service organizations and widespread availability of parts.

The American firm, Worthington, markets diesel-powered water pumps. Two British firms, Lister Engines, Ltd. and Rolls-Royce, also market 10-15 h.p. diesel engines for the irrigation pump market. English Electric and Perkins, also from the U.K., supply mobile diesel plants and diesel engines, respectively. Among the Japanese electrical equipment manufacturers active in Mexico, Mitsubishi markets large diesel plants, and Honda markets small gas and diesel generator sets.

Imports of electrical power equipment are generally subject to tariffs ranging from 20-35%. Preferential duties apply to imports of some equipment from member nations of the Latin American Free Trade Area (LAFTA) and the Andean Pact. Import licenses are generally required.

The largest distributor of diesel generators is the Mexican firm, Maquinaria IGSA, S.A. Approximately 90% of the generators sold are manufactured in Mexico with U.S. or British diesel engines, and the remaining 10% in the U.S. Generating capacity of products sold ranges from 3-5000 kw. Terms of purchase are normally 50% downpayment and 50% on delivery. Company credit is available only for major customers. An estimated 200 generators per year are sold by IGSA for agricultural applications, mostly in Sinaloa. This represents 15-20% of the total market. Major customers in the rural sector are the ejidos, which arrange credit for purchases through the Banrural. IGSA equipment is guaranteed for 6 to 10 months, depending on size and end use. Major government clients have been the IMSS (Mexican Social Security Institute) for rural clinics and PEMEX for petroleum field electrification.

Prices quoted at several electrical generator distributors in Guadalajara are presented in Table 5.1 below:

Table 5.1: Small Internal Combustion Generator Set Competition

Make	Power Rating	Fuel Type	Price*
Honda	500 watt	gasoline	$ 957.50
Briggs & Stratton	650 watt	gasoline	$ 917.50
Briggs & Stratton	1.8 kw	gasoline	$ 1,317.95
Briggs & Stratton	3 kw	diesel	$ 5,250.60
Briggs & Stratton	4 kw	gasoline	$ 1,914.90
Briggs & Stratton	7 kw	gasoline	$ 3,694.85
Briggs & Stratton	7.5 kw	diesel	$ 7,368.50
Fairbanks Morse	10 kw	diesel	$ 7,660.00
Fairbanks Morse	20 kw	diesel	$10,213.00

*Prices assume a 23.5 pesos/U.S.$ conversion rate, ex-warehouse, without 10% I.V.A. (Added Value Tax).

The table indicates that the principal competition for photovoltaics in stand-alone applications requiring less than 7.5 kw will be gasoline generator sets which are more economical for small power needs than diesel generator sets.

5.4 Climate for Investment

According to P/V industry representatives and Mexican government officials, no incentives for investment in photovoltaics currently exist in Mexico. However, DIGAASES officials are encouraging the Ministry of Patrimony and Industrial Development to provide fiscal incentives for PV use. An official of the Ministry of Patrimony and Industrial Development noted that if a photovoltaics plant were set up in an area designated as a priority zone under the National Industrial Development Plan, it would be entitled to a tax credit of 20%.

Figure 5.1 indicates the preferential zones established under Priority 1A for Industrial Port Development and Priority 1B for Urban Industrial Development. The importance given to the coastal and border areas reflects the industrial strategy of promoting the export of manufactured products. Credits against federal taxes will be granted only to majority owned Mexican firms who invest in fixed assets in industrial firms or increase employment in these zones. The amount of the tax credit will vary according to sectoral and regional priorities established by the Plan.

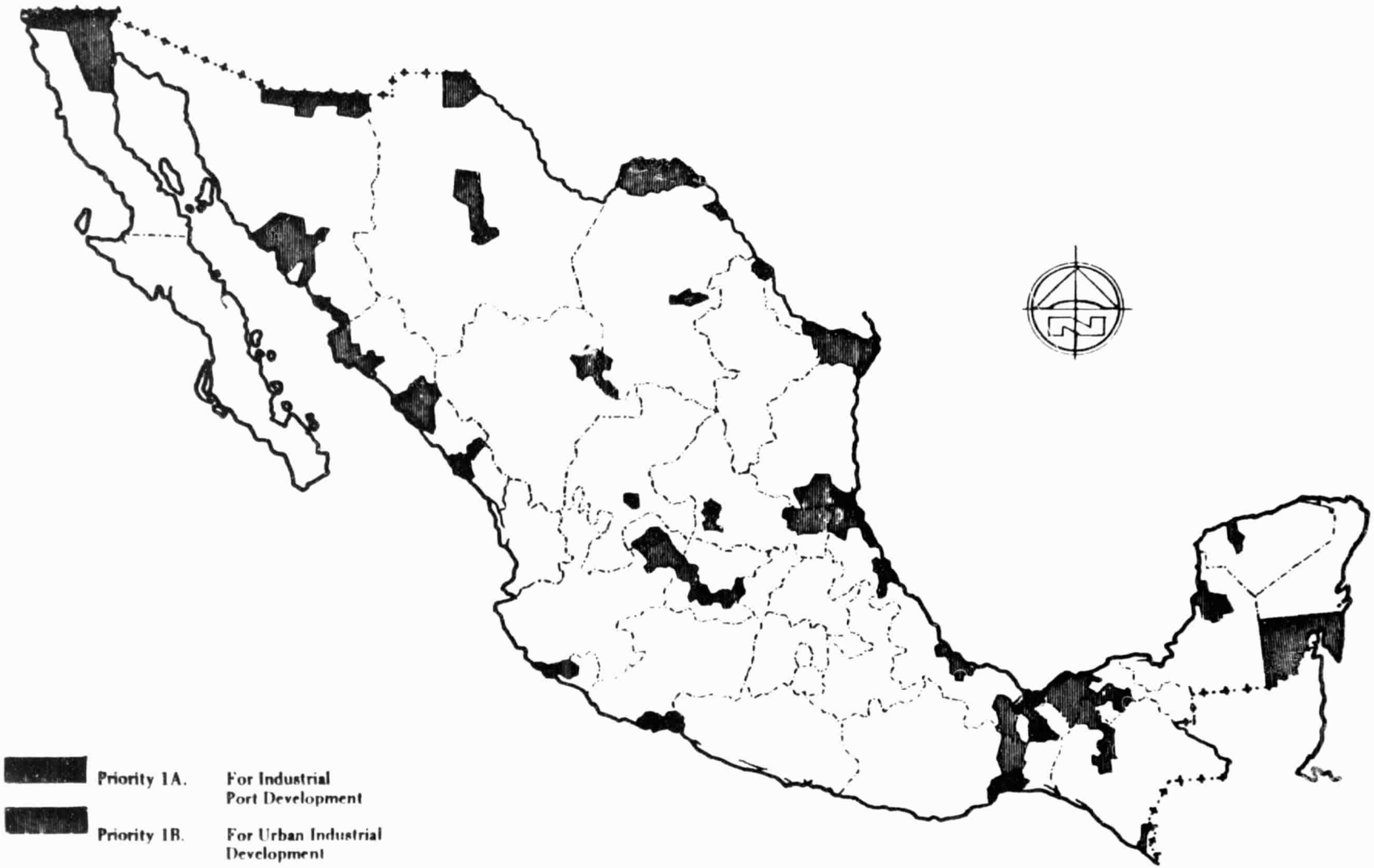
In addition, the Mexican government is encouraging U.S. companies to set up in-bond industries in the border areas. These companies can take advantage of cheaper Mexican labor and various tax incentives and export their products back to the U.S. without paying any Mexican duties. They may not, however, ship these products to other parts of Mexico without paying Mexican tariffs. One U.S. PV firm has reportedly already requested permission to set up an in-bond plant in Mexico to assemble and reexport PV modules.

The general investment climate in Mexico is currently quite bullish due to the prospering economy and the present Administration's pro-investment policies. However, PV does not appear to interest many private Mexican investors because of its long payback period (approximately 10 years). Mexican investors are primarily interested in one-year return on their investment of 40-45% in order to outpace the 30-35% inflation rate. Furthermore, uncertainty over the course of the Mexican government's policy after the Lopez-Portillo Administration leaves office in 1982 will tend to depress investment until a new policy is established.

5.5 Standards and Regulations

Generally all U.S. electrical standards are acceptable in Mexico and local standards are often based on U.S. standards, such as ANSI, NEMA, and ASTM. The CFE (Federal Electricity Commission) uses many of the methods and procedures developed by the U.S. Rural Electrification Administration.

FIGURE 5.1: ZONE I PREFERENTIAL INCENTIVES



Source: Mexico Industrial Development Plan, 1979-1982-1990 (abridged version)

The electric power supply in most areas of Mexico is 110/220 volts, 60 hertz, single cycle or three-phase. The Mexican Government prohibits the use of photovoltaics for power supply where AC is available.

The metric system of weights and measures is obligatory for labeling of goods. To be fully protected, goods having their trademarks registered in Mexico should bear the words, "marca registrada", the trademark, and the location of the factory (including country of origin).

5.6 Tariff Rates

Mexico began a gradual process of substituting prior import permits with tariffs in 1977. The effort is intended to make the future tariff structure as simple as possible to facilitate trade. The evolving Mexican tariff structure is based on domestic criteria, not on the General Agreement on Tariffs and Trade (GATT), to which Mexico does not subscribe. The principal criteria for setting the value of a tariff is whether or not the good is manufactured domestically. This has led to a certain amount of confusion regarding the tariff rates on imported photovoltaics.

The Mexican Tariff Register uses the Brussels Tariff Nomenclature (BTN). PV cells are classified as BTN #85.21 A012 and defined as "photoelectric cells, including solar, unmounted." The tariff rate for this classification is 10% because they are not fabricated domestically (aside from IPN laboratory production). However, PV panels and PV systems which contain domestically made parts are classified under BTN #84.59 B999, "Other machines". Tariff rates under this classification vary according to component parts and the discretion of the customs official. PV systems equipped with regulators, for instance, face a 30% tariff on the value of the entire product since regulators are manufactured in Mexico.* In order to avoid paying the higher rate on the entire PV system, the U.S. manufacturer can ship the balance of system components (e.g., alternators, batteries, etc.) separately from the PV modules or cells.

In addition to the tariff, the importer must also pay an additional 10-15% of value for importation rights and the 10% added value tax (IVA), which greatly increase the cost of the PV systems to the customer.

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* One P/V company representative noted that this rate is unwarranted since the DC regulators used in the system are not manufactured in Mexico.

Furthermore, the Director of the U.S. Trade Center in Mexico reported that PV panels brought into Mexico as exhibits for the U.S. Solar Trade Show, held in April, 1981, required prior permits issued by the Ministry of Commerce.

5.7 Conclusions

U.S. manufacturers face both advantages and disadvantages in developing the Mexican market. The principal advantages are that American photovoltaic technology is regarded as the best available, and several American firms are already active in the market establishing a favorable reputation.

Against these advantages, several disadvantages must be measured. First, no incentives currently exist for using PV in Mexico. Second, U.S. PV firms will have to compete with both domestic Mexican PV production and non-U.S. imports. Third, U.S. firms are not likely to have access to either Mexican private capital or government financing of direct investments. Fourth, American photovoltaic systems containing parts which are manufactured in Mexico face high tariffs.

In order to realize the photovoltaics market potential U.S. firms should:

1) perform as much as possible of the production and assembly of PV systems in Mexico to avoid high tariffs;

2) enter into joint-venture agreements with Mexican partners to facilitate government approval for establishing business in Mexico and to benefit from financial incentives offered, and

3) offer complete systems (e.g., PV powered television sets and pumps requiring low energy consumption).

6.0 FEASIBLE AGRICULTURAL PV APPLICATIONS

6.1 Cattle Watering

Sector Characteristics: The appropriateness of PV for cattle watering is investigated here for beef cattle on the range. (PV is not recommended for dairy cattle for the reasons discussed in Section 7.2.1; the same reasoning applies to feed-lot operations). In Mexico there are about 16.6 million head of cattle, most of them raised for beef on private ranches and ejido grazing lots of various sizes, with little or no supplementary feed. In most of the grazing areas (especially in the northern states), surface water is usually not found at convenient locations, so that cattle raising through the dry season is dependent upon the provision of water points. These water points are normally equipped with a windmill pump or a diesel pumpset. Water depths range from 10m or less (in the coastal plains) to 150m and more. Capacity of livestock wells ranges typically from less than 0.5 l/s to 3.0 l/s.

Development plans: Creation of additional water points is necessary for opening up additional areas to grazing, as well as for increasing the carrying capacity of the existing pastures through a more even utilization. However, the prevailing beef prices do not motivate private owners to sink many additional wells or realize other significant investments on their ranches. Thus most new cattle water points are associated with government investments in new ejido ranches, and are realized mostly through the SARH Directorate-General of Hydraulic works and Agricultural Engineering for Rural Development. This agency has among its objectives for the 1976-1982 period the development of 400,000 hectares in ejido cattle ranches. In 1980 about 400 projects were exectued, of which approximately 60 required wells.

Characteristics of existing windmill pumps: At the typical Mexico open-range livestock density of 30-40 ha per animal unit, about 200-300 head graze within a 5km radius, which is the maximum recommended distance to a water point. A water point for this number of cattle is often driven by an "aeromotor" windmill pump. Pumping depths range from 8m to 80m and more. A typical windmill pump with a 2" diameter piston and a 25cm stroke, operating at 30 strokes per minute furnishes about 0.25 l/sec or 0.9 m^3/hour. Assuming that during the months of maximum heat (April-May) a fully-grown cow consumes 60 l/day and that the average herd consumption (including the younger animals) is 45 l/head/day, a windmill pump supplies the required quantity in about 15 hours/day of operation; fortunately the above-mentioned months are usually windy. The windmills are usually provided with a 30 m^3 tank, which for 300 head of cattle at 30 l/day each would hold water for about 3 days. The windmill pumps are sturdy machines which need minimal maintenance; many 60-80 year old windmills were observed in operation. Maintenance consists of periodically changing the piston seals, and an overhaul necessitates only changing the piston, cylinder and connecting rods; the superstructure needs very little maintenance. On the other hand, the initial price of a windmill pump is high in comparison with the amount of water pumped, reaching US $3300 to US $5500 according to type (including installation but not borehole). Thus windmill pumps share many of the characteristics of PV pumps; high initial cost, negligible operating costs and low maintenance. In view of this fact, it is noteworthy that practically no new windmill pumps are being installed in Mexico; both public and private investors opt for the lower-cost (though shorter-lived) internal combustion engines.

The diesel powered pump for cattle watering: New water points are usually equipped with diesel motors hitched to pumping jacks. The pumping jack (a smaller version of the one used for oil pumping) is also a simple and sturdy machine requiring little maintenance, although its efficiency is low since no power is utilized during the down-stroke.[1] A typical pumping jack observed was rated at 0.76 HP at 20 strokes per minute, produced about 1.0 l/sec from a depth of 23m, and was in good condition after 24 years of service.

PV power for cattle watering: PV has several characteristics which make it ideally suited for cattle watering, namely:

(a) cattle water requirements increase with solar radiation, as does the discharge from a PV pump;

(b) whenever it is cloudy and the PV system supplies least water it usually rains, and the cattle can drink from surface depressions; thus the usual three-day reservoir capacity is sufficient for a PV system, and no extra investments in water storage capacity are required;

(c) cattle watering pumps are located at remote places where fuel transport and maintenance present real problems for diesel pumps; and

(d) the power requirements are small, so that a diesel engine (for which 6 HP is usually the minimum size) is under-utilized.

On the other hand, the windmill pump--which shares the above advantages--is being phased out owing to its high initial cost. Thus cost considerations are all-important. These are discussed in the following section.

1 In view of the small water quantities involved in cattle watering, it is not practical to replace the pumping jack by a deep-well borehold pump.

A cost comparison of a PV and an internal combustion pumpset for cattle watering was made, based on the following assumptions which represent a typical water-point installation in Northwest Mexico:

(a) the well, pump and tank installations will be similar in the two cases;

(b) the system will water 300 mature animals with a summer consumption of 60 l/head/day, for a total of 18 m^3/day;

(c) this amount will be pumped in five hours, at a discharge of 3.6 m^3/h;

(d) the water depth is 50m, plus 5m in friction losses;

(e) pumping-jack efficiency is 0.35, implying a power requirement of 2 HP from the motor.

PV system costs were calculated (Table 6.1) based on the following assumptions:

(a) the PV system will produce in the summer the equivalent of 5 peak hours (5 WH/Wp);

(b) the PV system will have a direct-coupled DC motor with an efficiency of 0.86, implying an array capacity of 1800 Wp;

(c) the PV modules will be nationally produced and will be installed by the SARH, at costs similar to U.S. costs (Tables 1.1-1.3);

Diesel motor costs were calculated (Table 6.2) based on the following assumptions:

(a) the pumpset will be installed by a public agency; this agency will install a diesel rather than a gasoline motor, in view of its greater durability;

(b) although in theory a 4 HP engine would be sufficient, in practice a 6-7.75 HP[1] engine will be installed, being the smallest diesel motor in wide commercial use;

(c) the diesel will also operate 5 hours/day, supplying a total of 18 m^3/day;

(d) pumpset operation (which consists of starting, refuelling and oil change) will be performed by the cattleman in the course of his normal duties and signifies no additional labor cost;

(e) the public agency making the investment will compute the diesel fuel saved by the PV alternative at its opportunity (international) cost of $0.31/l (the subsidized price in Mexico is $0.043/l).

Results of the cost comparison (Tables 6.1 and 6.2) show that PV will become cost-competitive with diesel for livestock watering in Mexico by about 1984. In that year the life-cycle costs for the PV system were calculated as

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[1] 6 HP at 1800 RPM, 7.75 HP at 2500 RPM.

TABLE 6.1: MEXICO--LIFE CYCLE COST OF A 1.8 KWP PV ARRAY WITH ELECTRIC MOTOR FOR CATTLE WATERING OR POTABLE WATER

Item	Initial Cost, $	Discounted Cost, $[b]
Electric HP DC motor (including starter, switch anu fuse box)	900[a]	900
Motor rewinding after 5 years[c]	250	120
Motor replacement after 10 years	900	220
Motor rewinding after 15 years	250	30
Total, motor life-cycle cost		1270

Year	1980	1982	1984	1986
1.8 KWp array, installed cost (Table 1.1)	30,900	14,490	10,730	6,970
1.8 KWp array, present value of maintenance cost	470	470	470	470
1.8 KWp array, life cycle cost (Table 1.1)	31,370	14,960	11,200	7,440
Motor life-cycle cost	1,270	1,270	1,270	1,270
Cattle watering system, life-cycle cost	32,640	16,230	12,470	8,710
Reservoir, 17.5m^3/day for 4.75 days at \$50/m^3 (for potable water only)	4,160	4,160	4,160	4,160
Potable water system, life-cycle cost	36,800	20,390	16,630	12,870

[a]DC motor cost assumed 40% higher than the cost of an equivalent AC motor to reflect the inherently higher manufacturing cost of DC motors and the cost of special importation.

[b]At a 15% discount rate.

[c]Other maintenance costs for the electric motor are negligible.

TABLE 6.2: MEXICO--LIFE CYCLE COST OF A 6 HP DIESEL ENGINE FOR CATTLE WATERING OR POTABLE WATER

Item	Initial Cost, $	Discounted[a] Cost, $
6 - 7.75 HP diesel motor	2400	2400
Overhaul after 3 years	1440	950
Overhaul after 5 years	1680	830
Replacement after 8 years	2400	780
Overhaul after 11 years	1440	310
Overhaul after 13 years	1680	270
Replacement after 16 years	2400	260
Overhaul after 19 years	1440	100
Salvage value after 20 years	(1500)	(90)
Small repairs and adjustments	50/yr	
Diesel fuel for 5h/day, 1.1 l/h[b, c]	670/yr	5110
Oil change, 2.5 l/100h at $1.50/l, with filter	80/yr	680
Operator, half-time at $5 day (potable water systems only)	910/yr	6550
		18,150

Year	1981	1982	1983	1984	1985	1986
Cattle watering system, life-cycle costs	11,600	11,770	11,950	12,140	12,330	12,530
Potable water system (w/ operator), life-cycle costs	18,150	18,320	18,500	18,690	18,880	19,080

[a] At a 15% discount rate.

[b] Low-power operation, at the international cost of $0.31/l plus transport to site (30 km of dirt road) at $0.03/l.

[c] Fuel and oil assumed to have a real cost escalation rate (above the inflation rate) of 3%.

about $12,470 and for the diesel system as about $12,140 (at international fuel prices of $0.31/l; even at the highly subsidized Mexican diesel fuel price of $0.043/l, PV would become price-competitive about 1986). The front-end cost of PV system by 1985 will be $9750, as compared to $2400 for the diesel engine. Note that at water depths of less than 50m, the cost of PV will be almost proportionately lower; for example, at a 20m depth (typical in the center of Yucatan), an array of about 800Wp and 1.5 HP motor will suffice, bringing the PV life cycle cost in 1982 down to $7450. If a pumping jack is used, the diesel life-cycle cost will be essentially unchanged at $11,770 (Table 6.2), so that at 20m depth PV should be substantially cheaper by 1982. The advantage of PV relies on the inherent inefficiency of diesel for low-power uses. Note that the calculations are very sensitive to the pumping-jack efficiency assumed (0.35). Note also that PV would still be more expensive than windmill pumps, so that the fact that windmill pumps are being gradually phased out should be a cause for concern to PV promoters.

Development perspectives: As PV is likely to be cost-competitive with diesel power for livestock watering between 1982 and 1984 (depending on pump depth), and as PV is superior to diesel in convenience and reliability, the SARH should introduce PV in new cattle water points, starting with pilot demonstrations, so that if acceptance is good, then by 1984 its use in low-volume pumping could be generalized.

Market size: The Directorate-General of Hydraulic Works and Agricultural Engineering for Rural Development is quite interested in PV livestock watering. However, due to the rapidly expanding nature of this agency's activities and the delays associated with installing any new system, any market size figures would be purely a conjecture. Assuming that four pilot projects are installed in 1982, increasing to 40 per year in 1986, with an average array size of 1.8KWp, the total demand for PV over the period would be about 200 KWp.

6.2 Rural Potable Water

Sector characteristics: Rural communities in Mexico are usually furnished with potable water through small stand-alone systems consisting of a well, pumpset, water tower, distribution network and house connections or public fountains. The SAHOP Directorate-General of Potable Water and Sewage, which is in charge of constructing and maintaining such systems, estimates that during the period 1976-1979 the percentage of rural inhabitants possessing water systems remained fairly static at about 35%, and that only 11% of the rural population had access to water at all hours.

Development plans: The present Administration has set the goal of of 60% coverage of the rural population with potable water at the end of his term (end of 1982). Due to massive government investments in the rural potable water sector, mostly through COPLAMAR, the percentage of rural inhabitants with potable water systems has increased by the end of 1980 to 45.5%. By the end of 1981 it is projected to reach 56.4% of the rural population (25.8 million inhabitants), mainly due to planned 1981 COPLAMAR investments of US $680 million. COPLAMAR projects are programmed for about 2500 communities in 1981 and for about 5200 communities in 1982. However, most of these projects consist of renovation and expansion of existing rural systems in communities which already have electricity (at an average cost of US$121 per beneficiary). Less than 5% of the projects consist of diesel-powered waterworks for communities which do not possess electricity; SAHOP is reluctant to implement diesel-powered projects in view of their maintenance problems. Considering the opportunity to capitalize on the existing rural electrification investments in communities which otherwise have very low socio-economic standards, this policy seems entirely logical.

Water supply standards: COPLAMAR projects are based* on the following consumption standards in liters per capita-day (lcd):

	House Connections		Public Fountains	
	Cold/Temperate Climate	Hot Climate	Cold/Temperate Climate	Hot Climate
Humans only, lcd	75	100	25	35
Humans and Domestic animals, lcd	100	150	36	50

The dynamic pumping head (including lift to water tower and friction losses) amounts to 20-100m. Typical discharges are 0.5 to 15 l/sec; hours of operation are 2.4 to 24 hours/day (averaging in practice 4-6 hours/day); required motor capacity is 5-30 HP, and transformer capacity 7.5-30 KVA. For a community of 500 inhabitants, at 35 lcd and 5 hour/day operation at a dynamic head of 50 m and a pump efficiency of 60%, the discharge would be 1.0 l/sec. Reservoir capacity is constructed for 4 to 8 hours of storage.

*Note that these requirements refer to the initial project year. Assuming a 3% population growth rate, after 20 years (the design horizon) the per capita consumption will be 40-55 lcd at house connections and 15-20 lcd at public fountains. Such consumption is normal for rural potable water systems.

Economic comparison of diesel and PV energy for potable water projects is made for a community of 500 inhabitants. Such a community will typically be provided with public fountains. The consumption rate is taken as 35 lcd and the dynamic head as 50m. All elements are similar for the two systems, except that the diesel motor is replaced by a direct-current electric motor (including a switch and a starter) with a PV array. The PV system will also require a larger reservoir capacity to store water for periods of insufficient insolation. The required storage capacity is very roughly estimated at 5 days for dry zones (say less than 800mm/year), 10 days for medium-rainfall zones (say 800 to 1600 mm/year) and 15 days for high-rainfall zones (say over 1600mm/year). The example uses a reservoir capacity of five days for the PV system and six hours for diesel. It is SAHOP policy to install a backup diesel motor for both diesel and electrical systems. The backup engine is only used if the main system fails. A half-time job for a motor attendant is included in the case of diesel (this is a real economic cost, even if the work is performed by a community member on a semi-voluntary basis); in the case of PV, the supervision cost is negligible. As potable water works are constructed with public funds, the analysis is performed at economic (international) price of diesel fuel (taken as $0.31/$l$), as the fuel saved by PV systems can in principle be exported for this price.

PV system characteristics: To deliver 1.0 l/s for 5 h/day at a dynamic head of 50m would require a system similar to that discussed for a cattle water point in Sec. 6.1, with a 2 HP electric motor and a 1800 Wp array. Assuming a five-day reservoir capacity for PV compared with 6 hours for diesel, an incremental capacity of 4.75 days at 17.5m^3/day will be required for PV at an estimated cost of $50/m^3, or a total of $4160. The PV costs are shown in Table 6.1.

Diesel system characteristics are also similar to those of a cattle water point (Table 6.2), except that attendant's wages for half-time work were included for the reasons discussed above.

Comparison of PV and diesel costs (Tables 6.1 and 6.2) reveals that for a community of 500 provided with public fountains, at a dynamic head of 50m, PV will be cost-competitive with diesel on a life-cycle basis starting in 1983. At this point, the front-end cost for a PV system will be about $18,000 (descending at about $12,000 in 1986), compared with $2400 for a diesel motor. Considering the fund availability in the Mexican accelerated program for rural water supply on the one hand, and the difficulties of operating and maintaining diesel motors in small communities on the other, a major shift to PV would be advantageous for communities of 500 inhabitants in Mexico about 1983 (or whenever installed array cost descend to about $7/Wp).[1] For smaller communities or at a pumping depth of less than 50m, the break-even year will be even earlier. If SAHOP policy is changed and the backup diesel is used during periods of low insulation, then the reservoir capacity could be reduced. However, since the reservoir is only 12% of array costs, there will be no significant reduction in life cycle costs.

Market projections: Assuming that over the period 1983-1986, 100 water supply projects will be installed annually in communities which do not have electricity and which average from 250 to 500 inhabitants, the theoretical maximum market size would be 400 units of 1-2KWp array capacity each, or a total on the order of 300KWp. The actual demand will be a fraction of this, depending mainly on whether the actual array price will come down as projected, and on the rate at which COPLAMAR and SAHOP decide to introduce PV. Assuming a gradual buildup over the period, the capacity installed during the period 1983-1986 might be on the order of 300KWp.

6.3 Small Grain Loaders

Institutional framework: The BORUCONSA (Bodegas Rurales de CONASUPO, S.A.- CONASUPO Rural Warehouses, Inc.), a subsidary of CONASUPO (National Company for Basic Foodstuffs), was established in 1967 to assure the farmers grain purchases at official prices. By now, BORUCONSA has some 10,000 grain warehouses throughout Mexico. Of these, about 1000 are small grain-reception warehouses (25-500 MT capacity) in rural locations which do not have electricity.

Grain loaders: All grain warehouses normally have small (5 MT/hour capacity) loaders for bulk loading of grain to bins or trucks. These are either of the conveyor-belt type or, more commonly, of the Archimedes'-screw type (locally called "bazooka", owing to its shape). Wherever the warehouses have electricity, these loaders have an electric motor, supplied through a cable which is moved around the warehouse yard. Where electricity is not available, the elevators are powered with small (3HP) gasoline motors. BORUCONSA has experienced serious problems with these motors, and estimates that only 50 of its approximately 1000 gasoline-powered loaders are in operating condition.

Use pattern: The grain loaders are normally employed throughout the year, except for the rainy season (June through August). The small loaders discussed here normally work 4-6 hours per day.

Economics of PV use: Considering the above use pattern, the grain loader could be powered by a 2 HP electric motor with a 2KWp PV array. DC motor cost is assumed to be $800, and array costs as per Tables 1.1-1.3 (including three-day battery capacity, which should be sufficient for this use). The 3 HP

[1] $7Wp in 1980 prices, i.e. (assuming an inflation rate of 20%). $12/Wp in 1983 prices.

gasoline motor is assumed to cost $500, to be overhauled after three years at a cost of $250 and replaced every 5 years. It is calculated to work 5 hours per day, 230 days/year, and consume 0.75 l/h gasoline at the international gasoline cost of $0.64/l plus $0.04/l transport surcharge; oil costs are taken as 10% of fuel costs. With these assumptions, the costs are as follows:

Life Cycle Costs of a Gasoline Motor and a PV System for a Grain Loader

Year	1980	1982	1984	1986
3 HP gasoline motor, life-cycle costs	8,900	9,130	9,610	10,130
2 KWp PV array w/ motor and batteries, life-cycle costs	48,970	30,730	24,730	18,130

Cost comparison: The above comparison shows that, even in 1986 costs, a 2KWp PV system will cost 80% more than the comparable gasoline motor. For grain elevating, however, the above comparison is not relevant since because of gasoline motor maintenance difficulties BORUCONSA normally must carry out grain handling in smaller warehouses by hand. Assuming this entails employment of five laborers for 230 days/year at a minimum wage of $5/day, the annual cost is $5750, and the present value of 20-year costs (at 15% discount) is $41,400. Thus compared with manual grain handling, PV will be cost-competitive by 1982.

The market for PV: Although the potential market size is considerable (on the order of 2000KWp), the rate of its development is a matter of conjecture; judging by the experience of PV for educational television (which has been proposed since 1978 and is economically competitive, but has yet to be introduced), this rate will be slow. Assuming that a pilot unit will be installed in 1982 with satisfactory results, a total of 40 units as a maximum might be introduced by 1986, with a total array capacity of 80 KWp.

6.4 Rural Refrigerators

System characteristics: Refrigerators are used in rural households for preservation of food and drink and on cattle ranches for conservation of livestock medicines and vaccines. Thus rural refrigerators help agricultural production as well as consumption. Such rural refrigerators are operated on butane gas. The butane refrigerator is a sturdy machine which has no moving parts and requires little maintenance; a small butane flame, much like a stove pilot light, warms a coiled pipe in which the coolant fluid evaporates and flows to another coil within the refrigerator where it condenses, absorbing heat, and flows back to the flame. The gas refrigerator has a useful life of 10-15 years, in comparison to 7-10 years for the electric refrigerator. The cost of a butane refrigerator of ordinary household size (10 ft^3) is about $1300, in comparison with about $640 for an equivalent electric refrigerator. Butane consumption is about 1 kg/day, at a cost of only $2.20 per 20 kg drum.

The market for butane refrigerators: Owing to the wide extent of the electric grid (Table 3.1), which reaches most locations in which inhabitants would have the purchasing power to buy a refrigerator, the use of butane refrigerators in Mexico is quite limited. Such refrigerators are normally imported from Brazil, and it is estimated that the total number of units in Mexico is less than 3000 and declining, as only about 200 units are sold annually. In this connection it is noteworthy that the kerosene refrigerator has been completely phased out.

Economics of PV use: The ordinary 10 ft^3 refrigerator has a 135w motor/compressor. Assuming that it works a total of about 8 hours/day, it could be fed by a 250Wp array. Taking the cost of a refrigerator with a DC motor at $800 and assuming a life of 10 years and compressor unit replacement every 5 years at a cost of $300, the life-cycle cost of a PV-powered refrigerator (with a 3-day battery storage) will be $4900 in 1982, descending to $3400 in 1986. In comparison, a butane refrigerator will have the following life-cycle cost:

Purchase Price	= $1300
Replacement after 10 years (minimal life) at 15% discount rate	= $ 320
Butane, one 20kg drum per 20 days at a cost	= $ 360
of $2.20 plus $0.60 for transportation (annual cost of $50), life cycle cost	= $ 360
Total, butane refrigerator life cycle cost	= $1980

Market perspectives for PV: The above figures show that even at projected 1986 PV prices, the life-cycle cost of a PV-powered refrigerator will be about twice that of a butane refrigerator over the period 1982-1986. At these prices, out of the approximately 200 persons who buy butane refrigerators annually, probably at most twenty (mostly large ranchers and country-house owners) would buy a PV-powered refrigerator owing to its superior convenience. This would place the total potential market size over the period 1982-1986 for PV-powered refrigerators at a maximum of 25 KWp.

6.5 Non-Agricultural Applications

The following non-agricultural applications of PV have already been introduced in Mexico or have been mentioned by Mexican officials as appropriate for PV use.

Rural Services: (a) Rural radio-telephones: The Ministry of Telecommunications and Transports has a pilot project in the mountains of Puebla.

(b) Tape recorders for rural schools: IPN has presented a project for introducing 4.5Wp solar battery chargers for tape recorders to 700 rural schools, showing this to be the most economic alternative.

(c) Educational TV: IPN has presented to PIDER a project for installing 100 PV-powered educational TV sets in rural schools.

Rural Appliances: There should be a significant demand for PV-powered TV sets for rural areas. Demand for PV-powered refrigerators, fans, lights, etc. would probably be minor in comparison.

Telecommunications: PV could be used to power TV and microwave relay stations, TV and radio repeaters, and other telecommunication equipment in remote locations.

Signalling: PV is advantageous for light buoys, small isolated lighthouses and offshore oil rigs, radio beacons for guiding aircraft, warning lights on isolated highway intersections and railway level crossings, etc.

Measuring: PV could be used in Mexico for unattended operation of weather stations, stream seismic detectors and other measuring devices.

Cathodic protection: Could be an important application of PV in Mexico, and is apparently being introduced by PEMEX on its rapidly expanding pipeline system.

7.0 MARGINALLY FEASIBLE PV APPLICATIONS

This chapter discusses several uses of power in the Mexican rural setting which were investigated but generally were not found to be promising for application of PV power for the reasons detailed below. However, in some instances, due to localized factors, their use could be feasible.

7.1 Pumping Applications

7.1.1 Small-Scale Irrigation

Sector characteristics: The irrigation sector in Mexico is divided basically into three subsectors:

(a) the major SARH irrigation districts (typically 10,000 to 100,000 ha or more and surface-irrigated);

(b) the "small" irrigation projects of the SARH Directorate-General of Hydraulic Works for Rural Development, which typically range from 100 to 2500 ha each; and

(c) small traditional private-sector irrigation projects, usually of a few hectares each, based on stream diversions or small pumps.

Development plans: Irrigation development in Mexico is conceived to be a public undertaking, and practically all expansion of the irrigated areas is performed by the SARH. The Six-Year Plan 1976-1982 calls for the Directorate-General of Hydraulic Works for Rural Development to irrigate about 450,000 new hectares, of which 320,000 by gravity and 130,000 by 2400 wells (averaging about 5 ha each). This well-drilling program is essentially terminated, and the SARH plans for the period 1981-1982 include 1500 additional wells for 75,000 ha, plus another 200,000 well-irrigated hectares for the coming six-year plan. Practically all new wells are electrified (through a joint program of SARH, CFE and the Rural Credit Bank). SARH is reluctant to install diesel-powered wells owing to their typical fuel supply and maintenance problems.

Farm sizes vary widely, but the average national farm size in the ejido (small farm) sector is 4 ha, and this is also the typical farm size on the above-mentioned well development projects.

The crops irrigated include a wide variety of grains, fodder crops, oilseed, fruits and vegetables.

The irrigation method is typically surface irrigation, although in recent years considerable progress has been made in installing sprinkler and drip irrigation systems.

Groundwater depth in well-irrigation projects is typically 20 to 40m and in some regions (e.g., Sonora) much deeper. Even in Yucatan, where the coastal areas typically have water depths of less than 10m, in the sites of the irrigation projects groundwater depth is 20-60m.

Irrigation time and frequency: The irrigation season is normally from October to May. On large projects, water is distributed up to 14 hours and in peak months even 24 hours per day, and the farmers irrigate in turns; small farmer-operated pumps usually work about five hours per day, mostly in the early morning, and the water turned directly to the field without an accumulation basin. The number of irrigations is usually 10 or more per year for irrigated pasture and orchards, 3-4 for field crops and vegetables.

Comparisons of a diesel and a PV irrigation system was undertaken under the conditions most advantageous for PV in Mexico, namely with a dynamic head of 20m for a farm size of 4 ha, assuming five peak hour-equivalent of insolation, maximum evapotranspiration requirements of 5mm and an overall irrigation efficiency of 62%. Water requirements are therefore 320 m^3/day, which implies a pumping rate of 64 m^3 per hour of peak sunlight. Total pumpset efficiency was taken as 50%. This system could be driven by a 9-13KW diesel motor or by a electric motor with a 7KWp PV array. Since irrigation hours do not coincide with those of maximum insolation, the PV system would require a one-day (320 m^3) reservoir capacity. It was furthermore assumed that the public agency undertaking the investment would make the comparison at economic (international) fuel prices.

Economic feasibility of PV for irrigation: Based on the above assumptions, Tables 7.1 and 7.2 show that at projected 1986 PV and fuel costs, the PV systems will have a life cycle cost of $39,370, as compared to $27,510 for the diesel system--a difference of over 40%. If the farmer changes practices and irrigates only when the sunshines, no storage will be needed. However, life-cycle costs of the PV system will still be higher than for the diesel system in 1986 ($33,000 compared to $27,500).

Discussion: The above results agree with previous work on the subject. An economic analysis of PV power for small irrigation[1] found that, under assumptions favorable to PV, at a price of $4.00/KWp (very close to the 1986 price of

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[1] Richard D. Tabors, The Economics of Water Lifting for Small Scale Irrigation in the Third World: Traditional and Photovoltaic Technologies, MIT Energy Laboratory Technical Report No. MIT-EL-70-011.

TABLE 7.1: MEXICO--1986 LIFE CYCLE COST OF A

7 KWp PV ARRAY WITH MOTOR FOR IRRIGATING A 4 HA FARM

Item	Initial Cost, $	Discounted[b] Cost, $
Electric DC 10 HP motor	2500[a]	2500
Motor rewinding after 5 years	500	250
Motor replacement after 10 years	2500	1250
Motor rewinding after 15 years	500	60
1 day reservoir capacity ($320m^3$ at $\$20/m^3$)[c]	6400	6400
7 KWp PV array, initial cost in 1986 (Table 1.3)		27,000
7 KWp PV array, present value of maintenance cost (Table 1.3)		1820
Total, life-cycle cost for PV system in 1986		39,370

[a]DC motor cost assumed 40% higher than the cost of a corresponding AC motor.

[b]At a 15% discount rate.

TABLE 7.2: MEXICO--1986 LIFE CYCLE COST OF A 12 - 18 HP DIESEL MOTOR FOR IRRIGATING A 4 HA FARM

Item	Initial Cost, $	Discounted[a] Cost, $
12 - 18 HP diesel motor	3840	3840
Overhaul after 3 years (60% of purchase price)	2300	1510
Overhaul after 5 years (70% of purchase price)	2690	1290
Replacement after 8 years	3840	1260
Overhaul after 11 years	2300	490
Overhaul after 13 years	2690	440
Replacement after 16 years	3840	410
Overhaul after 19 years	2300	160
Salvage value after 20 years	(2400)	(150)
Injector checks and small repairs	100/year	720
Diesel fuel (41/h for 5h/day, 9mo/yr, at projected 1986 international fuel price of $0.36/1 plus transport at $0.03/1)	2090/yr	15,940
Oil, at 10% of fuel cost	209/year	1600
Total, life cycle cost for a diesel system in 1986		27,510

[a]At 15% discount rate.

$3.87/KWp assumed in the present study), PV will be competitive with diesel at a depth of about 4m. At this depth, PV life-cycle costs on a 1 ha farm will be equal to diesel life cycle costs per hectare on a 4 ha farm. Thus PV is not intended to replace diesel motors for irrigation but to bring similar advantages to very small farms at very shallow groundwater depths (typical of delta regions). These conditions are not found in Mexico. Simply put, groundwater depth in Mexico is too great for economic use of PV in small-scale irrigation up to 1986 and beyond. By 1986, the subject should be considered again in light of PV and fuel prices prevailing at the time.

7.1.2 Auxiliary Irrigation and Drainage in High-Percipitation Areas

Production characteristics: In the states of the humid tropics region of Mexico, such as Tabasco (percipitation 1500-3500 mm/year), the authorities are beginning to introduce supplementary irrigation for planting maize, beans, rice, soybeans and vegetables with the late rains (Jan.-Feb.), providing several auxiliary irrigations in March and April and harvesting during the dryest period (May-June). Electric pumpsets are used where electricity is available and internal-combustion pumpsets are used in other locations.

Reasons for not considering PV use:

(a) The pumps in question are quite large (typically 10"), using 40-45 HP Volkswagen or Perkins motors and irrigating about 100 ha each.

(b) The same pumps are used for drainage during the season of heaviest rains (Sept. - Nov.). At this time they are often required to work 24 hours per day, just when sunshine availability is lowest. (In the irrigation season they also work 16-18 hour days).

(c) In their use as drainage pumps, mobility is required to follow the changing water level.

7.1.3 Irrigation of Tree Nurseries

Production characteristics: The CONAFRUT (National Fruit Cultivation Commission) in each state maintains one or several nurseries, usually of 1-2 ha each, for fruit seedlings. These nurseries have small irrigation pumpsets (e.g. a 2" pump with a 3 HP motor).

Reasons for not considering PV use: Such tree nurseries are located near towns or villages which have electricity supply. Thus PV power is not necessary.

7.2 Refrigeration Applications

7.2.1 Fish Reception Centers

System characteristics: Cold storage facilities are necessary in fishing villages to preserve the catch until it is shipped to the market. Villages which possess electricity normally have a 5-10 MT cold storage facility or larger. A 10 MT facility has two 7.5 HP electric motors to drive the compressors and two 1/4 HP electric motors for circulation of the refrigerating fluid. The motors work (intermittently) all year; on the Gulf coast the important fishing season is the hurricane season (Sept. - Jan.), when long periods of cloudiness (7-10 days) are frequent. Small villages which do not possess electricity normally have small (2 m^3) standard ice boxes, which are restocked with ice blocks brought by the trucks on their return from the larger fish markets, which have ice plants. The number of villages which have or could use fish cold storage and are not connected to the grid is small (e.g. about 12 in the state of Tabasco, an important fishing region).

Reasons for not considering PV use: Owing to the 24-hour operation and the necessity of working during the rainy season, an all-PV system for fish cold storage would require an excessive array capacity which would make its cost prohibitive. The most promising use of PV in fish preservation is for driving the small (¼ HP) coolant circulation pump, in conjunction with other (heat-exchange) solar technologies for accomplishing the actual refrigeration. Such hybrid solar refrigerators are under development in the Materials Research Institute of the UNAM, but are not yet in commercial production. In any case, due to the small number of non-electrified fish reception centers (perhaps 100 in all of Mexico) and the small PV power requirements (¼ HP), the total PV market in this activity is small, and over the next five years is likely to be negligible.

7.2.2 Cold Storage for Fruits and Vegetables

Production characteristics: Cold storage is used for some fruits and vegetables, especially table grapes, apples and potatoes grown in the central plateau region. These crops are grown on irrigation projects.

Reason for not considering PV use: The cold storage facilities are normally located at the population centers of the production areas, and these (especially in irrigation projects) are connected to the electricity grid.

7.3 Ice Production

System characteristics: Ice production in rural areas is important for use in ice boxes, vending of cold drinks, fish preservation in coastal regions, and other uses. Ice production is an energy-intensive process: a small (10 MT/day) rural ice plant has one 40 HP motor/compressor, one 7.5 HP and two ¼ HP motors for circulation of the ammonia. Ice plants work 24 hours per day. Ice consumption is year-round and normally reaches a peak in the summer months. Ice for fish preservation on the Gulf coast is necessary during the main fishing season (Sept. - Jan.) when there are often week-long cloudy periods.

Reasons for not considering PV use: The need for large energy inputs and 24 hour/day operation makes ice production an inherently inappropriate process for PV application. As in the case of fish cold storage, PV would be useful only for powering the coolant-circulating motors of ice plants in which the cooling process is performed by a heat-exchange solar system. Such a hybrid solar system is apparently in pilot demonstration in Baja California Sur. Another small system (150 kg ice per day, with about 1 HP solar motor capacity) is under development at the UNAM Materials Research Institute. Further installations will follow the evaluation of these projects, and total PV capacity installed in this application during the coming five-year period is likely to be small.

7.4 Veterinary Extension Centers

System characteristics: Each cattle-producing state has several livestock extension centers, which offer veterinary services to the surrounding ranches. Each livestock extension center has a refrigerator for conservation of the veterinary medicines. However, such centers are located in villages or towns which have electricity. The livestock extension agents start out every morning from these centers on their rounds with thermos boxes containing ice and medicines for the day.

Reasons for not considering PV: Owing to the above situation, veterinary extension does not need power sources in locations which are not served by the electricity network. The prospects for replacing butane refrigerators used by private individuals in rural areas with solar-powered ones were discussed in Section 6.4.

7.5 Artificial Insemination Centers

Production characteristics: The liquid nitrogen used for deep-freezing of the semen is produced in about ten locations in Mexico, either as a by-product of liquid oxygen production for industrial purposes or in specialized machines. These machines have 40kw electric motors and can produce up to 200 kg/day of liquid nitrogen if operated continuously. Such machines are located in urban centers, and each machine furnishes liquid nitrogen to several states. The liquid nitrogen is transported in 120kg tanks to artificial insemination centers, where it is sold to cattle raisers who normally keep it in 25kg thermos semen containers. Such a container needs refilling with liquid nitrogen once every several months.

Reasons for not considering PV use: It is clear from the above description that the artificial insemination process does not require power except in the main urban-located plants, and thus does not offer an opportunity for the use of PV energy.

7.6 Grain Drying Applications

The present situation: Maize and sorghum are harvested and delivered to warehouses from November until March. Especially from November to January the grain is often moist and must be dried for storage. Grain dryers with a capacity of 10 to 30 MT/h are used to dry maize and sorghum in some locations (e.g. Tamaulipas and Michoacan). Grain dryers are not used by the official grain-receiving authority, BORUCONSA, which handles most grain in Mexico; BORUCONSA uses sun-drying on cement platforms or in the bags. All grain dryers in Mexico are fuel-fired. There are some plans for small (5-6 MT/day) woodfired dryers, but the cost and bulk of the wood and the present low fuel prices give little incentive to their adoption.

Reasons for not considering PV use: In a fuel-powered dryer, most of the fuel is used for burning to produce warm air. The fuel consumption of the small (typically 1-3 HP) fan of the drier is insignificant in comparison. In this situation, the installation of PV arrays to power the fans would offer no significant advantage (especially since the process is necessary during the rainy season, when PV systems provide the least power). PV use is logical only in combination with solar grain driers, to make them totally independent of fuel.

7.7 Maize Shelling [1]

The present situation: Almost the only use of a stationary power source in Mexican agriculture besides water pumps is for maize shellers. About 120 shellers exist in the three states of the Yucatan peninsula, so that there are perhaps 1000-2000 shellers in the whole of Mexico. Some 70% of the shellers are powered by a tractor power take-off and 30% by an independent gasoline engine. The latter are usually the smaller type, driven by a 5 HP or a 7 HP gasoline motor and producing 1200 to 2100 kg/h of grain respectively. The larger type uses a 10 HP or a 12 HP gasoline motor and produces 2400-3600 kg/h.

Use pattern: The shellers are mostly employed about three months per year (Sept. - Nov.). They normally work 6-8 hours per day, in the morning.

Economics of PV use: The smaller sheller could run on a 3 HP electric motor. Assuming 4 hours of peak sunlight per day during the shelling season and the above use pattern, it would need about a 5 KWp array capacity and a 3-day battery storage. This system would have at projected 1986 prices a life-cycle cost of about $34,200. On the other hand, for a 5 HP gasoline motor costing $750 (assumed to be overhauled at a cost of $350 every third year and replaced every fifth year), used 600 hours per year, the life-cycle cost in 1986 will be only $9400. Thus PV is not economically competitive in this application. Indeed the combination of a short working period per year, long working hours and need for battery storage represents the most disadvantageous situation for PV.

7.8 Maize Dough Mills

Production characteristics: One of the few machines widely used in the rural areas of Mexico is a mill for grinding maize into dough (nixtamal) for the day's tortilla consumption. The mill normally works 2-3 hours per day in the early morning.

1/ Removal of the grains from the cob.

The economics of PV use: The nixtamal mill could be operated by a 3 HP electric motor with a 3 KWp array capacity. A 3-day battery storage at a minimum will be necessary in this application. For this system, the projected 1968 cost will be about $21,000. The alternative will usually be a 5-7.5 HP diesel motor (Table 6.2). Nixtamal mills are operated by small private entrepreneurs; these will base their economic calculations on the market diesel fuel price of $0.04/l. At this price (and allowing $0.02/l for fuel transport to the village), life-cycle costs in 1986 will be about $7800. Even at economic diesel fuel prices, the 1986 life-cycle cost of a diesel system will be $14,100, in comparison with $21,000 for a PV system. Considering the greater life-cycle cost of the PV alternative, the private-sector nature of nixtamal milling and the low fuel prices, it is virtually certain that no miller will opt for it.

7.9 Copra Drying

Production characteristics: Coconut copra is placed for drying in large square vats over a diesel- or kerosene-fired furnace. Coconut fibre is not used for firing the furnace due to the inconvenience in its handling. Typical plant capacity is 600-800 MT/year of copra. Each batch is dried by 24 hours of continuous firing. Operation is mostly during the rainy season (chiefly August to October). A small electric or diesel motor is used to drive a fan for blowing the flames and directing them toward the drying vats.

Reasons for not considering PV use:

(a) Most or all such plants have access to the electric grid.

(b) The quantity of diesel of kerosene consumed by the engine is insignificant.

(c) The continuous operation of the plant with a PV powered motor during the rainy season would require a large battery capacity for 15 days of 24-operation, the cost of which would be prohibitive.

7.10 Packing Sheds for Fruits and Vegetables

Production characteristics: Tomatoes and other commercially-grown vegetables are sorted and packed in boxes in sheds near the production areas, since they would be damaged if transported in bulk. Fruit such as bananas and oranges, on the other hand, are normally trucked in bulk to a central packing station which has conveyors and other packing equipment.

Reason for not considering PV use: The simple sheds used for vegetables do not have power equipment which could use PV, and the larger sheds are invariably located where grid electricity is available.

7.11 Sisal Stripping Plants

Production characteristics: Sisal is grown in plantations over large areas (about 150,000 ha) in northern Yucatan, as the sisal plant is well adapted to the rocky soil and low precipitation of that region. The leaves are periodically cut and shipped by truck to stripping plants, where the fibers are extracted and sent to a central plant for production of ropes, sacks, rugs, etc. The stripping plants are located in the vicinity of the plantations due to the weight loss involved in the process. However, the stripping process requires large amounts of energy. A typical stripping plant which was visited, works two eight-hour shifts per day, year round and processes about 130 tons per shift. This plant utilizes six electric motors with a total capacity of about 290 HP in the stripping process, as well as fourteen motors totalling about 105 HP in the drying process.

Reason for not considering PV use: Due to the large requirements for energy, stripping plants are located exclusively where electricity is available. The network in Yucatan reaches a sufficient number of sites appropriate for locating new plants.

7.12 Animal-Raising Applications

7.12.1 Dairies

Production characteristics: Dairies need relatively small amounts of electricity. In one typical medium-sized dairy (260 animals, of which 150 were in production) which was visited, the following equipment had been installed.

Dairy Power Equipment

Item	Power Required	Use Hours	Maximum KWH Demand
Vacuum pump for milking	2.25 KW	3-7 a.m.	9
		3-7 p.m.	9
Compressors for Refrigeration Tank	3.75 KW	24 hrs/day	90 1/
Mixer for Refrigeration Tank	0.375 KW	24 hrs/day	9
Milk Pump	0.75 KW	3-5 a.m.	1.5
Bottling Equipment	5 x 100 W	3-5 a.m.	1
Water Pump	2.25 KW	intermittently	6.72 2/
Lighting	10x100 W	7p.m.-5a.m.	10
Peak KW required	13KW		136.25

Reason for not considering PV use: Practically all dairy operations (except some small traditional private operations, which do not use any power) are located near the power grid, especially since dairies are typically located near fodder sources on irrigation projects, which are electrified.

7.12.2 Poultry Farms

Production characteristics: An important government activity in the rural areas is the promotion of cooperative poultry farms, with the aim of assuring self-sufficiency of the rural areas and small towns in poultry meat. The typical unit is of 5000 birds, and a farm gradually increases the number of these units. Electricity requirements of such a unit are minor, consisting of about:

lighting: five 60W bulbs	= 300W
heating: five 120W heaters	= 600W
water pumping (1/3 HP pump)	= 250W
	1150W

Reasons for not considering PV use:

(a) Although energy requirements for poultry farms are small, those concerning heating are critical since even a one-night blackout of the heating system may kill the entire flock. Thus for high reliability, very large battery capacity will be needed.

1/ Assuming compressors run 50% of the time.

2/ Assuming operation for a total of 3 hours.

(b) Government policy is to install poultry farms only where electricity is available. In view of the expansion of the rural electrification grid, which is projected to reach, by the end of 1982, almost all villages of 500 inhabitants or more, the government has a large choice of villages possessing electricity in which to locate poultry farms.

7.12.3 Pig Farms

Production characteristics: As in the case of poultry farms, the government installs a large number of cooperative pig farms to assure rural self-sufficiency in pork products. A typical unit consists of about 200 to 300 animals, including about 40 breeding sows. Electricity requirements of such a unit are:

lighting: twelve 100W bulbs	= 1200W
heating: six infrared 220W bulbs	= 1320W
water supply: pump	= 380W
	2900W

Reason for not considering PV use: Government policy is to locate pig farms only where electricity is available. In view of the large number of electrified but otherwise poor villages available as project sites, this policy is not likely to change.

7.13 Production of Fish Fingerlings

Production characteristics: Fish fingerlings for stocking are produced at one or a few central locations in each state which has this program.

Reason for not considering PV use: All the production sites have electricity, and there is an adequate choice of sites which possess electricity for the location of future plants.

7.14 Aquaculture

Production characteristics: The cultivation of fish and shrimp is practiced either in enclosures in running water, or in large lagoons which provide sufficient surface for oxygen exchange.

Reason for not considering PV use: The semi-intensive production technology which is used (to reduce production costs) simply does not require pumping, by PV power or otherwise.

C - 2

7.15 Projectors for Extension Agents

System characteristics: Agricultural extension in Mexico uses mobile units to inform the farmers of improved agricultural techniques. A mobile unit is a car equipped with loudspeakers to summon the farmers, a tape recorder, movie (16mm and super-8) and slide projectors. The loudspeakers feed directly from the car battery. The tape recorder works on 4-6 ordinary (1.5V) disposable batteries. The slide projectors are provided with current from a 400W, 110V gasoline generator. The generator is used only when the community visited does not possess electric current, which, in practice, happens some 20% of the time. The generator is operated in this case up to 2 hours per night, costs apparently about US $1900, consumes 1 liter of gasoline per hour, and may last 5-10 years or more. It feeds the projector directly, without batteries. The extension agents consider this generator to be a satisfactory tool, its main defect being the noise which it makes during the demonstrations. It is estimated that about 40 mobile units exist in Mexico at present, and as many as 200 may be in service at the end of 1981, (one at each of the SARH 132 dry-farming districts and about 50 irrigation districts, several at the subdistrict level, and some for the extension units of animal health service, rural bank and national seed production company).

Reasons for not considering PV use:

(a) The constant vibration on the rough roads which the extension agents will travel could damage the PV panels in a short time unless they are constructed of extremely sturdy and durable material (one agent was of the opinion that "it wouldn't last a month").

(b) The use in the evenings of a projector charged by a PV array implies the existence of a battery bank. This battery bank can be recharged at the extension center the night before leaving for the field, avoiding the bother and expense of the PV array altogether.

8.0 CONCLUSIONS

The important parameters which determine PV prospects in Mexico are:

(a) Cheap Energy - the price of diesel fuel is U.S. $0.043/liter (U.S. $0.16/gal.), of gasoline U.S. $0.12/liter (U.S. $0.46/gal.), and of electricity for rural consumers about U.S. $0.04/KWH. In real terms, the price of fuel is about constant and the price of electricity is declining.

(b) Extensive Electric Grid - the electric grid is planned to reach, by the end of 1982, practically all Mexican communities of over 500 inhabitants and 63% of those in the 250-500 inhabitants range.

(c) Strong government activity in the rural sector - the government of Mexico is conducting a vigorous investment program in the rural sector, totaling some $2 billion per year coordinated through organizations specifically oriented to marginal areas (COPLAMAR and PIDER), plus large amounts directly to the executing ministries (Agriculture and Hydraulic Resources, Public Works, etc.), and definitely has the leadership in the rural sector;

(d) Strong PV development program - Mexico is probably the Third World country which is most advanced in PV technology. In the future Mexican PV production will supply a major part of Mexico's demand for PV equipment..

(e) Cost consciousness - PV must be shown to be cost-competitive with the alternative power source, at least (for government planners) at international fuel prices, before it can expect widespread application.

The market for PV in the agricultural sector during the period 1981 - 1986 will be limited to the following applications:

Application	Year of Cost Competitiveness	Maximum Probable Effective Demand Thru 1986
Livestock watering	1982 to 1984	200 kwp
Rural water supply	1983	300 kwp
Small grain loaders	1982	80 kwp
Rural refrigerators	--	25 kwp
		605 kwp

The above figures relate to effective demand, i.e., the capacity which might actually be installed. Considering the inevitable delays associated with the startup of any new activity, these figures are probably on the high side. Moreover, the above figures are at best order-of-magnitude estimates since the amount of public investments in these activities during the period 1983-1988 will only be determined once the Administration establishes its development goals. Once the cost-competitiveness of PV in a certain activity has been established (at international fuel prices) and PV adequately demonstrated in a pilot project, a major shift to PV in that activity can be expected.

Value of the market: at system prices projected to descend from U.S. $8.00/Wp in 1982 to U.S.$3.90/Wp in 1986 (July 1980 cost base), the value of the agricultural PV market over the period will be about $3.6 million in 1980 prices (about $6 million in current prices).

Marginally feasible agricultural applications: The following applications were investigated, but found generally not appropriate for PV use, at least until after 1986:

(a) Pumping applications: small-scale irrigation, auxiliary irrigation and drainage, irrigation of tree nurseries.

(b) Refrigeration applications: fish reception centers, cold storage, ice production, veterinary extension and artificial insemination centers.

(c) Crop processing: grain drying, maize shelling, maize dough mills, copra drying, sisal stripping.

(d) Animal raising: dairies, poultry and pig farms, production of fish fingerlings, aquaculture.

(e) Other: projectors for extension agents.

The most frequent reasons for marginal applicability of PV in the above activities is that the grid reaches all locations in which they are carried out, or that the usage pattern (operation during the rainy season, long working hours) implies battery and array capacity which would make PV cost prohibitive.

Other markets for PV: These rather limited perspectives indicate that the main market for PV in Mexico over the next five years will be in sectors other than agriculture; in particular:

(a) rural services - rural radio telephones, school tape recorders, educational TV, refrigerators for rural clinics;

(b) rural appliances - especially home TV sets, and to a lesser extent refrigerators, fans and lighting in rural homes;

(c) telecommunications - TV and microwave relays, TV and radio repeater stations, etc.;

(d) signalling - airline, highway, railway and marine signals;

(e) measuring devices - automatic weather stations, stream gages, traffic counters, seismic detectors, etc; and

(f) cathodic protection - for the rapidly expanding PEMEX oil pipeline network.

These markets were outside the scope of work of the present study.[1] Note that the private sector market will be small and limited mostly to PV powered TV sets and other appliances; the major market for PV will be in the public sector.

The IPN (with Mexican private sector interests) is likely to become the major supplier of PV modules for the public sector, especially for rural applications. Outside sources are likely to be limited to:

(a) supplying raw materials and machinery to the IPN production;

(b) filling the gap where public sector demand exceeds IPN production;

(c) furnishing PV modules as a part of complete systems (e.g., for telecommunications equipment or measuring devices); and,

(d) providing PV kits for operating rural appliances.

PV manufacturers who want to realize this potential should:

(a) perform as much as possible of the production and assembly in Mexico to avoid the higher import tariffs on complete PV systems;

(b) enter into joint-venture agreements with Mexican companies to facilitate government approval and to benefit from financial incentives; and,

(c) offer complete systems (e.g., a TV set, PV array and battery which are matched to each other and adjusted to local insolation levels).

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[1] However, Pacific Northwest Laboratory in a report for the U.S. DOE entitled Export Potential for Photovoltaic Systems, DOE/CS-0078, April 1979, estimated the market size for the following P/V applications in Mexico: communications systems - 50 KWp in 1982, doubling by 1986; cathodic protection systems - 20-100KWp in 1982, 100-400KWp by 1986; rural potable water systems - 30 - 100KWp in 1982, 300 - 1500KWp by 1986; village power systems 10 - 100KWp in 1982, 100 - 500KWp by 1986. Potential annual sales for photovoltaic systems in Mexico is projected to be 110-350 KWp in 1982 and 1000-2600KWp in 1986.

APPENDIX A - CONTACT LIST

FEDERAL DISTRICT AND STATE OF MEXICO

MEXICAN GOVERNMENT ORGANIZATIONS

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CFE (Federal Electricity Commission) International Commission of Planning, Administration and Programming (CIPAP)

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Ing. Juan Eibenschutz -- Coordinator General

Distribution Management

Rio Rodano 14, 3 er piso, Mexico 5, D.F.
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CONACYT (National Council for Science and Technology)

Insurgentes Sur 1814, Mexico 20, D.F. -- Tel. 5-34-73-69 or 5-34-77-78
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COPLAMAR (General Coordination of Plan for Marginal Areas)

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PIDER (Integrated Plan for Rural Development)

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STATE OF OAXACA

Motores y Refacciones de Huajuapan

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PIDER -- Region Mixteca

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STATE OF TABASCO

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United States Trade Center

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SARH -- CONAFRUT (National Fruit Cultivation Commission)

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SARH -- Irrigation District No. 3

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STATE OF YUCATAN

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Philco De Yucatan, S.A. (Electrical Refrigerators)

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SARH -- Artificial Insemination Center

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Ing. Arial Mora -- Head of Hydraulic Program

SARH -- Sub-Program of Production and Agricultural Extension

Calle 53 No. 481, Merida -- Tel. 3-71-91 or 3-93-98
Lic. Rolandro Gongora -- State Delegate of Extension Communications
Ing. Gerardo Delgado Gonzalez -- District Delegate of Extension Communications
Tec. Jose Ramos Gonzalez -- Technician in charge of Mobile Audiovisual Unit

S.P.P. -- Ministry of Planning and Budget (PIDER Program)

Calle 33-B, No. 544, Merida, Yucatan -- Tel. 532-88 and 532-53
Lic. Maximo Garza Sanchez -- S.P.P. Regional Delegate
Ing. Abelardo Rosado -- Head of Supervision and Control Unit
Ing. José Luis Perec Merida -- Project Analyst
Ing. Ruben Valladares -- Project Analyst
Lic. José Gonzalez Gomez -- Promotion of PIDER Program

STATE OF ZACATECAS

COPLAMAR, Concepcion del Oro

Ing. José Cardena, Regional Supervisor of Training and Cooperative Employment Program for Development of Natural Resources

Fondo Candeliera

Dr. Vet. Belisário Rubio -- Regional Supervisor
Sr. Elias Briones -- Head of Maintenance, Pumping Equipment

Tanque del Alto Ejido, Mazapil Region

Sr. Marcelino de la Rosa, Commisar
Sr. Emilo Sanchez Medellin, Secretary

APPENDIX B - DOING BUSINESS IN MEXICO

B.1 Introduction

This appendix examines the distinctive features of doing business in Mexico. Section B.2 provides information on Mexican business practices relevant to U.S. business. Regulations and procedures regarding the importation of American goods into Mexico are treated in the section B.3. Section B.4 deals with climate for foreign investment in Mexico.

B.2 Mexican Business Practices

Perhaps the most difficult adjustment to make for Americans doing business in Mexico and elsewhere in Latin American is the difference in perception of time. In general, Mexicans do not have as rigid a sense of time as Americans. While the degree of punctuality will vary with the individual, it is fair to say that appointments are regarded as more flexible in Mexico than in the U.S. Therefore, it is important that Americans adopt as relaxed an attitude towards time as possible, while still retaining the degree of professionalism and cordiality customary in Mexican business transactions.

While Spanish is the offical language, many Mexican businessmen and government officials speak excellent English, often as the result of American university educations. Nevertheless, it is good practice for American firms to send personnel to Mexico with a good command of Spanish. To do otherwise is to reinforce the impression in Mexico and elsewhere in the world that Americans are not sufficiently sensitive to other cultures. Similarly, materials such as catalogues and pamphlets should be printed in Spanish. This is particularly true when dealing with Mexican government agencies. It is also a good idea to bring along an ample supply of business cards to exchange at meetings.

Mexican business contacts should always be addressed by their titles unless they are personal friends. Some of the most commonly used titled are listed below. Masculine titles generally end in "o" and feminine titles in "a" e.g. Lic.--Licenciado(a)--person with a bachelor's degree; Ing.--Ingeniero(a)--person with an engineering degree; Arq. - Arquitecto (a) -- person with an architecture degree; Dr. - Doctor (a) -- person with a doctorate.

Offices of private firms are generally open five days a week from 9:00 a.m. to 6:00 p.m., or from 8:30 a.m. to 5:30 p.m. with one hour for lunch. Some commercial offices are open on Saturday until 1:00 p.m. Government offices are open from 8:00 a.m. to 3:00 p.m. for normal business hours. However, evening appointments can usually be arranged with government officials.

B.3 Exporting to Mexico

Although Mexico's trade policy has been liberalized somewhat in recent years, there are still many obstacles to American exports. The Lopez Portillo Administration has announced a general policy of reducing the use of import permits and relying on import duties instead. Prior import permits must still be obtained from the Ministry of Commerce for about one-third of all imports. Requests should be submitted to the General Directorate of Foreign Trade Controls (Dirección General de Controles al Comercio Exterior) which conducts a study of the product and sets the tariff and/or grants the import permit. Decisions on applications are usually made within 30 days and the licenses are usually valid for 180 days and may be revalidated for a similar period. The granting of licenses depends on such factors as whether domestic goods are capable of meeting local demand and whether the goods are considered necessities or luxuries.

The Mexican tariff systems was revised in 1965 to conform with the Brussels Tariff Nomenclature, and its structure is quite complex. In most cases, a specific duty is levied based on the weight of the imported merchandise and an ad valorem duty is added. The ad valorem duty is assessed on either the invoice value or on an official valuation, whichever is higher. The official valuations, which have been established for most products, are typically higher than invoiced or market values. The ad valorem rates are high, particularly on luxury items and on products that compete with locally produced goods. The average rate is 35%, but the rates on some luxury items run as high as 100%. Duty-free items include among others, agricultural machinery, wheat, aluminum, tin and certain drugs and chemicals.

There are no restriction or controls on payments for imports or exports. However, imports or exports that are subject to a licensing requirement must be cleared by the National Foreign Trade Bank (Banco Nacional Comercio Exterior, S.A.) which levies a small fee based on the value of the goods.

B.4 Foreign Investment Climate

The government's program of Mexicanization, begun in 1960 and still in effect today, seeks to ensure that foreign investment benefits Mexico as well as the foreign investor. Among the benefits which Mexico expects to derive from the program are an increase in employment, import substitution, expanded exports, new technology, and a more skilled work force. The Mexicanization program is comprised of several laws governing tax incentives, manufacturing programs, import permit requirements and foreign exchange regulations.

The Law to Promote Mexican Investment and Regulate Foreign Investment, which became effective in May 1973, requires that foreign investment in Mexico be registered with the National Register of Foreign Investment, administered by the Ministry of Patrimony and Industrial Development. This law applies to:

1) Foreign individuals and corporations with equity investments in Mexico,
2) Mexican companies with majority of capital stock foreign-owned or controlled,
3) Real estate trusts with foreign participation,
4) capital stock shares owned by foreigners or deposited or guaranteed in favor of foreigners, and
5) any transfer of ownership of the above.

Foreign participation in a joint venture is normally limited to 49% of share capital, the remaining 51% must be Mexican-owned. For firms already established in Mexico, more than 25% of share capital or more than 49% of fixed assets may not be held by foreigners without the prior consent of the National Commission on Foreign Investment. Such approval is only granted when the investment is in a priority industry or geographic area.

However, the Mexican government has shown flexibility in adapting some of the regulations regarding foreign ownership in its negotiations with prospective foreign investors.

All new enterprises, whether domestic or foreign-owned, must apply to the Ministry of Foreign Relations for a permit to organize a corporation. The following factors are most likely to influence the Ministry of Foreign Relations:

1) the advantages of the proposed investment to the Mexican economy in the areas of job training, technology transfer, import substitutions, production destined for the export market, and the value of the proposed investment for industrial integration.
2) the lack of investment interest by, or unavailability of, local investment capital.

The Ministry of Patrimony and Industrial Development issues a list indicating the products which are either not produced in Mexico or not produced in insufficient quantities. Foreign investors may obtain the list and any additional information regarding the range of incentives available for investment in Mexico from the Direccion General de Industrias, Secretaria de Patrimony Fomento Nacional, Avenida Cuauhtemoc No. 80, Mexico 7, D.F.

For additional information regarding doing business in Mexico, consult:

Business Study: Mexico (New York: Touche Ross International, Dec. 1979)

Doing Business in Mexico (New York: Price Waterhouse), Oct. 1979.

U.S. Department of Commerce, Overseas Business Report, Marketing in Mexico, January, 1981.

U.S. Department of Commerce, The Mexican Market--What U.S. Exporters/Investors are asking, May 1981.

APPENDIX C - MAJOR DOMESTIC AND EXPORT CROPS

Corn

27% of arable and permanent cropland devoted to this crop; 9,400,000 MT production.

Corn is the staple grain of Mexico, and the basic food item in the diet of the rural population. For this reason corn is the most widely cultivated crop. The fall crop contributes about 90% of the year's production, and is dependent upon rainfall for water requirements.

Wheat

3% of arable and permanent cropland devoted this crop; 2,200,000 MT production.

An increased domestic consumption of bread, along with cattle feed requirements and decline in cropped hectarage has led to increased wheat imports, chiefly from the U.S. Low support prices have turned away farmers to the production of export crops such as cotton, safflower, sesame and chick peas.

Sorghum

4% of arable and permanent cropland devoted to this crop; 2,300,000 MT production.

Sorghum is largely a rainfed crop, and adverse weather patterns affect production greatly. Sorghum is by far the most important feed grain in Mexico. When production declines so, too, does the number of commercially kept dairy cows.

Beans

6% of arable and permanent cropland devoted to this crop; 700,000 MT production.

Beans are a staple within the Mexican diet. They are normally a smallholder crop produced by traditional means. Despite a large increase in planted area in Chihuahua, bean harvest for 1979 was only two-thirds of its 1978 production, illustrating once again the vagaries of weather to Mexican agriculture.

Soybeans

2% of arable and permanent cropland devoted to this crop; 6,000,000 MT production; 700,000 MT imported.

Oilseed products continue to rise, both as a human food oil and livestock meal. The government's efforts to provide a protein sufficient diet for its urban poor will probably lead to increased human consumption of soya flour. Only limited success has been obtained in increasing the production of copra and sunflower crops for crushing into vegetable oil, so soybeans may be turned to in search of yield increases.

Sugarcane

3,600 MT production, 3,893 MT exported at $14,358,000 value.

Domestic sugar production has increased by about 5-7% a year--Mexico being one of the world leaders in soda consumption. Sugar is grown by smallholders along the Gulf Coast. Ninety-four percent of the ejidatario producers cultivate cane on less than 10 ha. each. Some of the 1979 crop was left unharvested due to unusually heavy rains, labor shortages, and aging sugar mill equipment.

Cocoa

.2% of arable and permanent land is devoted to this crop; 36,000 MT production; 8,391 MT exported at $14,500 value.

Cocoa is primarily grown in Tabasco. The increase in 1979 was due to rehabilitation of old trees. Domestic consumption is high because of consumer demand for chocolate products, and government regulations require all domestic needs to be filled before exports are allowed.

Coffee

1% of the arable and permanent land is devoted to this crop; 3,800,000 bags (60 kilo bags) production; export value of $370,000,000.

Coffee is grown primarily by smallholders along the slopes of the Gulf Coast. It is raised almost entirely as a cash export crop, coffee consumed domestically being generally of a non-exportable grade.

Cotton

1% of arable and permanent land is devoted to this crop; 1,520,000 bales production; at $140,000,000 export value.

Cotton is grown on irrigated and rainfed lands, with heavy mechanical inputs in the northern region where it is grown under irrigation. Recently the government has limited irrigated hectarage devoted to this crop because of cool, wet weather in the irrigated areas which experienced flood conditions in 1979, insect damage, and drought conditions in the rainfed areas.

Livestock (Beef)

1980 beef production estimated at 1.065 million metric tons. Fresh meat exports totalled about 3800 MT

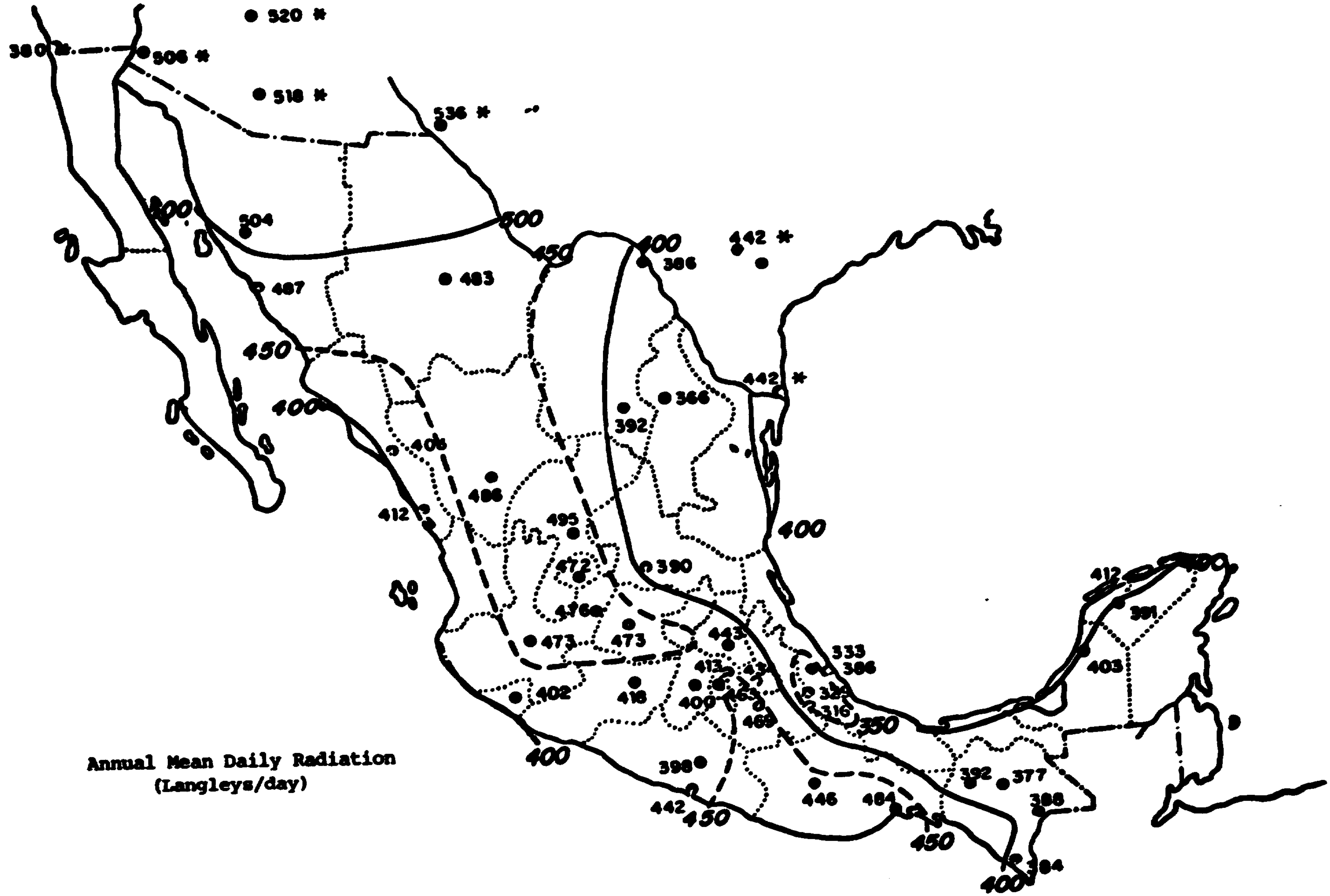
Livestock production, which accounts for one-third of the agricultural production, has increased steadily throughout the 1970's by about 4% annually. Mexico has three major beef cattle regions; the arid and semi-arid northern grassland ranges; the wet tropics along the Gulf Coast; and the dry tropics along the Pacific Coast. The tropics produce mainly for domestic consumption, with the wet tropics becoming a major supply area for Mexico City. The north produces feeder cattle and beef for export.

APPENDIX D - INSOLATION DATA

SUMMARY

MAXIMAL AND MINIMAL SOLAR RADIATION IN MEXICO
(in langleys/day)

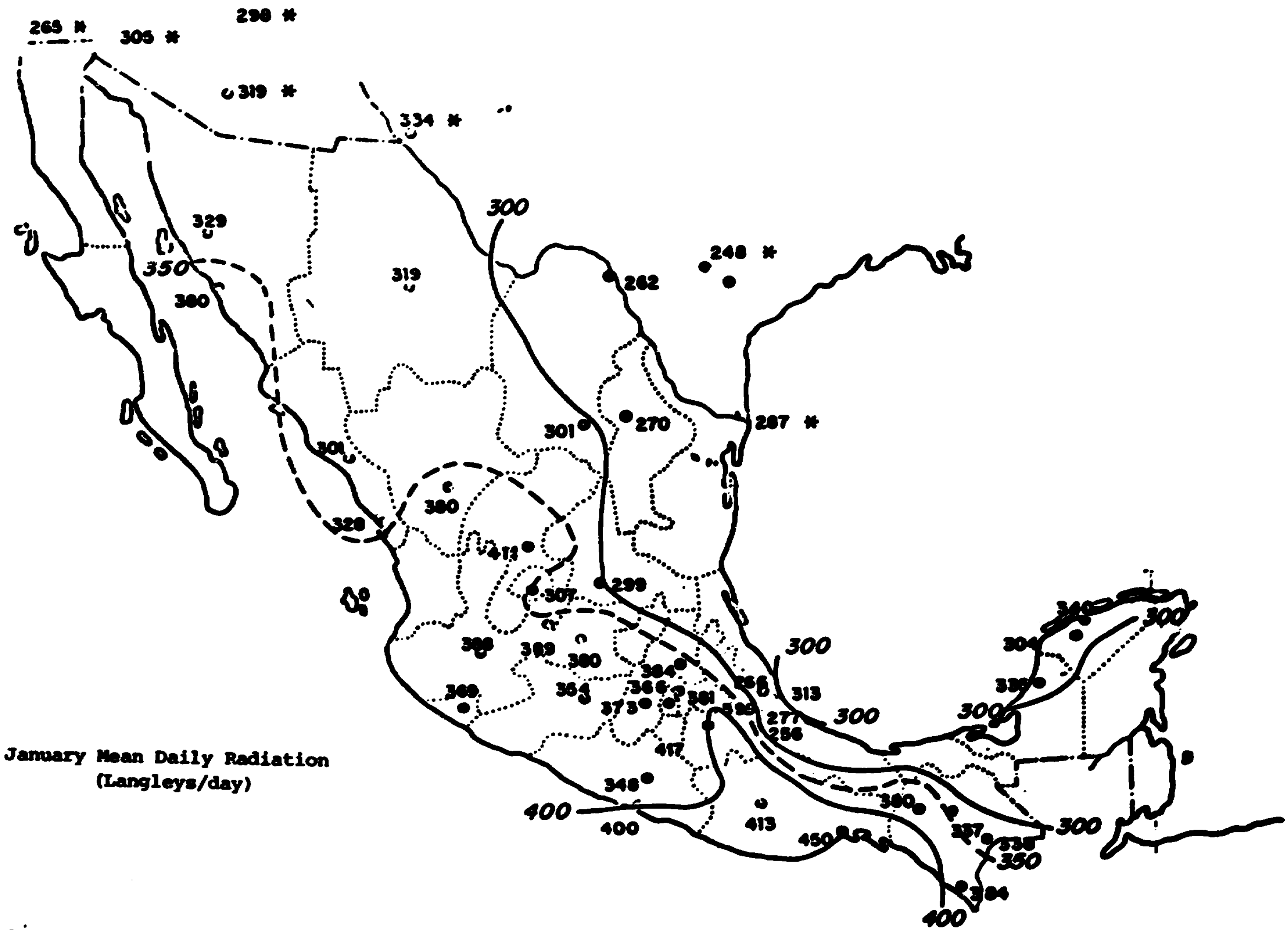
	Minimum	Maximum
Annual	375 (Los Tuxtlas) 380 (North Veracruz)	540 (Baja California Sur) 525 (Sonora)
January	250 (Northeast)	500 (Michoacan Coast, Guerrero, Oaxaca)
February	325 (Northeast)	575 (Colima Coast) 550 (Jalisco and Guerrero Coast)
March	375 (North Veracruz, South Tampico)	600 (Guerrero)
April	450 (North Veracruz)	675 (Guerrero and Oaxaca)
May	450 (Northeast, North Veracruz)	700 (Baja California Sur, Sonora)
June	375 (South and East Chiapas)	700 (Baja California Sur, Sonora)
July	350 (Edge of Isthmus)	675 (Baja California Sur)
August	350 (East and West Chiapas, East Oaxaca)	625 (Baja California Sur)
September	250 (West Chiapas, East Oaxaca)	600 (Baja California Sur coast) 575 (Baja California Norte, Sonora)
October	300 (Nuevo Laredo) 325 (NE, Los Tuxtlas)	500 (Baja California Sur coast) Guerrero and Oaxaca coasts)
November	300 (Los Tuxtlas)	525 (Guerro coast)
December	250 (Los Tuxtlas, North Coahuila)	500 (Oaxaca coast) 500 (Oaxaca)



Annual Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

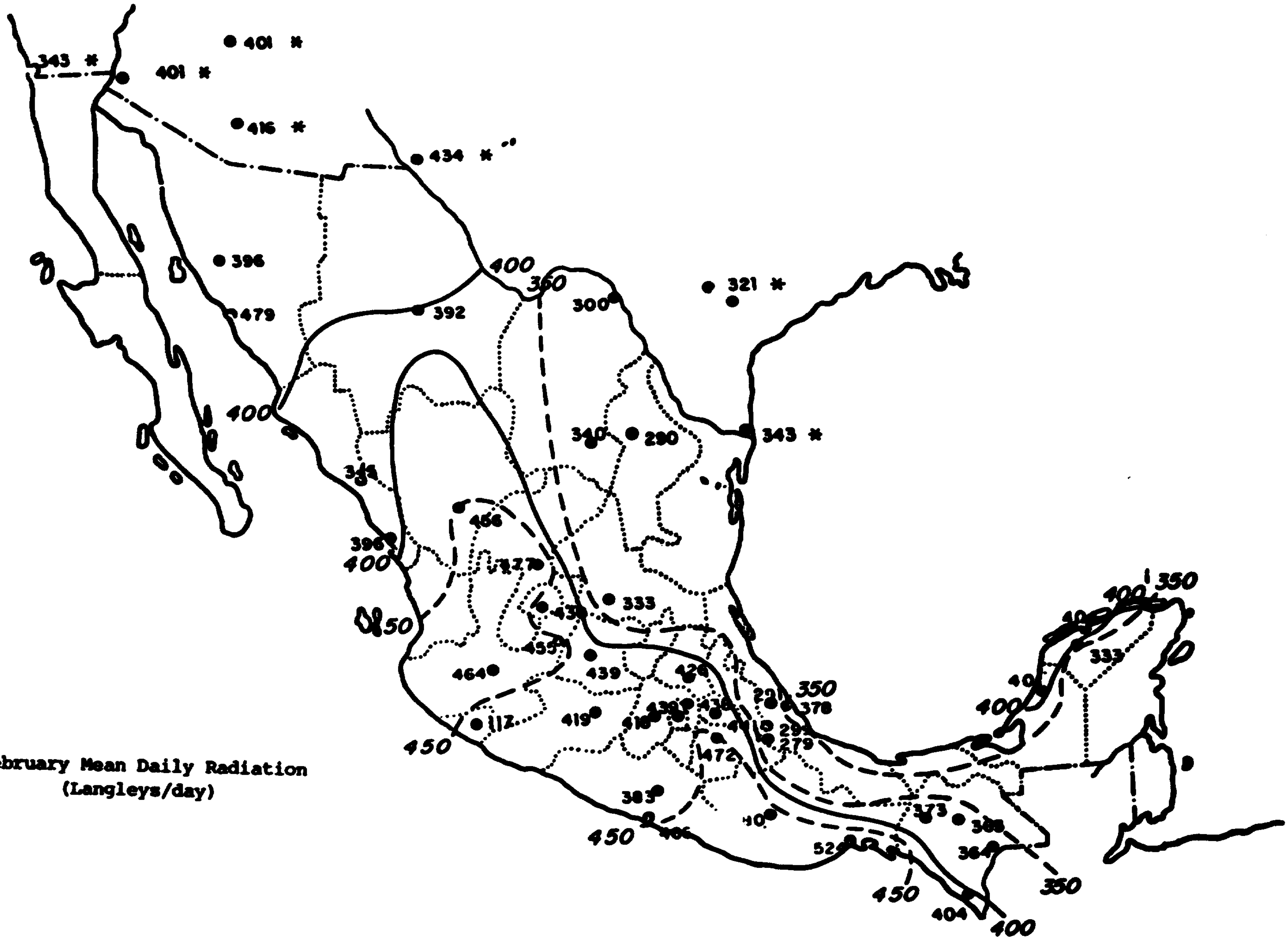
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



January Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

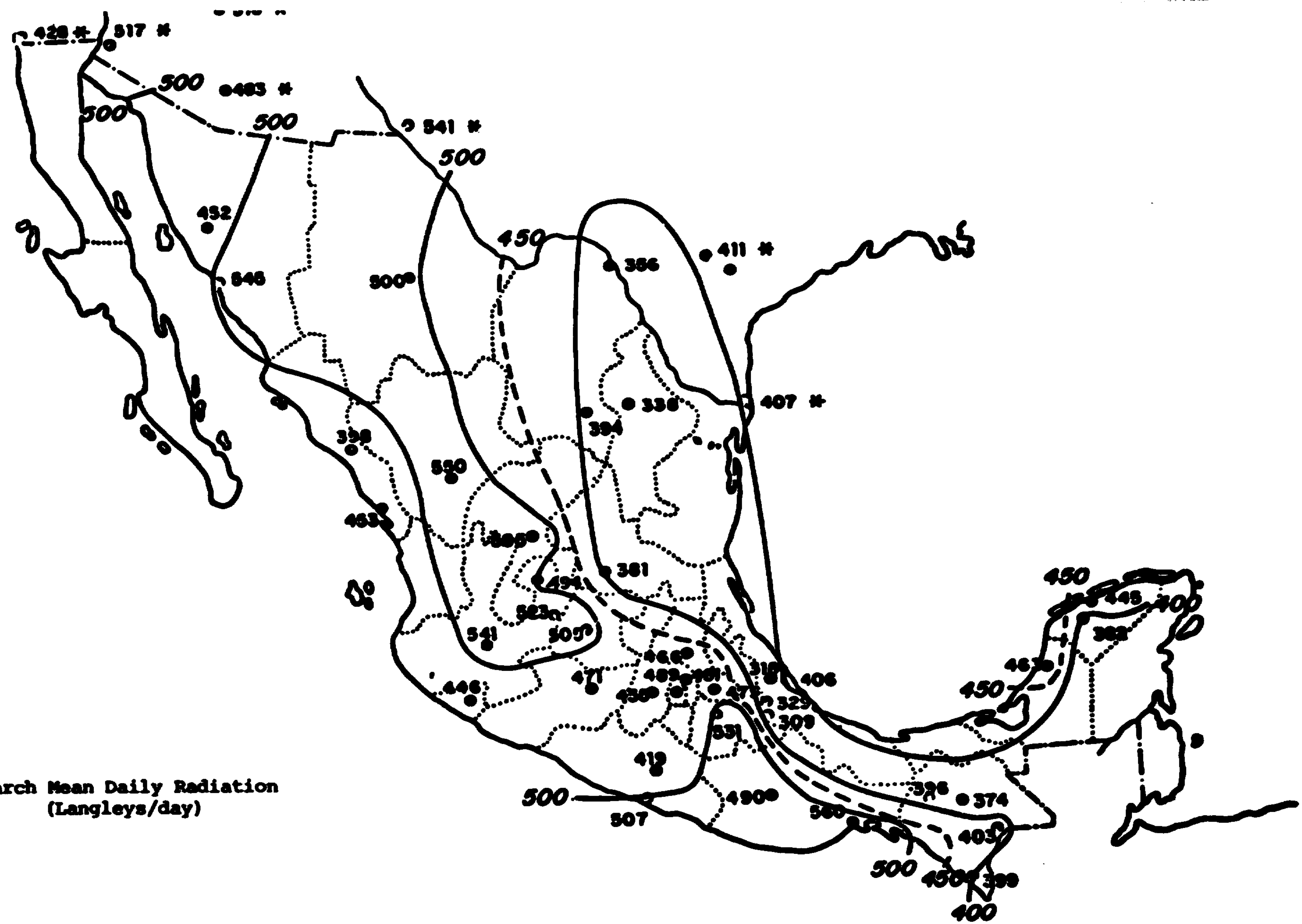
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



February Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

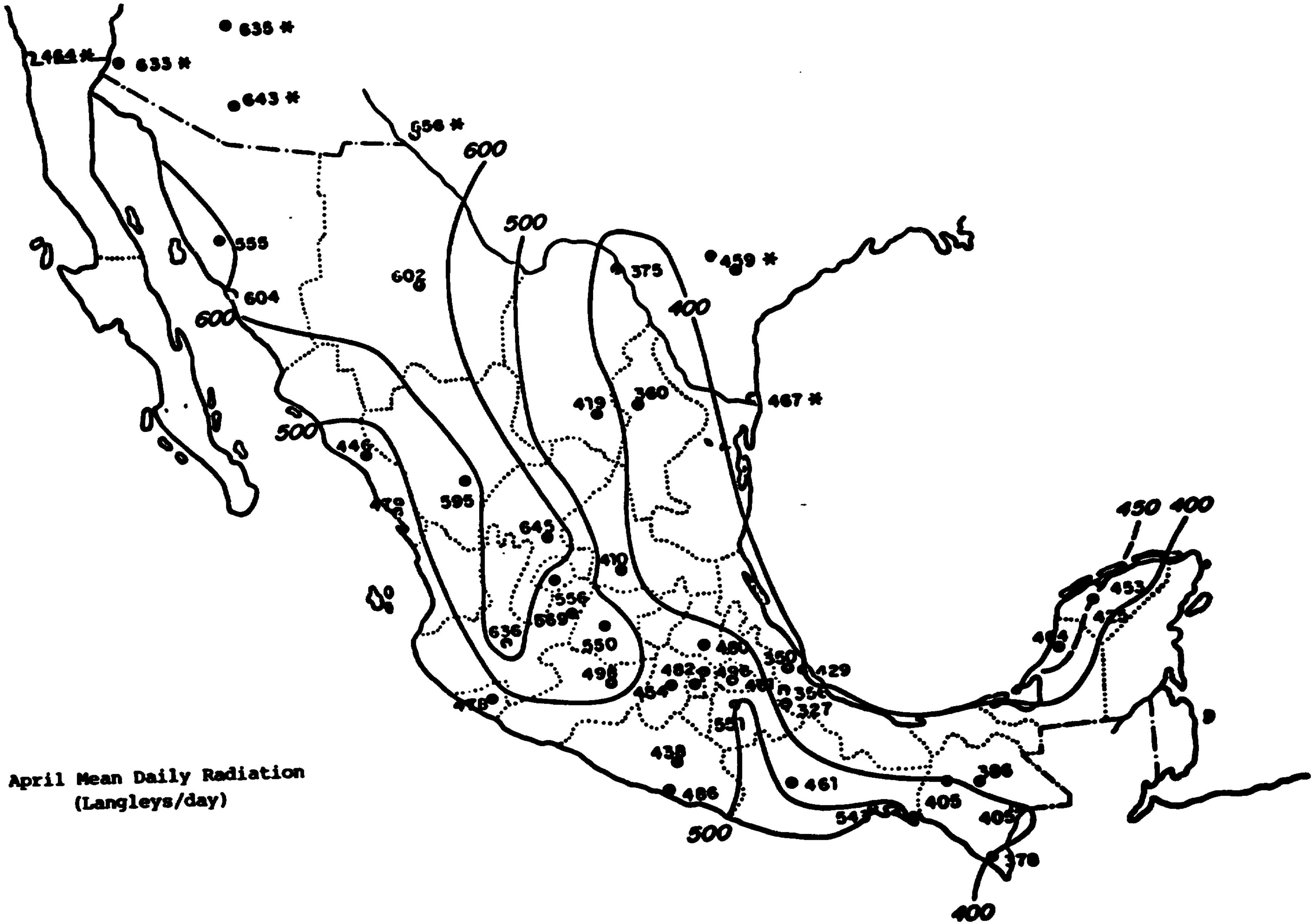
SOURCE: Rafael Almanza and Serafin Lopez. Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



March Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

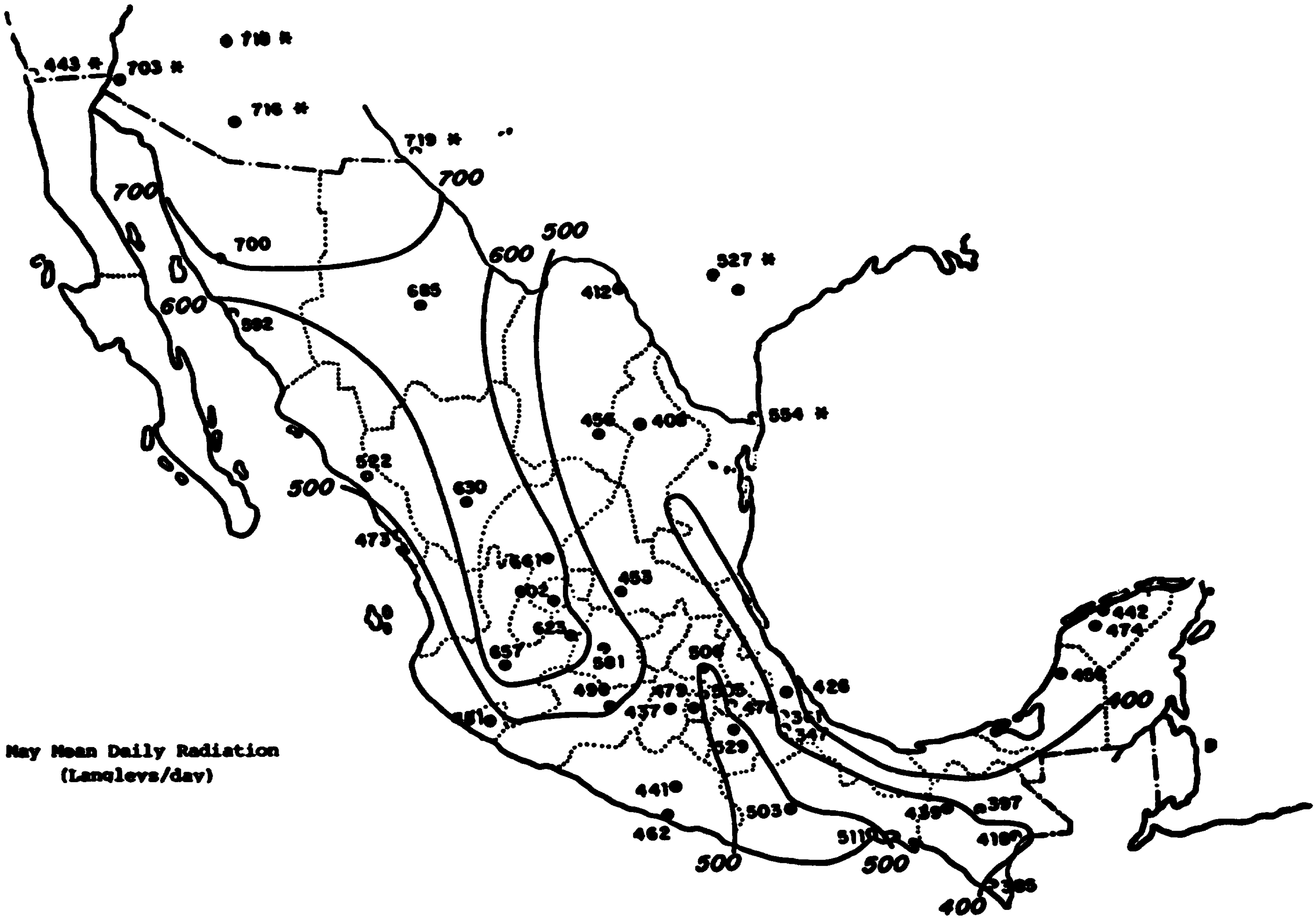
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Gl[illegible]al en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



April Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

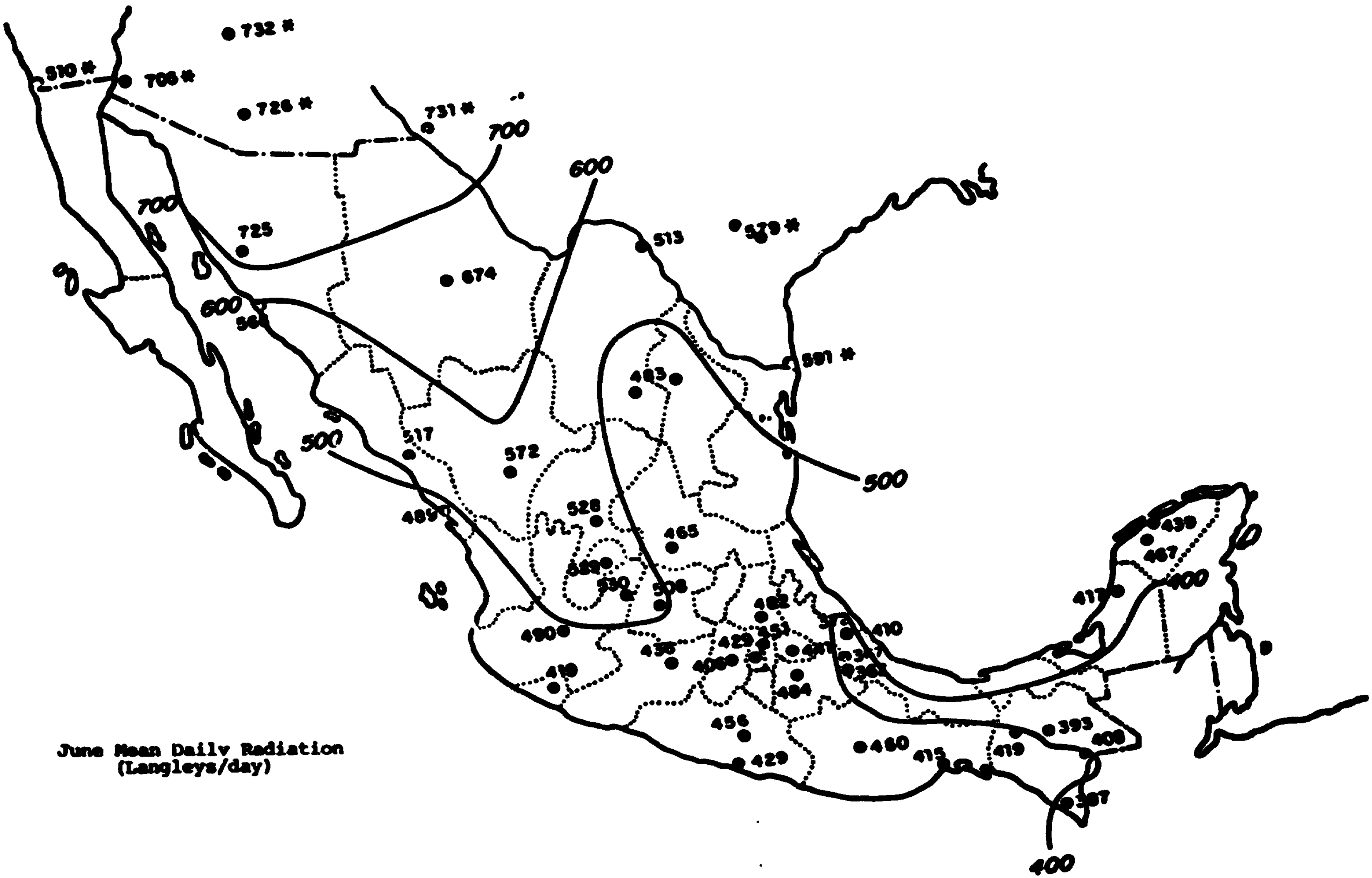
SOURCE: Rafael Almanza and Serafin Lopez. Radiación Solar Global en la República Mexicana Mediante Datos de Insolacion, UNAM: Mexico, D.F.



May Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

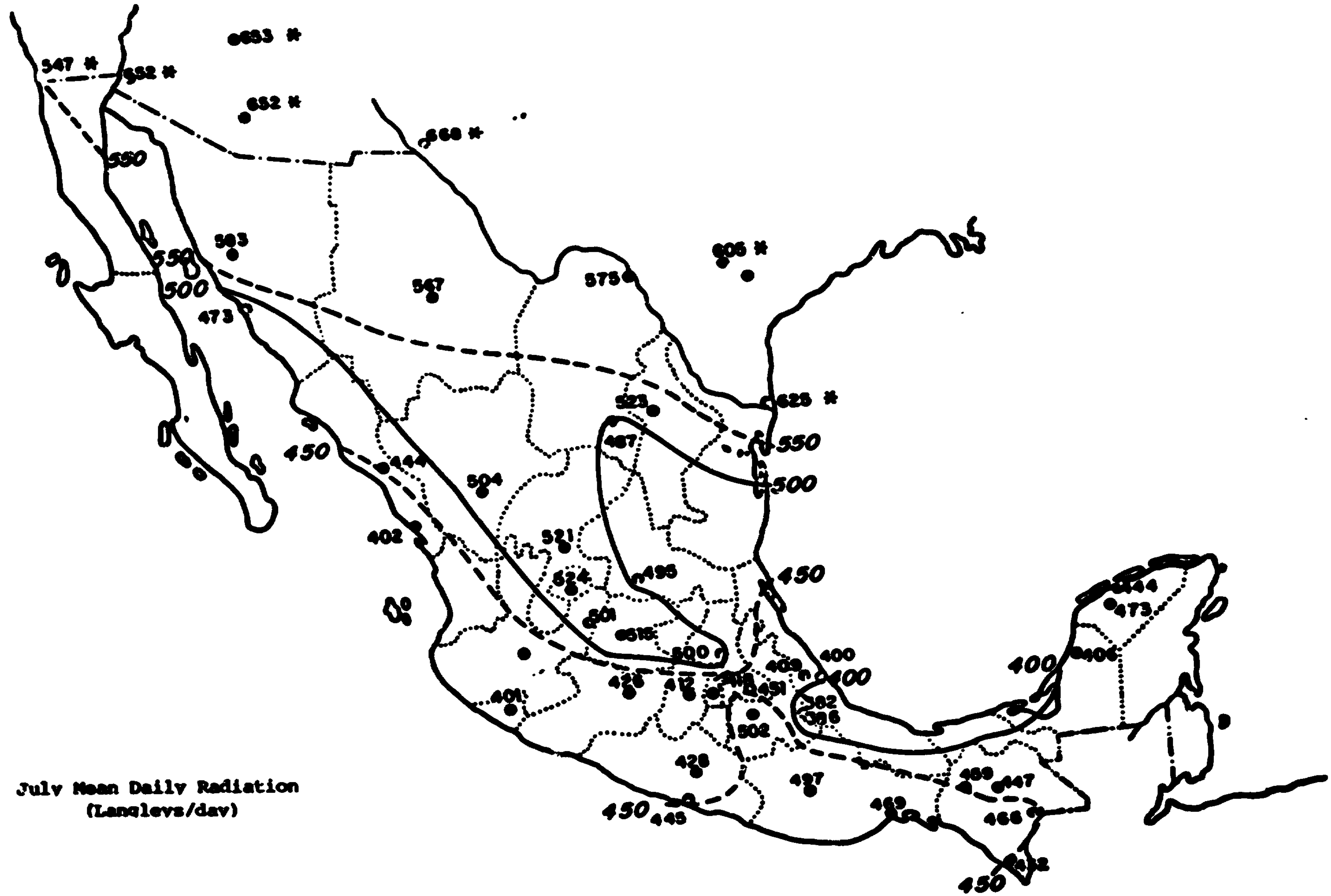
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



June Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

SOURCE: Rafael Almanza and Serafin Lopez. Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



July Mean Daily Radiation
(Langleys/day)

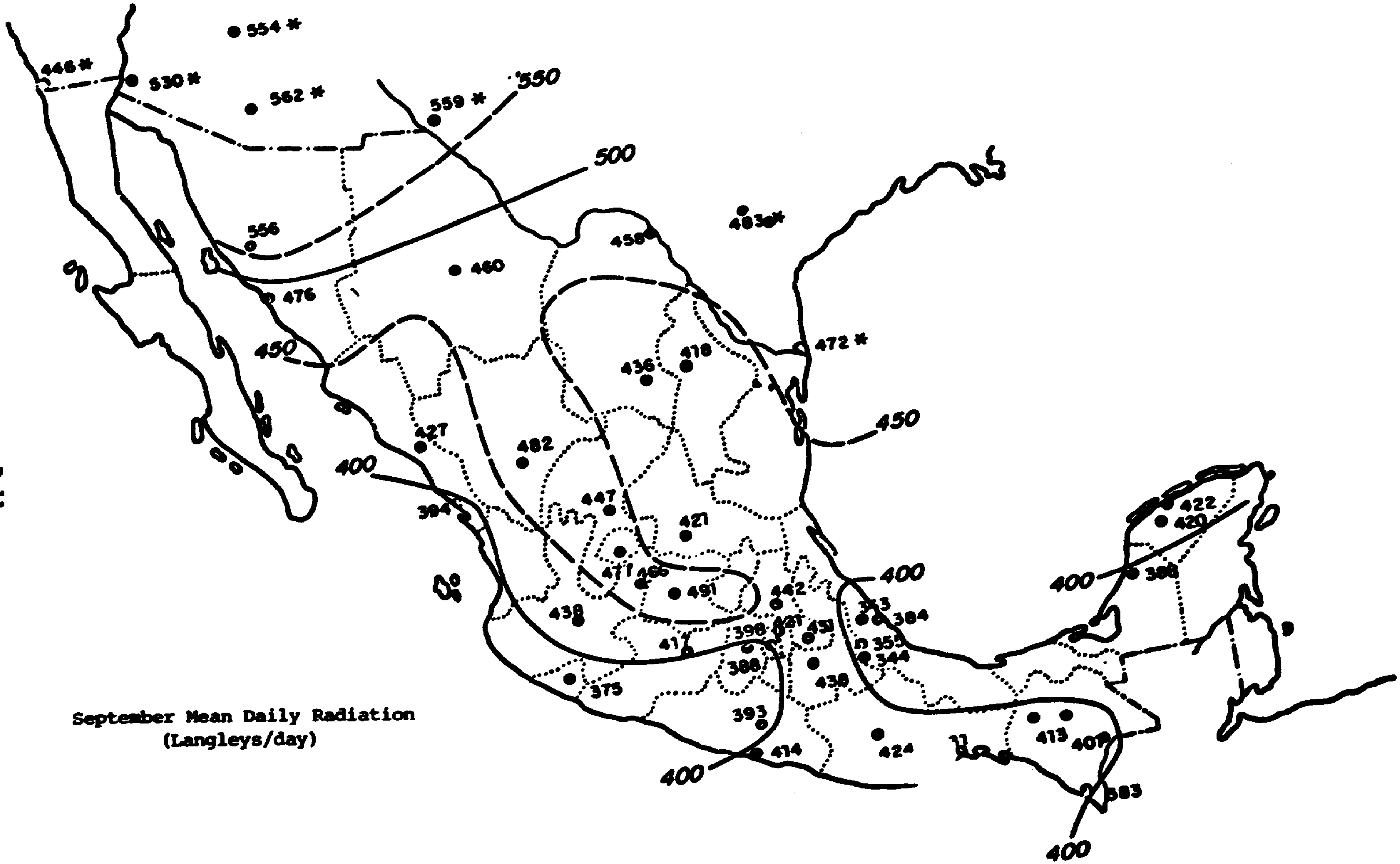
*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.

August Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

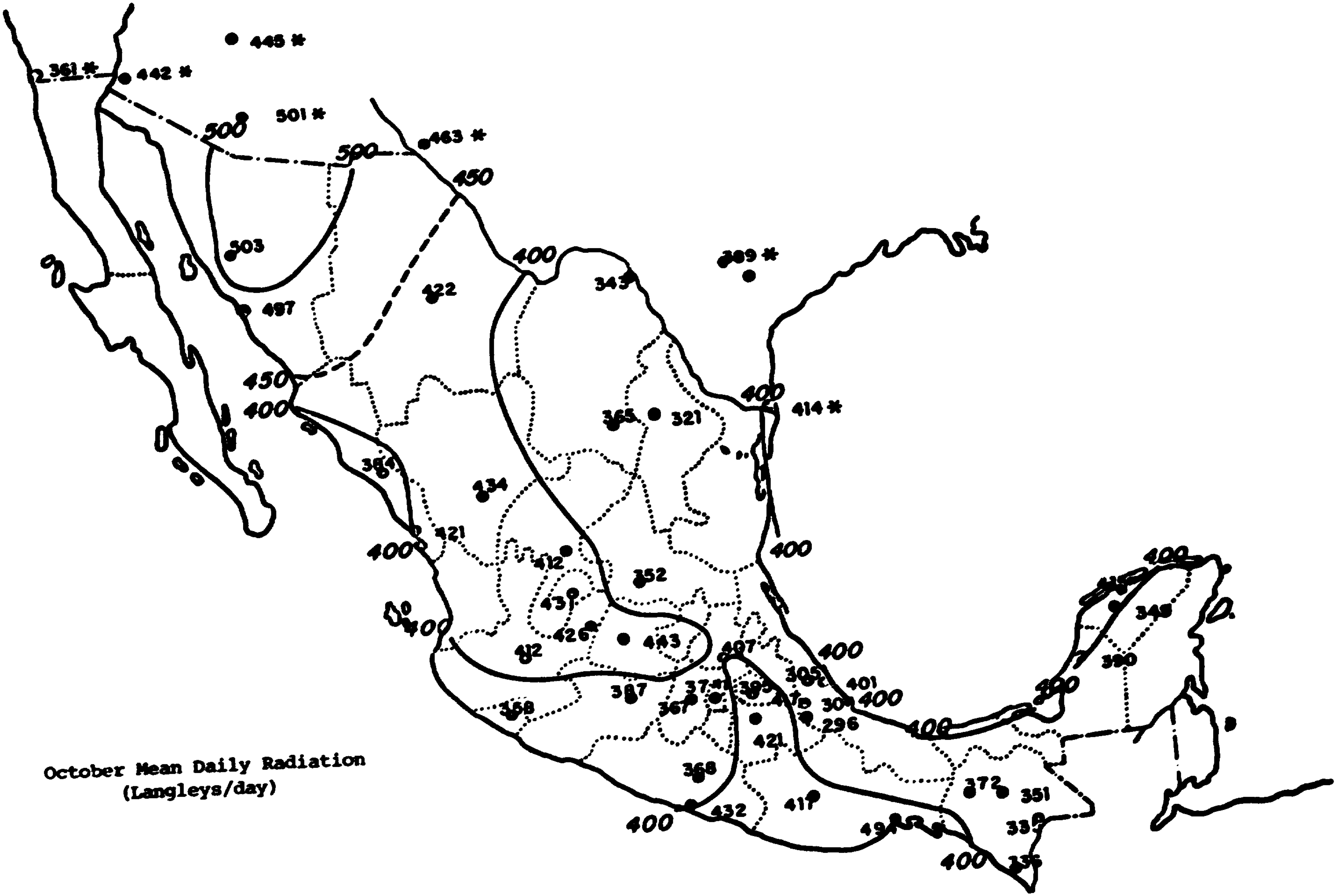
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



September Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

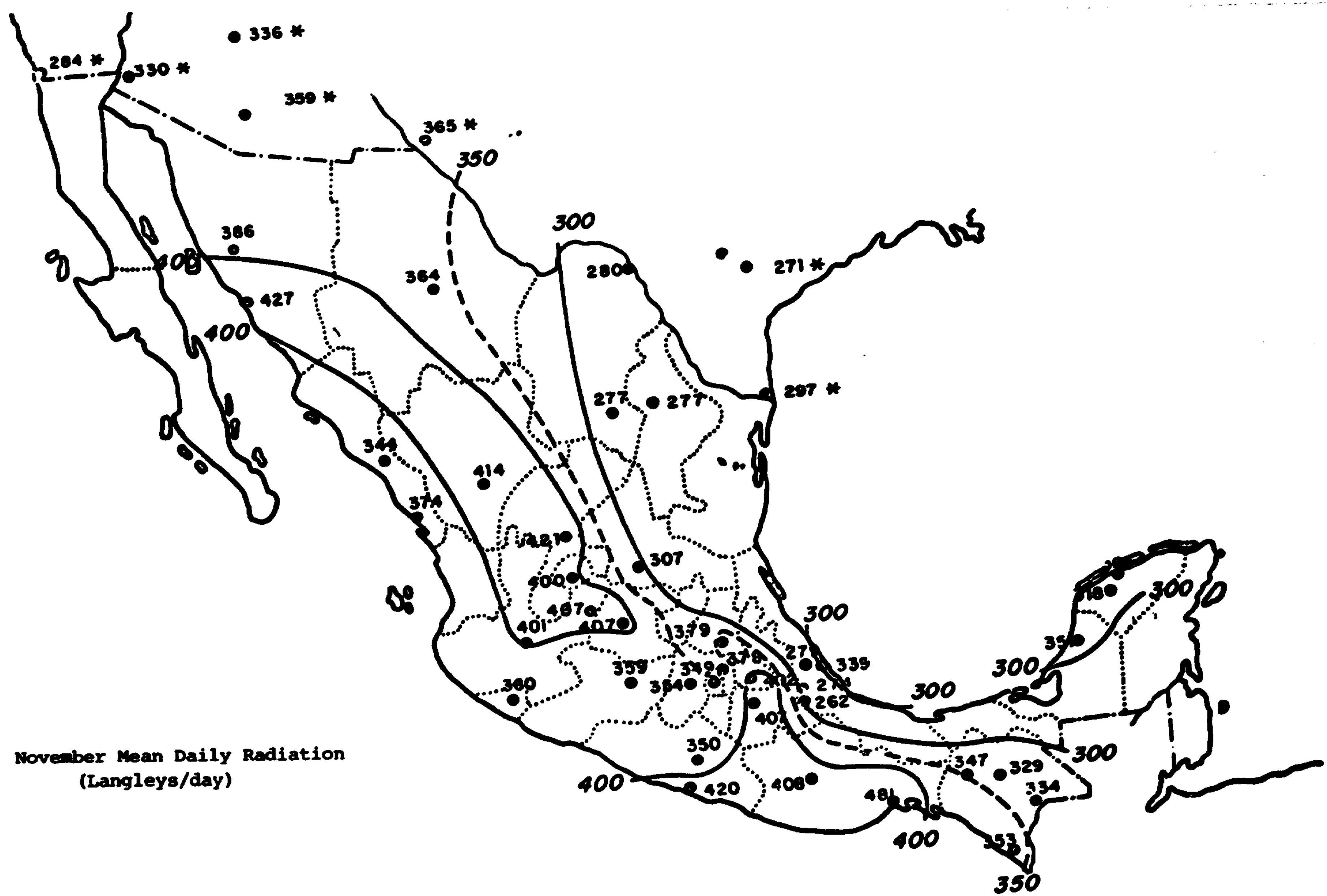
SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



October Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

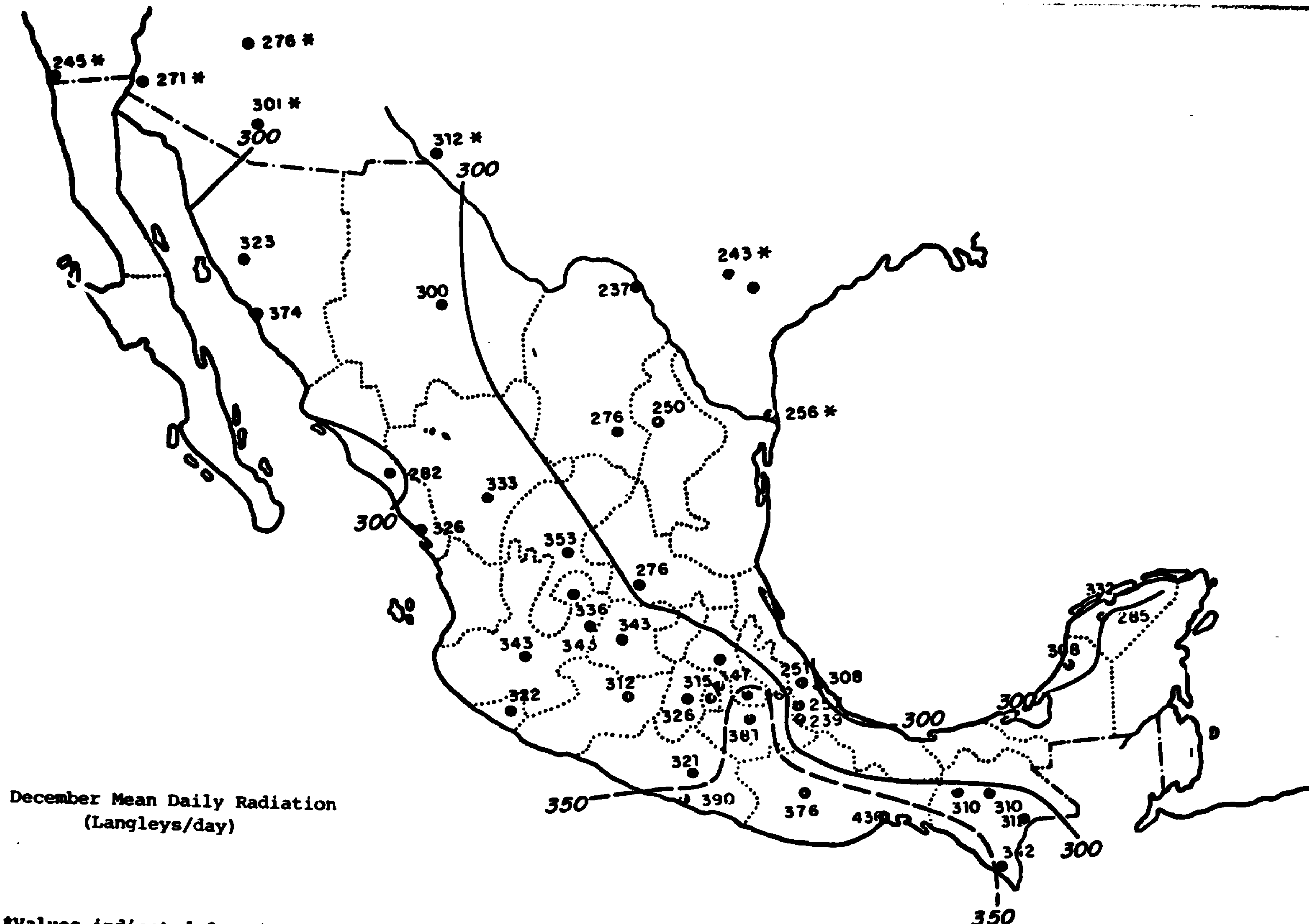
SOURCE: Rafael Almanza and Serafin Lopez. Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



November Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

SOURCE: Rafael Almanza and Serafin Lopez, Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.



December Mean Daily Radiation
(Langleys/day)

*Values indicated for the U.S. taken from I. Bennett, "Monthly Maps of Mean Daily Insolation for the United States", Solar Energy, Vol. 10, No. 3 (1965).

SOURCE: Rafael Almanza and Serafin Lopez. Radiación Solar Global en la República Mexicana Mediante Datos de Insolación, UNAM: Mexico, D.F.

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