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Potential for Energy Farms in the Dominican Republic

A Preliminary Analysis

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ABSTRACT

This report assesses the potential for generating electricity from dry forest energy farms in the Dominican Republic. In addition to a national assessment of dry forest energy potential, the report describes a conceptual Dominican Republic dry forest energy farm and conversion facility. The economics of this facility used to generate electricity are compared with those of oil-fired electric generation options. The report also contains a recommended plan for energy farm development in the Dominican Republic and indicates need for further analysis.

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EXECUTIVE SUMMARY

This report documents a preliminary assessment of the potential of generating electricity from biomass fuels produced on lands considered marginal for agriculture production in the Dominican Republic.

The Dominican Republic occupies the eastern two-thirds of the island of Hispaniola in the Caribbean. It has a population of about five million people and an area of 18,704 square miles. The unemployment rate in the country is estimated at between 20-40%, generally higher in the rural areas where 54% of the population lives. The country does not have any substantial domestic energy resources. Imported oil is by far the most important fuel, contributing 96.7% of the total commercial energy consumption and 90% of the total energy used for electricity generation. Recent increases in oil prices and generally depressed (although fluctuating) sugar prices have caused negative balances of trade.

It is with a view to decreasing the dependence on oil (with its attendant negative pressure on balance of trade), providing rural employment opportunities, and possible utilization of large expanses of marginal lands that the USAID Mission in the Dominican Republic has initiated this preliminary assessment.

The major conclusions reached in this study are:

(1) The Dominican Republic has about 8.4 million tareas* (1.3 million acres) of arid and semi-arid lands available for biomass farming. This land translates into a total potential of 200 MWe to 1400 MWe of installed electrical capacity, based on the biomass yield estimate used for these unirrigated dry forests. If lands that are presently used or potentially earmarked for agriculture or utilization of forest lands in the mountain areas are considered, the estimate of potential could be much higher.

(2) Biomass farming in the dry forest areas should be based on minimizing costs of production (rather than maximizing yields by intensive agriculture) using local farming methods with high labor input (rather than large-scale mechanization), and with minimum use of imported petro-based

*1 acre = 6.5 tareas

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fertilizers in order to achieve the twin objectives of providing rural employment and reducing trade deficits.

(3) We believe that the conversion method to generate electricity most appropriate to the Dominican Republic (in the 2-50 MW range) at this time is wood combustion to generate steam for driving a turbo-generator. Retrofitting existing oil- or coal-fired boilers with wood pyrolysis units (for charcoal and gas) or using a combined cycle are not recommended because of the potential risk associated with retrofits and with new technology, respectively. Depending on the end use desired, numerous conversion options are available in the several hundred kilowatt range, but these are not studied in any detail in this report.

(4) Preliminary cost estimates for a conceptual design of a farm and a wood-fired electrical generating facility as discussed in Items 2 and 3 above were compiled. Based on these cost estimates, cost of generating electricity from wood-fired plants ranges from 5.68 centavos/kWh for a 50 MW facility to 10.06 and 14.06 centavos/kWh for a 5 and a 2 MW facility respectively. The comparable costs of electricity from oil-fired plants is 12.4 centavos/kWh for a 50 MW facility. Thus, wood-fired facilities appear attractive from an economic standpoint even if smaller facility sizes are considered.

(5) The major challenge in implementing a biomass farming facility lies in marshalling and motivating a large force of workers to plant, tend and harvest the biomass. This endeavor belongs in the domain of rural and community development and is not addressed in this technoeconomic analysis. It should be kept in mind that a 50 MW facility needs 1,257,000 tareas of dry forest land and during the establishment phase (first five years), there will be a seasonal demand (50 days) for approximately 20,000 workers. About 1,000 workers will be employed (mostly for 110 days/year), each year for the rest of the production period. Smaller plant sizes need proportionately fewer workers. Whether biomass farming leads to net employment gains will depend on the alternative uses for this land.

(6) Of the two sites studied, the Mao site, under the control of the Instituto Superior de Agricultura (ISA) in Santiago, is most suitable for experimentation and pilot development from numerous standpoints discussed in this report.

(7) Varieties of Leucanea, Acacia, and Prosopis appear prime candidates for biomass farming in the dry forest area

because of their potential for rapid growth under arid conditions.

(8) Biomass farming should be considered in the Dominican Republic for other objectives such as producing wood for other uses (including charcoal).

Based on the conclusions stated above and our observations, we make the following recommendations:

1. A program to test methods of production and species at the Mao site should be initiated under the supervision of the ISA staff. This site is typical of the dry forest area, is under one ownership (ISA), has a nearby source for labor, has good highway access, and most of all, will have the technical guidance of an enthusiastic ISA staff. A preliminary development plan is contained in Appendix B of this report. In the initial stages, the Mao site could be used for charcoal production and can augment ISA's portable charcoal kiln program. This provides for a minimum investment option in the near term, while small-scale conversion technologies are examined exhaustively.

2. A separate study (which can draw on this report) of the relative economics and conversion technology options should be initiated for determining the potential of small (under 1 MW) biomass-fueled electrical generation facilities for remote applications. We understand that a 200 kW facility is being planned in Panama, and a 1.5-3 MW facility is being planned in the Philippines. The Government of Fiji is examining use of small wood-fired boilers and steam turbines (greater than 200 kW) and village-scale producer gas units (10-40 kW) to fuel modified petrol or diesel generators. It is necessary to gather more accurate data on biomass farming in an arid region both on productivity and costs of establishing a farm. A key element of the cost of biomass fuel in this report is the productivity estimate which is not verified. An effort to verify this could be undertaken in conjunction with species experimentation by ISA (Item 1).

3. This study considered lands that were not suitable for agriculture or timber production. We believe that the issue of using highly productive lands for biomass fuel production should not be a closed one for the Dominican Republic. It would be useful to conduct a study of economic competitiveness of various options available for timber production and agricultural lands in the framework of various world market scenarios for commodities.

4. The scope of this study did not include market analysis. It is recommended that price/demand (location, projections, etc.) for electricity, wood, and charcoal be undertaken before capital investments are made.

5. Because of the apparent demand for both charcoal and electricity in the Dominican Republic, a feasibility study of producing these jointly by retrofitting a pyrolysis unit to an existing oil-fired boiler should be undertaken. The Nichols-Hereshoff furnace is essentially well established technology for this purpose.

1.0 INTRODUCTION AND BACKGROUND

1.1 Objective

This report documents a preliminary assessment of the potential of generating electricity from biomass fuels* produced on lands considered marginal for agriculture production in the Dominican Republic.

1.2 Country Background

In this subsection the geography, climate, population and economy of the Dominican Republic are described.

1) Geography

The Dominican Republic comprises an area of 18,704 square miles (48,442 square kilometers) and occupies the eastern two thirds of Hispaniola, the second largest island in the Caribbean.(1) The country is bounded on the north by the Atlantic Ocean, on the east by the Mona Passage which separates it from Puerto Rico, on the south by the Caribbean Sea, and on the west by Haiti (Figure 1).

Five mountain ranges cross the country oriented from the northwest to the southeast. The Cordillera Central, with an elevation of 5,000 to 8,000 feet, divides the country in two parts. Pico Duarte, located in this range, is the highest peak in the West Indies (10,414 feet). North of the Cordillera Central lies the Cordillera Septentrional (4,000 feet in elevation). Two smaller ranges, the Sierra

*For purposes of this report, biomass-fueled facilities are synonymous with wood-fired plants.

FIGURE 1
RELIEF FEATURES OF HISPANIOLA
(DOMINICAN REPUBLIC AND HAITI)

de Neiba and Sierra de Bahoruco, are located on the southern peninsula. Finally, the Cordillera Oriental, which is more hilly than mountainous, runs from the Samana Bay to the foothills of the Cordillera Central.(2)

Although approximately 60% of the land is mountainous, the Dominican Republic has several very fertile areas. The breadbasket of the nation is the Cibao Valley, which is the 5,180 square kilometer strip of land between the Cordillera Central and the Cordillera Septentrional. In the San Juan Valley, situated between the Cordillera Central and the Sierra de Neiba, cattle, rice, beans and coffee are produced. To the east in the foothills of the Cordillera Oriental, cattle and sugar are the most important products.

Several rivers flow through the Dominican Republic, but most are shallow and, consequently, unnavigable. They are important for irrigation and hydroelectric power, however. The Cordillera Central is drained by the Yaque del Norte and Yuna Rivers. The Artibonito and Yaque del Sur Rivers drain the San Juan Valley. The Ozama River, which provides a sea port at Santo Domingo, and the Macoris River, which provides a port at San Pedro de Macoris, are navigable for several miles and are both used for shipping sugar. Near the Haitian border is Lake Enriquillo which is a salt lake 23 miles in length and 11 miles in width.

2) Climate

The Dominican Republic lies within the tropical zone, but because of high elevation and trade winds from the Atlantic Ocean, it

has a somewhat varied climate. Rainfall is concentrated in the north and east, averaging 2000 mm/year. It diminishes to the south, averaging 750 mm/year along the Haitian border. There are two rainy seasons occurring in the second and fourth quarters of the year, and from June to November the island is threatened by hurricanes and tropical storms. The national mean temperature is 25°C (77°F), decreasing to 21°C (69°F) in the mountains.(3)

3) Population

The majority of the Dominican Republic's 5.0 million (1977) people are concentrated in the Cibao Valley and in the area surrounding Santo Domingo, the capital.(4) Spanish is the national language, although French patois may be heard among the Haitian immigrants.

In spite of the trend toward urban migration (one of the highest urbanization rates in the world since 1950), the population is primarily rural (54% in 1975), with most of the labor force age 15 and over being employed in agriculture (58% in 1977) or services (26% in 1977). Adult literacy was 67% in 1975.(4)

4) Economy

According to the World Bank, the Dominican Republic has made impressive economic progress since its constitutional government was elected in 1966. Per capita income doubled over the period 1968-1974, and GDP expanded at an annual real rate of 11%, rising from $1,104.2 million in 1964 to $3,609.5 million in 1975.

The country's economy depends primarily on agriculture (18.2% of GDP in 1976), commerce (17.6%), and manufacturing (17.5%). Primary

agricultural products are sugar and sugar by-products (contributing 40.5% of commodity exports in 1976), coffee (14.1%), cocoa (7%), and tobacco (5.6%). Sugar processing forms the largest part of manufacturing activities, accounting for 44.3% of manufacturing value added in 1975. Food, beverage, and tobacco production (27.3%) and paper, printing, and chemicals (9.3%) are also important.(5)

1.3 Energy Situation

This discussion is organized into three areas: resources, current supply/demand, and energy projections. The best and most recent source of energy data is "A Preliminary Assessment of Energy Supply and Demand in the Dominican Republic" by McGranahan, et. al. at Brookhaven National Laboratory, Upton, New York (November 1979).(6) The following is summarized from this BNL Report and an FAO publication.(7)

1) Resources

The Dominican Republic is heavily dependent on foreign sources of energy. All oil is imported. There are some indications of oil, coal and peat, and geothermal resources, but reserves of these have not been determined. Hydro-electric sites totaling a potential of about 1 GW_e installed capacity have been identified, and small-scale hydro sites are presently being inventoried. Solar energy appears to be a viable source, while wind energy does not.

The 1973 FAO report on forest resources of the Dominican Republic estimates that there are about 1 million hectares of forest in

the country covering 22% of the surface area. Of this forest area, 34% was found to be in its natural state, the remainder having been depleted by logging (38%), charcoal production (17%) and other uses and causes (11%). Due to recent (1967) restrictions on logging, the deforestation has been slowed considerably. The current estimate of wood production for firewood and charcoal is 17.27 quadrillion Btus (10^{12} Btus) annually, of which about 90% is for firewood. Bagasse residues are extensively used for generating steam and electricity in sugar mills.

2) Energy Consumption Patterns

Total energy consumption has been growing at a rate of 8% and was 122.4 quadrillion Btus in 1977. Most of this growth was due to increased use of oil-based fuels which accounted for two thirds of energy consumption in 1977 as opposed to only half in 1970. Hydro resources accounted for 2.2% of the energy resource in 1977, primarily because of water requirements for irrigation. Wood consumption (including charcoal) fell slightly and only accounted for 14% of the energy consumption in 1977, down from 26% in 1970. This decrease is probably due to rural to urban migration and substitution of wood and charcoal by oil-based (LPG and kerosene) fuels in the urban areas. Bagasse is being used for electricity generation, for fuel production and as animal feed.

The sector breakdown of energy will not be detailed here except to point out that:

a) The industrial sector energy demands accounts for 38% of the national oil consumption, 61% biomass energy, and 38% of electricity sold by the public utility.

b) Transportation accounts for 22% of the national oil consumption but only 15% of total energy use.

c) The fuels used in the residential sector are primarily LPG, electricity, and charcoal in urban areas and wood and charcoal in rural areas. The breakdown is estimated to be 38% wood, 28% charcoal, 12% LPG, 11% kerosene, and 10% electricity.

3) Energy Projections for the Year 2000

Detailed projections of commercial and non-commercial energy demand prepared by BNL will not be presented here but two major points should be noted:

a) The demand for electricity is expected to grow at 8.9% in a business-as-usual case (Case I) and 7.6% in a conservative case where price effects on demand are considered (Case II).

b) The national oil requirements are expected to grow at a rate of 7.8% and 6.3% in the two respective cases.

c) Assuming that wood and charcoal will be consumed only in the rural areas, the use of wood and charcoal might be expected to increase at the 2.1% rate of increase of the rural population. Wood and charcoal presently supply 62% and 24%, respectively, of the total fuels used in the rural areas.

The above statistics on the present and projected energy patterns clearly point to the likely increase in oil dependence, increase in demand for electricity and the continued use of wood resources. It is thus clear that alternatives to generating electricity other than by imported oil are crucial to the Dominican Republic. Based on the projected increase in use of wood, it may be prudent to consider cultivation of fast growing species of trees and grasses,

even if oil substitution for electricity generation were not an acute need.

1.4 Report Outline

Section 2 presents an assessment of the potential of biomass from dry forest regions in the Dominican Republic. Section 3 contains a conceptual design and cost estimate for a biomass farm in the dry forest region using the specific case of the Mao site owned by Instituto Superior de Agricultura in Santiago. Section 4 contains a discussion of the conversion alternatives for various sizes of the facility, describes the recommended alternative and provides cost estimates for various plant sizes. Section 5 contains a comparative economic analysis for generating electricity using biomass fuels and oil-fired facilities. Appendix A documents the economic analysis calculations, while Appendix B contains a biomass farm development plan.

2.0 ASSESSMENT OF POTENTIAL

2.1 General

Cultivable land available for biomass production is already used for the production of biomass - mainly foodstuffs - produced both for internal consumption and foreign trade. A ground rule for this assessment was that energy farming would have to use that stock of land marginal to present or anticipated agricultural use.

This marginal land falls into two broad categories:

1. High precipitation, steep slope, mountainous country in which forestry and high pasture are the chief uses, and

2. Low precipitation, moderate to steep terrain in which fuelwood production and woodland grazing are the chief uses.

The first contains the more productive lands, but is located mainly away from the source of labor and on slopes too steep to consider for energy farming (40% to 100%). Energy farming requires that the land be intensively managed for biomass using trees grown in short rotations. This means that as often as every two years, harvesting crews must work on these slopes, and tending crews must work constantly during the initial plantation establishment period to minimize competition from undesirable vegetation. Some heavy equipment is generally used for the former. This operation and cultivation pose the threat of much greater soil erosion than current forestry practices. Similar to what Rodriguez[8] stated in his report, MITRE has also concluded that the arid region called by

Holdridge[9] the "dry forest" (Figure 2) offered the best opportunities for development of energy farming.

2.2 Identification of Land Area

In locating the land where energy plantations could be established, a process of elimination was employed. With the help of the Dominican Republic Forestry Agency, a map (Figure 3) was traced of the area in or adjacent to the dry forest which contained no sustained slope greater than 30%. This eliminated the larger mountain ridges and was done to avoid the potential of large-scale soil erosion and the inefficiencies of working steep slopes.

Next, assisted by the Dominican Agriculture Secretariat, all of the areas of present and expected future agricultural cropping were delineated. This was done by using data from the Comprehensive Resources Inventory and Evaluation System (CRIES),[10] fieldchecking information from CRIES, and relying on the expert opinions of employees of that department. Interpretation of the 1:50,000 scale LANDSAT imagery of 1973 was used also. All of the remaining land is considered available for energy farms--8,417,000 tareas* (approximately 1,300,000 acres).

2.3 Description of Soils

CRIES has designed a resource classification system for use in agricultural and rural sector planning. The system merges soil map information with plant life zones, and the resultant unit is called

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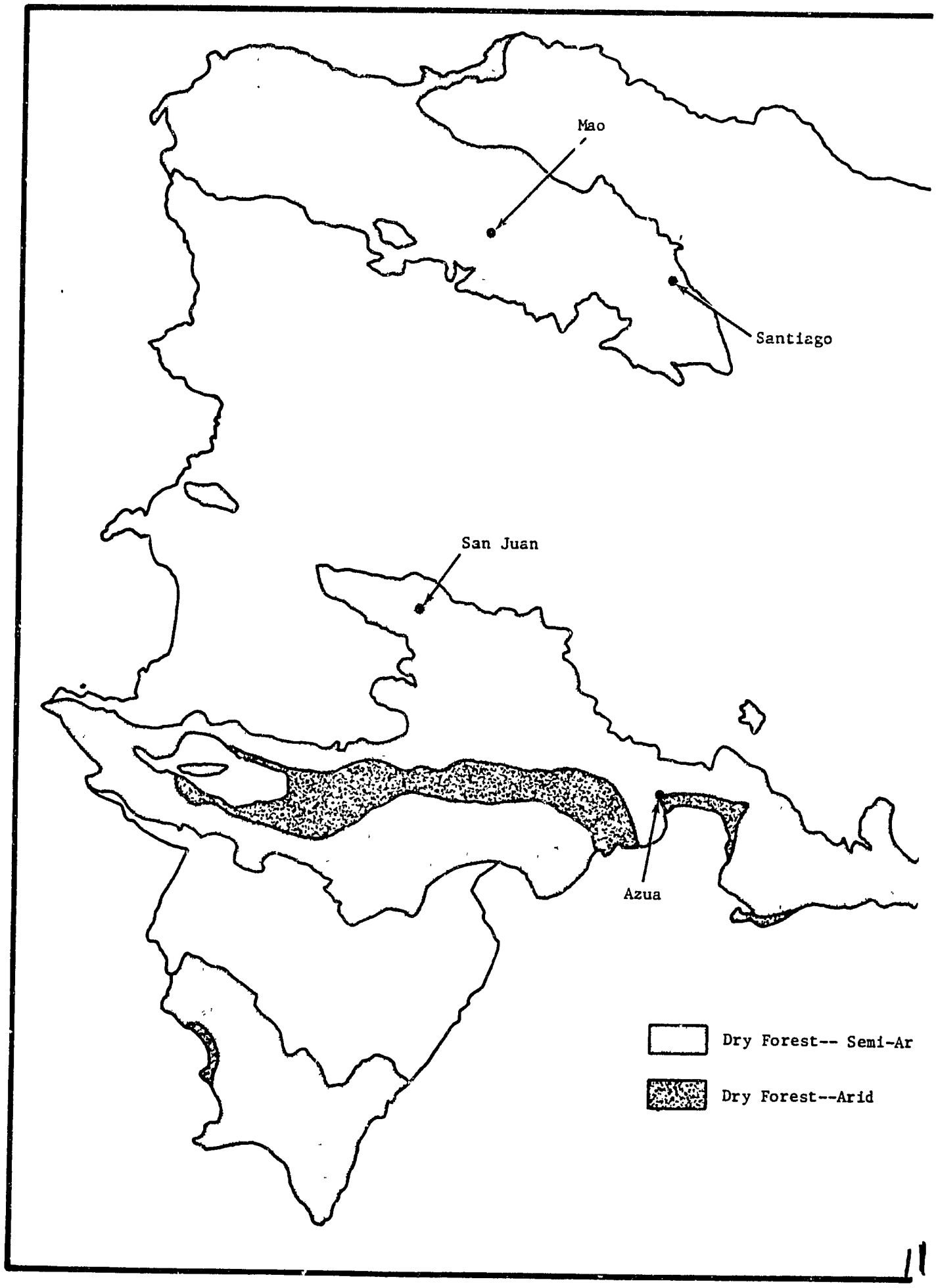
*1 tarea = approximately 1/16 of a hectare or 0.15 acre.


Mao
Santiago
San Juan
Azua
Dry Forest-- Semi-Ar
Dry Forest--Arid

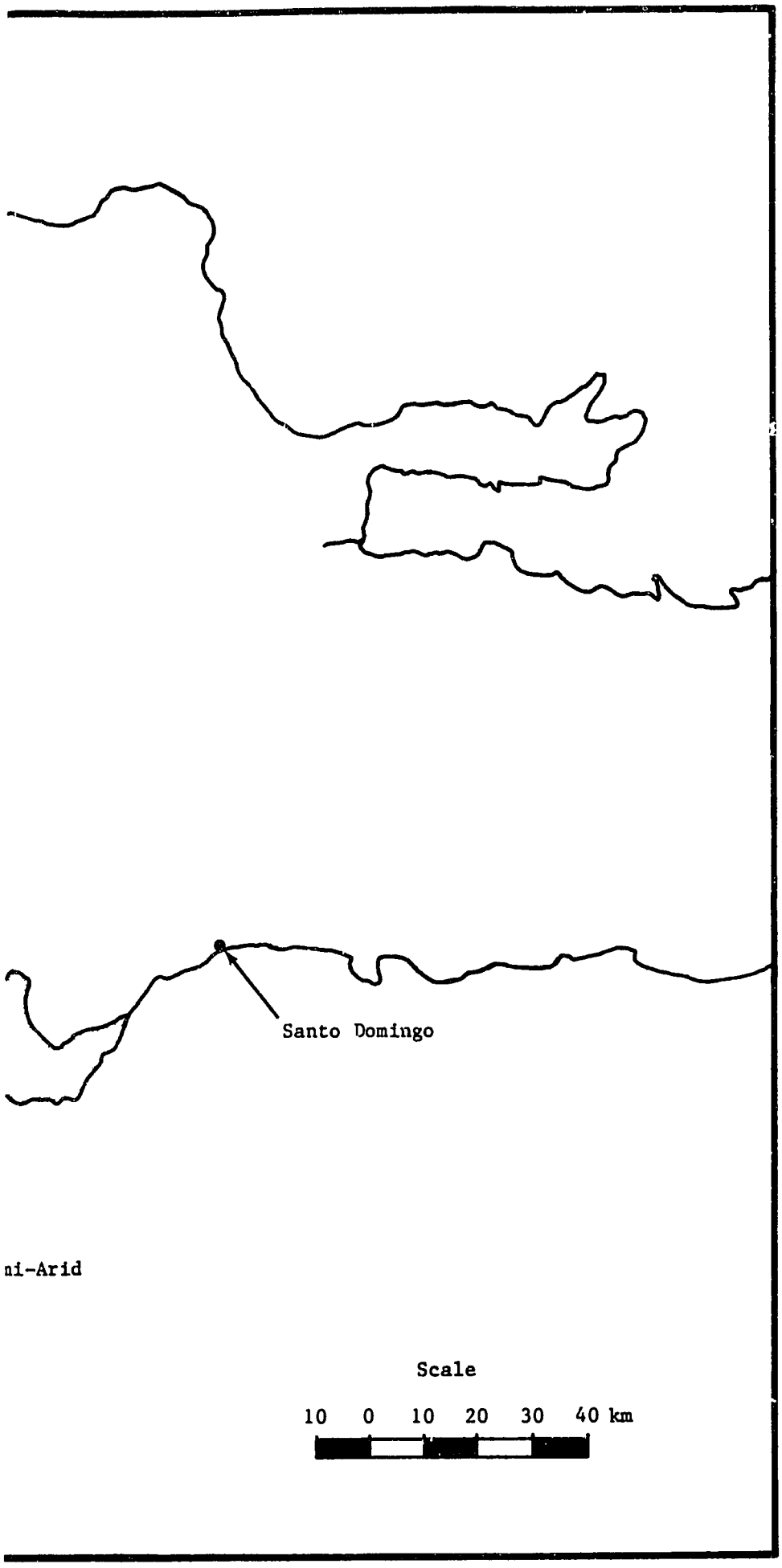
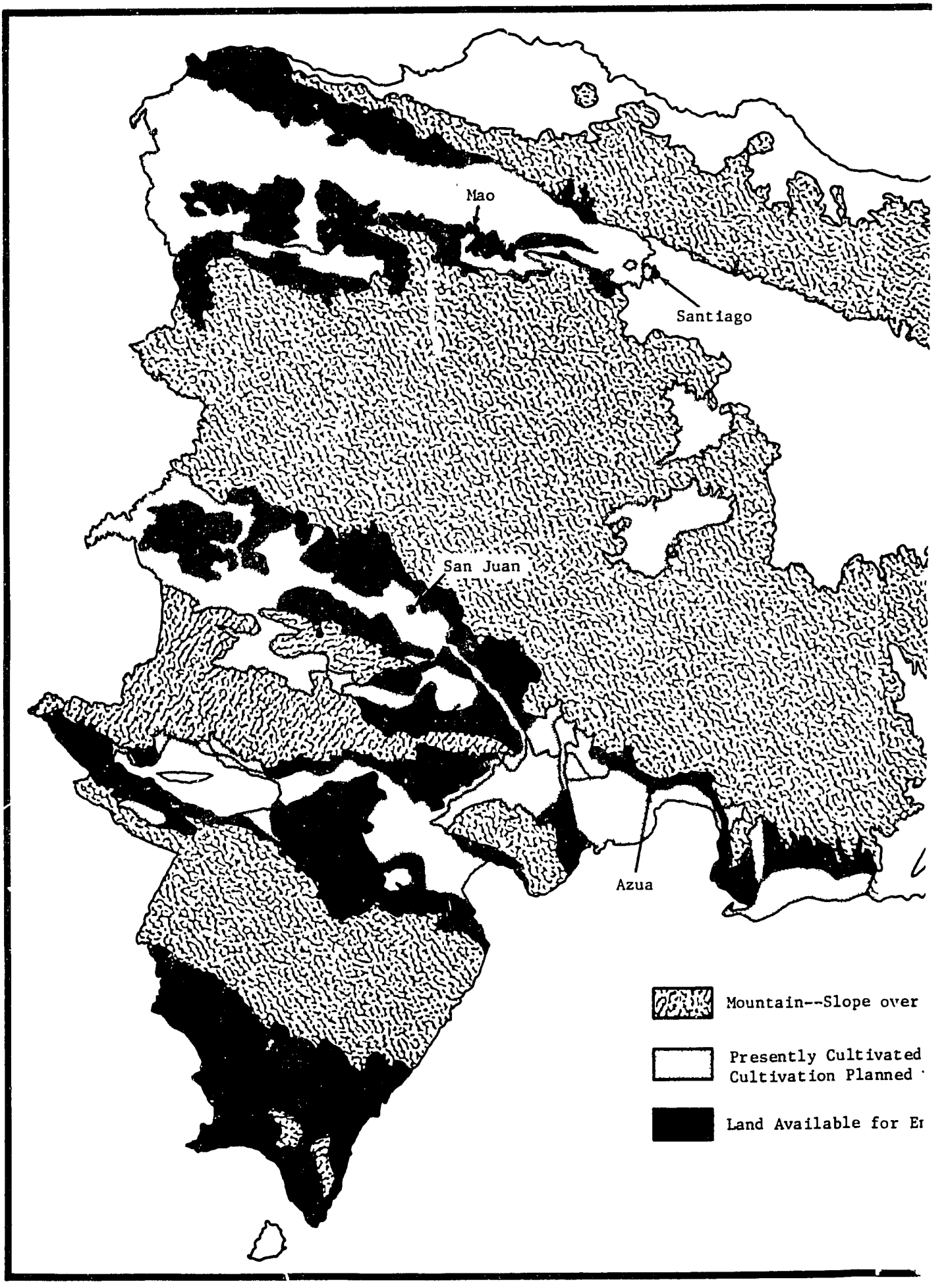


FIGURE 2
ECOLOGICAL ZONES
DESCRIBED BY L.R. HOLDRIDGE
FOR THE DOMINICAN REPUBLIC


Mao
Santiago
San Juan
Azua
Mountain--Slope over
Presently Cultivated
Cultivation Planned
Land Available for E

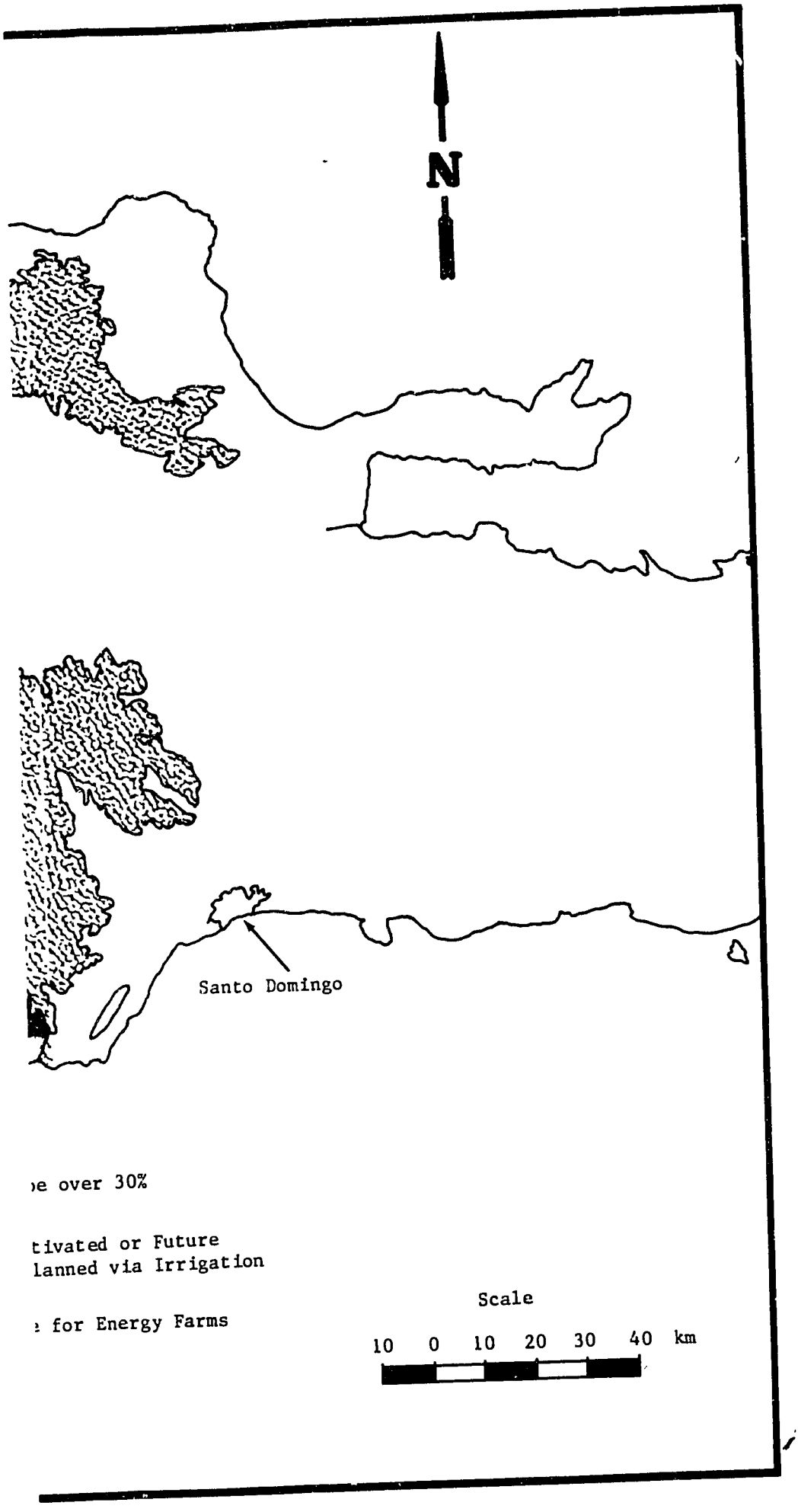


FIGURE 3
LAND AVAILABLE FOR ENERGY FAI
IN THE DOMINICAN REPUBLIC

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an RPU (Resource Planning Unit). The land available for energy production is found in RPU's 25, 28-32, 35 and 36 which are located in the Western half of the country. These are basically limestone derived soils occuring as clay loam on slopes of 5 to 30%. Some soils are stoney or cobbley, and all occur in areas of rainfall deficient for traditional agricultural cultivation. One of the areas near Lago Enriquillo (RPU 28) is saline and flat.

The primary barrier to greater productivity for those soils is lack of moisture. Any serious attempt to farm these areas for energy or agricultural purposes should consider the costs and benefits of providing additional water to generate growth year round.

2.4 Production Potential

The production potential of the land was approximated using data from Jennings and Ferreiras,[11] since the FAO forest inventory of 1973[7] did not cover the dry forest, and no other comprehensive measure of productivity exists to our knowledge.

Jennings and Ferreiras classified the dry forest into four major types according to productive capacity (Table I). The productive capacity was determined by the authors by interviewing people who lived and worked in the dry forest. These people were asked when the land was farmed last, so the interviewer could determine the age of the trees. This is an ad hoc process and is not an inventory based on tree growth measurements over a period of time.

TABLE I

Productive Capacity of Various Types of Dry Forest

TYPE	ANNUAL INCREMENT m^3/ha/year*	GTE/TAREA Year**	AREA (Hectares)
Mao/Lajas	5	0.32	104,000
Linea/Segundo	3	0.19	335,000
Tristeza	2	0.13	44,500
Cortado	1	0.06	107,000
Total			590,500

*Source - reference 11

**GTE=green tons equivalent (30% moisture). For this moisture content and assuming a specific gravity of wood of 0.9, 1 m^3/hectare-year = 0.06404 GTE/tarea-year.

The total area of the dry forest is 9,448,000 tareas. MITRE has identified 8,417,300 tareas of this total area as available for energy farming. Table II provides an estimate of the forest productivity on this land, assuming the classification proportions in Table I hold for the entire land area identified. Although the annual increment used in Table II reflects only the productivity of the species used to produce charcoal, these will be the baseline productivities given in this report. The reason for this decision is that no information exists for us to believe that the dry forest could support greater productivity in an unmanaged state. Using this average productivity calculated from the table (1,555,949 GTE/8,417,300 tareas = 0.185 GTE/tarea) and assuming an electrical energy conversion factor of 7572 GTE/MW, the estimate of energy production in the unmanaged state is 205 MW. This may be rounded to 200 MW.

The production potential of an unmanaged forest is a fraction of the potential if traditional forest management practices were applied. These practices include selection of high yielding species, spacing control, control of rotation age, application of irrigation and reduction of competition. Because dry forest management is not well developed, no accurate production figures are available to estimate the upper limit of productivity that could be expected in the Dominican Republic. However, the production estimates by the National Academy of Science for Leucaena leucocephylla (K-8)[12] are 20 m^3/hectare-year or 1.28 GTE/tarea-year. Applying this

TABLE II

Estimated Annual Production of Various Species Used for Charcoal Production in the Dry Forest

TYPE	ANNUAL INCREMENT GTE*/tarea/year	AREA (Tareas)	ANNUAL PRODUCTION (GTE)
Mao/Lajas	0.32	1,481,500	474,080
Linea/Segundo	0.19	4,781,000	908,390
Tristeza	0.13	631,300	82,069
Cortado	0.06	1,523,500	91,410
Total		8,417,300	1,555,949

*GTE = Green tons equivalent (30% moisture)

productivity factor to the charcoal species native to the Dominican Republic dry forest and assuming that proper species selection and appropriate site preparation and tending procedures will be carried out, the potential of electrical generation from these dry forest regions may be as high as 1,418 [(1.28/0.185)(205)] MW. Thus, the range of potential may be stated as 200 to 1,400 MW.

3.0 CONCEPTUAL FARM DESIGN AND COST ESTIMATES

In this section, a conceptual farm design, using the Mao site as a specific illustration, is described. The information provided here should be useful in developing the Mao site, but its major purpose is to provide a basis for cost and manpower estimates for biomass farming.

3.1 Energy Farm Conceptual Design for Energy Farm Establishment and Operation

3.1.1 Site Selection

When the MITRE team visited the Dominican Republic, several potential sites for demonstrating the feasibility of energy farming were visited. Two are examined in detail here.

One is located near Azua, at the village of Barrera. The forest is actively used for the production of charcoal and grazing of cattle and appears to be the only source of income for the village. The site is at the foot of a mountain ridge with a slope of 10% to about 30%. The soil is stony and slightly eroded but generally deep enough and quite capable of supporting sustained forest growth. The traditional dry forest species of Prosopis and Acacia were present. The land is government owned, according to officials of the D.R. Agriculture Department.

The other site is located near Mao and consists of about 16,000 tareas of forest land owned by ISA (Instituto Superior de Agricultura) and granted to the Institute for experimental purposes. At present, the forest is used for grazing and some charcoal or fuelwood

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production. Some areas were once under cultivation. Prosopis, Leucaena and Acacia are present as were many other species identified by Jennings and Ferreiras.(11)

The land form of the Mao site is rather flat in the eastern part, but the northern and western portions are irregular with many hills and ridges up to 15 meters high and slopes up to 35%. There are two distinct, separate areas in respect to crop productivity - the tops of the hills with a thin layer of topsoil supporting short growth and the flat areas or valley floors with a deep layer of topsoil (contributed by the hill tops and slopes) supporting relatively tall growth.

This site near Mao is recommended for the development of a demonstration production area because of the following reasons:

1. A variety of sites, from deep soil, flat land to hilly, thin soil areas are present to typify the conditions found in the majority of the land identified as available for energy farming.

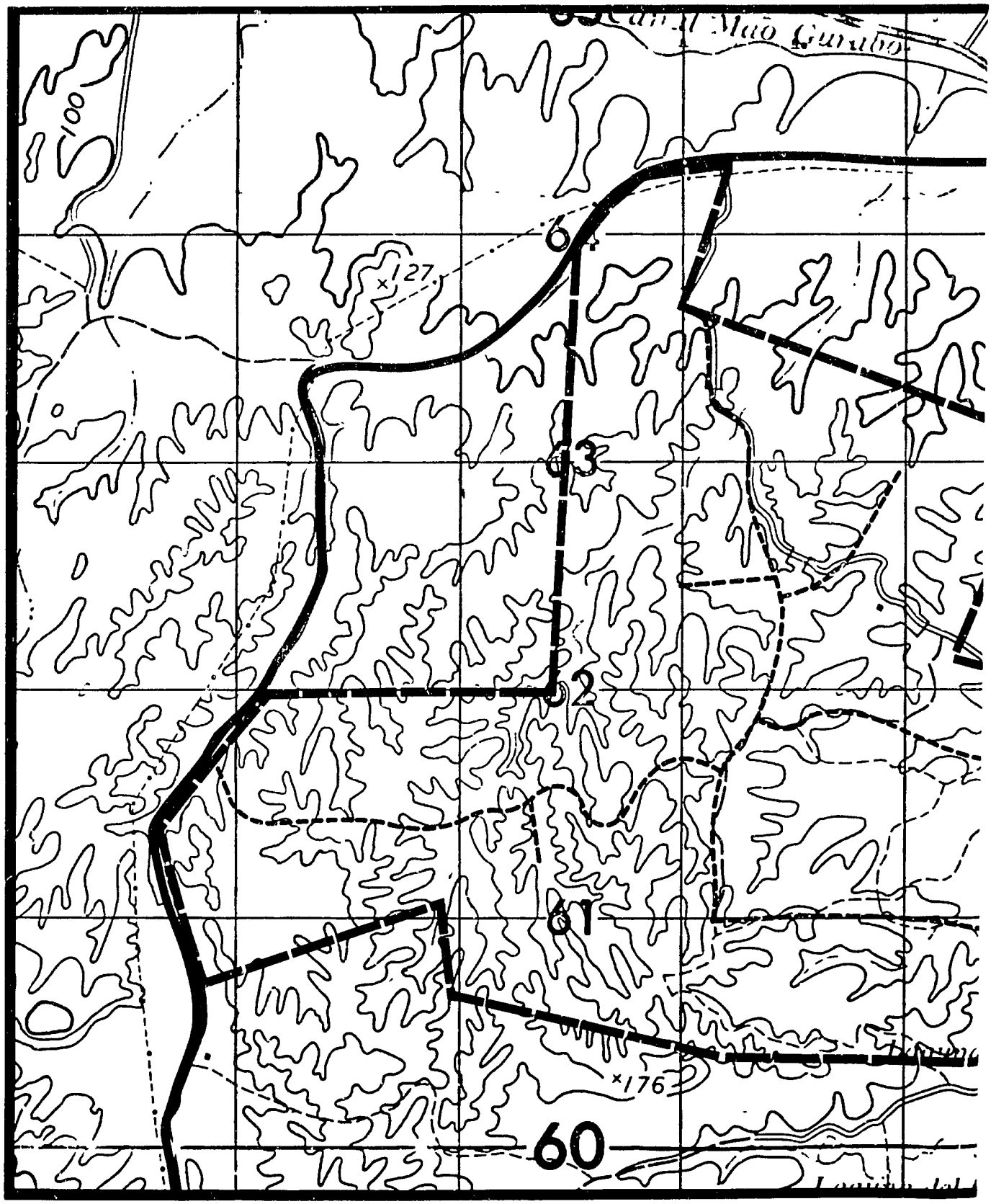
2. ISA is located nearby and can conveniently manage a research, development and demonstration operation.

3. The whole site is under one ownership (ISA), and that owner is predisposed favorably to the prospects of an energy farm.

4. Labor to operate the farm is located in abundance in and near the village of Mao.

5. There is good highway access to the site.

This site is depicted in Figure 4, which is a topographic projection of the area showing the property lines of the land and a part of the city of Mao. All of the site cannot be used to demonstrate


100
×127
64
63
62
61
×176
60

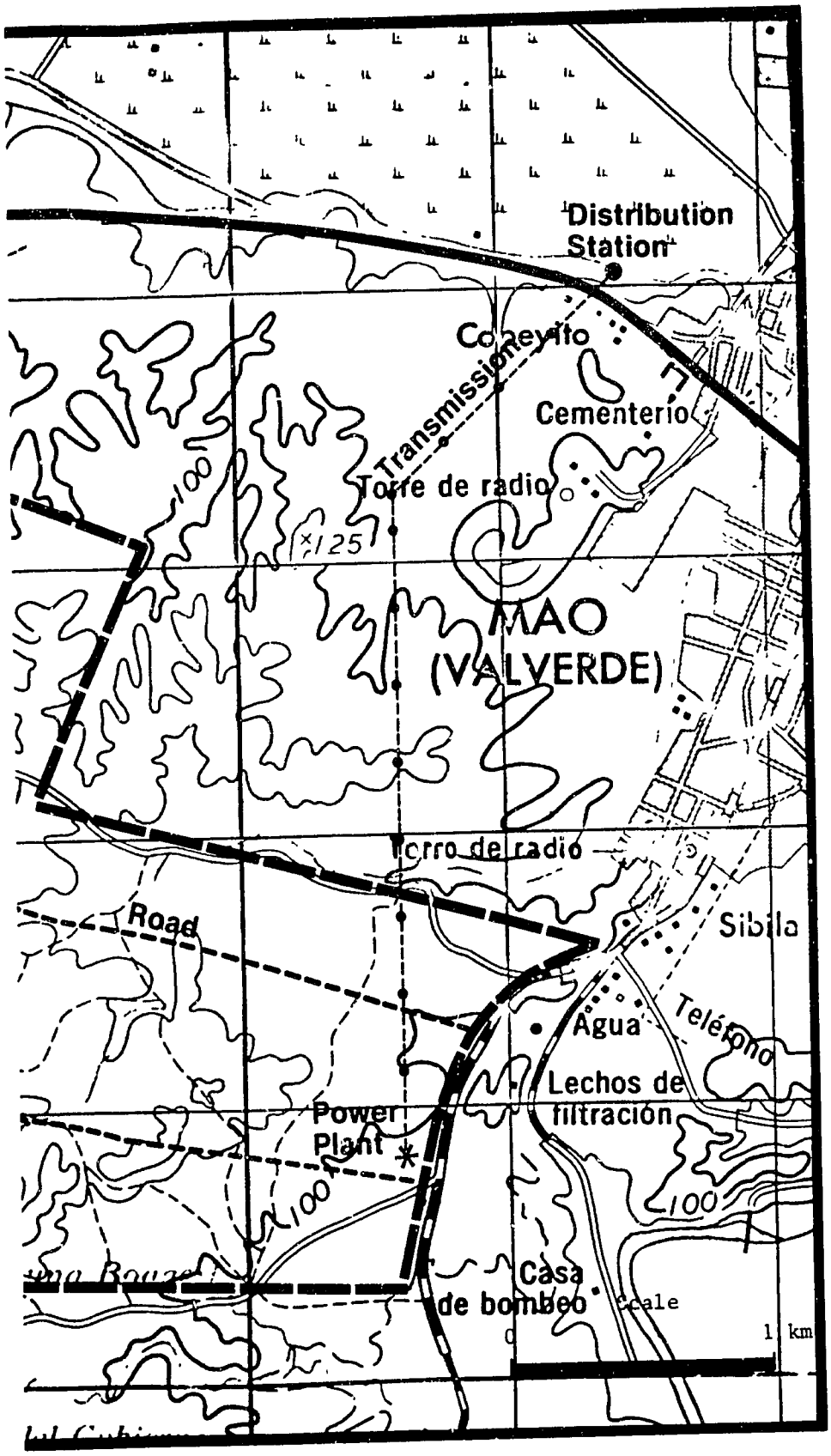


FIGURE 4
ISA DEMONSTRATION SI

energy farming, because ISA would like to use some of the more productive land for other experimentation. The potential demonstration area is delineated by a bold, dashed line.

If the site were to be used to demonstrate energy farming concepts, the species grown could also be very well adapted to marketing for charcoal production. This project would integrate well with ISA's interest in promoting the use of more efficient charcoal kilns.

In order to illustrate an application of the energy farm concept in the dry forest area, this ISA site will be considered typical, and an energy farm will be designed to its conditions. This design, although done for only 16,250 tareas (see Figure 4, the area within the heavy dashed line) is virtually scale independent in respect to establishment, tending and harvesting methods. Thus, the design could be applied to larger or smaller areas of land. Only the chipping, transporting and energy conversion methods are scale dependent.

3.1.2 Establishment and Operations Plan

3.1.2.1 The Concept and the Reality. Energy farming is, at present, a concept, although several pilot facility designs have been performed. The energy farm concept has been described, often with great detail,[14] as a very large scale, highly mechanized operation requiring large inputs of energy and money. Such operations depend on intensive management to obtain optimum growing conditions. Requirements include fertilization, irrigation, use of pesticides and

herbicides. The land must be topographically regular enough to permit mechanized establishment, tending and harvesting.

The characteristics of the dry forest area would prohibit it from being considered as an energy farm candidate if the conventional concept standards were to be applied. Yearly rainfall of as low as 600mm concentrated in two periods of the year for a total of 4-5 months precludes the high growth rates currently conceived. Conventional irrigation in so rugged (topographically) an area would be difficult, although a trickle irrigation system (perhaps solar-powered) should be investigated. Mechanical cultivation of the slopes of the ISA site could contribute to further erosion.

In a country with high rural unemployment and relatively low labor rates, a high degree of mechanization would be uneconomical. Mechanized equipment is also probably unsuited to the land form irregularities. Fertilizer is expensive and energy intensive - helping defeat the goal of using energy farms to offset the high cost of imported energy. Clearly, if the Dominican Republic is to employ energy farming techniques, it should consider approaches different from the conceptual farms heretofore envisaged. Instead of designing an energy farm to maximize biomass production, the dry forest energy farm will be designed to produce biomass with the following objectives.

1. Minimize the cost of production.

2. Utilize rural labor and local production methods as much as is practicable.

3. Minimize the use of imported energy.

3.1.2.2 Elements of the Plan. The proposed plan for an energy farm at the ISA site is based on the following assumptions.

1. Planting and tending will be accomplished with hand tools - machetes, etc.

2. Harvesting will be done by labor intensive methods, similar to the way that fuelwood is cut for charcoal production.

3. Harvested trees will be forwarded to the road's edge via animal power - either mule or oxen.

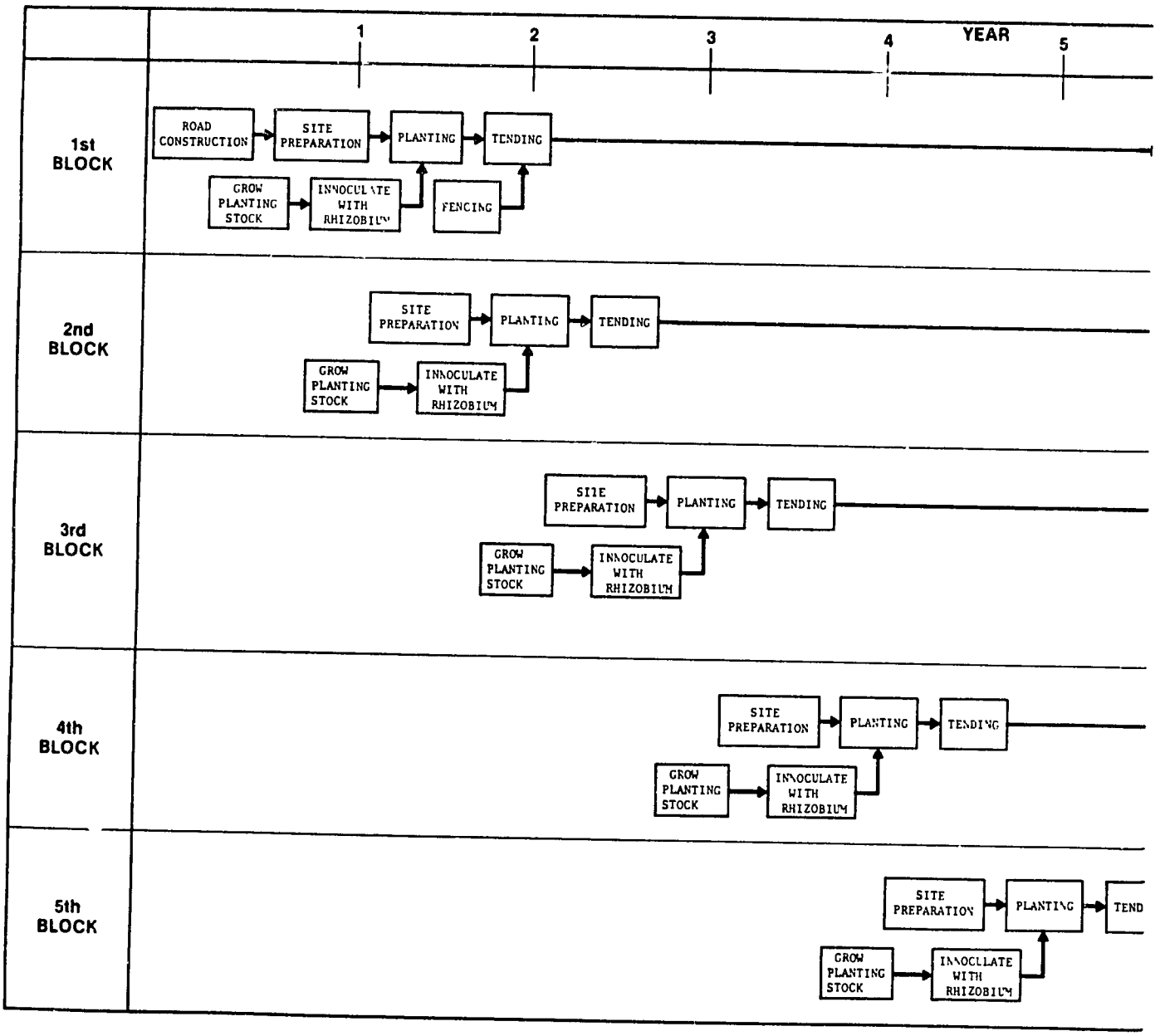
4. Trees will be converted to a feedstock suitable for boiler fuel by using an industrial tree chipper.

5. Trucks will transport the chips to a generating site.

The diagram (Figure 5) shows the functional elements of the plan and the time in which they are expected to be accomplished. The repetitive nature of the elements--site preparation, planting, tending, and harvesting indicate that the crop is expected to mature in five years.* Therefore, every year for the first five years, one fifth of the land area must be prepared and planted. The sixth year and every year thereafter, one of the areas can be harvested.

Road construction should be accomplished first to aid access by the site preparation and planting team. The road system is located so that most of the trees are less than 600 meters from the road, an

*Rotation age is chosen on the basis of expected optimum harvesting efficiency for manual logging. Trees no larger on the average than 18 cm in diameter at the stump and about 7 m in height are expected in five years.


YEAR
1
2
3
4
5
1st BLOCK
ROAD CONSTRUCTION
SITE PREPARATION
PLANTING
TENDING
GROW PLANTING STOCK
INNOCULATE WITH RHIZOBIUM
FENCING
2nd BLOCK
SITE PREPARATION
PLANTING
TENDING
GROW PLANTING STOCK
INNOCULATE WITH RHIZOBIUM
3rd BLOCK
SITE PREPARATION
PLANTING
TENDING
GROW PLANTING STOCK
INNOCULATE WITH RHIZOBIUM
4th BLOCK
SITE PREPARATION
PLANTING
TENDING
GROW PLANTING STOCK
INNOCULATE WITH RHIZOBIUM
5th BLOCK
SITE PREPARATION
PLANTING
GROW PLANTING STOCK
INNOCULATE WITH RHIZOBIUM

28

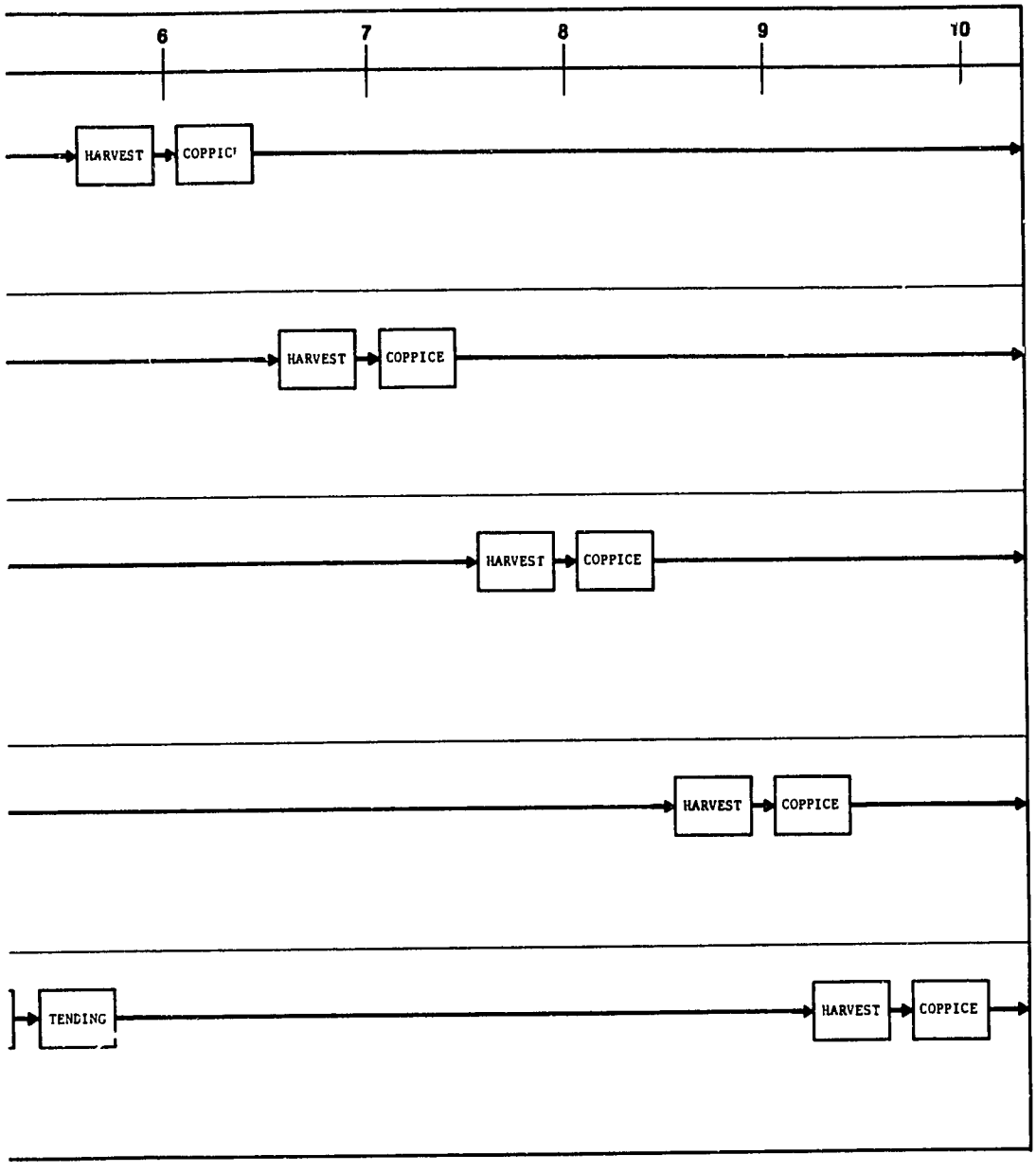


FIGURE 5
PLANTATION ESTABLISHMEI

economical distance to skid with a mule or an ox. The road is designed for passage by the chipper and large chip-carrying trucks. To save cost, paving is not recommended. Care was taken to locate the five-meter-wide roads on the hilltops where soil is thin and tree production low. This location also facilitates construction by requiring few side cuts and the attendant loss of productive land.

Fencing is necessary to protect the trees from destruction by goats and fuelwood cutters. Approximately 18 kilometers of fencing and three gates are required for complete enclosure. Traditional barbed wire and post construction is recommended.

Site preparation is necessary to eliminate competition for sun and moisture. There are three methods proposed; each method being a function of the severity of slope.

1. Long, steep slopes (25% of site) - allow the trees large enough for charcoal or fuelwood production to be cut and require that the branches be piled in the gullies; clear by machete (chapeo) all other vegetation and pile in gullies for erosion control.

2. Irregular short slopes (60% of site) - allow fuelwood to be cut but leave enough trees and brush to be cut and scattered, covering the ground well. Burn this brushy residue to clear the site of vegetation and seeds as much as possible and discourage sprouting.

3. Nearly flat, cultivable soils (15% of site) - clear the vegetation using the method for irregular, short slopes. Land can then be plowed on the contour just before planting.

Accompanying site preparation is the clearing of a firebreak all around the property for a width of six meters. This is done by cutting brush and pulling it away from the firebreak. This area may be

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plowed to prevent fire traveling across the break. Site preparation is best done during the dry season just before the rains in May/June.

One of the species that appears to be ideally suited for the dry forest area and has the fast growing character needed for efficient biomass production is the K-8 type of Leucaena.* Leucaena occurs naturally in the local area; therefore, the K-8 type is expected to be well adapted to local conditions. In order to avoid the problem of dependance on one tree species for success, at least one other species should be chosen. Prosopis and Acacia* are well adapted and fast growing species that have been identified. Both of these trees have the added advantage of nitrogen fixation. For areas bordering on 1000 mm of annual rainfall, Casuarina* and Calliandra* may be used as well.

Planting may best be accomplished using planting stock grown in large, polyethylene containers at a nursery on the eastern part of the site near a water supply. Seedlings can be grown in these containers for six months before outplanting. The inoculation of the containers with the Rhizobium needed for nitrogen fixation can be accomplished at the nursery. Trucks will be used to carry trays of 100 containers close to the planting site. Mules can carry two trays each of these containers from the road's edge to the planting location.

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*See Development Plan (Appendix B) for further information about these and other species.

Planting can be done in two-man teams - one man to select the microsite and dig holes, the other to plant the tree and fill in the hole. About five percent of the area will not be planted due to inadequate soil conditions.* The spacing of plants about one meter by one meter will allow access for tending and not induce undue competition for soil moisture between trees. For Leucaena, it may be important to maintain close spacing to minimize the production of low branches. This concentration of growth makes tending, harvesting and transport more efficient.

Tending is a function of slope, similar to site preparation. Since moisture is severely limited, it is necessary to minimize the root competition for moisture and nutrients. Recommendations on tending based on slope are:

1. Long and short slopes (85% of site) - for the first six months after planting, cut (chapeo) the aerial portion of competing sprout vegetation to the ground every two months and cut again at one year.

2. Nearly flat, cultivable soils (15% of site) - use a machete to cut (desherbe) competing vegetation out, root portion too, for the first six months after establishment and cut again at one year.

The harvesting will be done in each area five years after planting, on a rotating basis. It will take a shorter time after the first cycle when the root system is already established and the production period may be shortened to four years. Trees growing in the valleys and flat land (where nutrient-laden soil has not eroded away) will

*An estimated 1% of the area is devoted to roads.

grow faster than the trees at the tops of the slopes, so adjustments in harvesting schedules will have to be made on the basis of tree growth.

The harvesting system envisaged for the energy farm is composed of: (1) cutters using axes to fell trees with a diameter less than 18 centimeters at coppice level; (2) teamsters with oxen or mules to skid trees to a pile at the road's edge (oxcart wheels and axle may be used as a sulky to keep the butts of the trees off the ground); (3) a chipper, powered with a diesel engine to process the tree stems and branches to fuel size at the road's edge; and (4) trucks with van bodies to carry the chips blown into the vans to the generating plant.

Except for the occasions when rain is intense, no reason is seen to restrict harvesting to a given season. There may be an ideal season for initial coppice growth (probably when soil moisture is high), but no information to corroborate this was found.

3.1.2.3 Estimated Production Rates and Costs. In order to determine the profitability of this energy farm concept, production rates of the elements previously described were estimated, and costs of labor, supervision and equipment were determined. Table III identifies the production rates and costs of establishment and harvesting. Table IV calculates the manpower needed to produce the feedstock. Please note that these methods, production rates and costs have been estimated by discussion with foresters within the D.R.

TABLE III

COST COMPONENTS OF ENERGY FARMING

Element	Year(s)	Productive Rate Cost Rate	Cost/Tarea	Applicable Tareas	Total Cost/Yr.	Average Cost Per Tarea/Yr.	Total Cost Discounted To First Year
Site Preparation							
Method 1	0,1,2,3,4	1 tarea/day/worker @ 5 pesos/day 1 foreman/20 workers @ 6 pesos/day	5.30	4062 (1/5th)	4306		
Method 2	0,1,2,3,4	1½ tarea/day/worker @ 5 pesos/day 1 foreman/20 workers @ 6 pesos/day	3.53	9750 (1/5th)	6884		
Method 3	0,1,2,3,4	1½ tarea/day/clearer @ 5 pesos/day 1 foreman for 20 clearers @ 6 pesos/day	3.53	2438 (1/5th)	1721	4.62	
		1½ tareas/day/2 man plowing team 1 foreman for 30 workers 5 pesos/day/worker 6 pesos/day/teamster 1.5 pesos/day/ox 6 pesos/day/foreman	4.30	2438 (1/5th)	2097		
Road Construction 13 kilometers	0 1-20	5000 pesos/km (construction) 1000 pesos/km (maintenance)	0.06	16,250 16,250	65,000 1000		65,000
Fence Construction 18 kilometers	1	180 pesos/km	0.20	16,250			3,240
Planting							
Planting Stock	1,2,3,4,5	589 trees/tarea @ 5¢/tree	29.45	3250	95,712		
Planting Operation	1,2,3,4,5						
Transport Truck		1000 trees/trip (6 kilometers) @ 80¢/kilometer	2.82	3250	9,165	46.57	
Mule		200 trees/trip @ 8 trips/day @ 3 pesos/day	1.11	3250	3,607		
Planting	1,2,3,4,5	500 trees/2 man team/day @ 5 pesos/manday 1 foreman for 5 teams @ 6 pesos/manday	3.19	3250	42,868		
Tending							
Method 1	1,2,3,4,5	5 tareas/manday @ 5 pesos/manday 1 foreman/10 men @ 6 pesos/manday	1.12	4062 (1/5th)	910		
Method 2	1,2,3,4,5	5 tareas/manday @ 5 pesos/manday 1 foreman/10 men @ 6 pesos/manday	1.12	9750 (1/5th)	2184	1.16	
Method 3	1,2,3,4,5	4 tareas/man day @ 5 pesos/manday 1 foreman/10 men @ 6 pesos/manday	1.40	2438 (1/5th)	683		
Harvesting Cutting	6-30	4 tons/manday @ 5 pesos/manday 8 tons/man-ox day @ 8 pesos/man-ox day 1 foreman/10 men @ 6 pesos/manday	1.50	3250	4875	1.50	

TABLE IV

MANPOWER NEEDED FOR 50 MW ENERGY FARM (1,257,000 Tareas)

Production Element	Year										
	1	2	3	4	5	6	7	8	9	...	30
Site Preparation[1]	4,998	4,998	4,998	4,998	4,998						
Planting[1]	15,196	15,196	15,196	15,196	15,196						
Tending[2]		522	1,043	1,043	1,043	1,043	1,043	1,043	1,043	...	522
Harvesting[3]						165	165	165	165	...	165
TOTAL	20,194	20,716	21,237	21,237	21,237	1,208	1,208	1,208	1,208		687
Total (Adjusted to 220 day year)[4]	4,590	4,851	4,976	4,976	4,976	586	586	586	586		343

[1]Seasonal employment - number of workers, each employed 50 days/year.

[2]Seasonal employment - number of workers, each employed 110 days/year.

[3]Full time employment - number of workers, each employed 220 days/year.

[4]Total worker years needed each year to perform all functions (number of workers X days worked ÷ 220 days).

Forestry Agency and with the ISA staff.* A thorough investigation of the available areas delineated in Section 2 should be made, and preliminary tests of methods, species and treatments are suggested in Appendix B of this report.

Note that the Mao site of 16,250 tareas would produce 4,893 GTE/year using the 5 cubic meters/hectare-year productivity estimate from Reference 11. If a power plant were to be constructed at the Mao site, a 269 kilowatt unit operating at 10 percent efficiency would match this annual biomass production. However, the analysis in Section 5.0 shows that units in the 2 to 5 MW range are the smallest economically feasible wood fired units for delivering electricity to the national grid. Approximately 6.1 Mao sites would need to be aggregated to form a biomass farm to serve a 2 MW conversion facility operating at 12 percent efficiency.

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*Mr. Ramon Rodriguez and Mr. Alberto Rodriguez, respectively.

4.0 CONVERSION OPTIONS AND COST ESTIMATES

In this section, the various conversion options for generating electricity are described, and one option is chosen for the conceptual design for which the costs are estimated.

4.1 Conversion Alternatives*

4.1.1 Conventional Systems

Conventional wood to electric generation uses direct combustion of wood in boilers which produce superheated steam to drive turbine generators. There are a number of designs for wood-fired boiler systems. The simplest (and oldest) designs are pile burners. Figure 6 illustrates a typical pile burning "dutch-oven" system. Dutch oven systems are usually installed today to dispose of very wet unsized bark where stack emissions are of major concern.

In a pile burner, wood is fed onto a pile either from the top or from the floor of the combustion chamber. Gasification and burning occurs on the surface of the pile. Gases pass into the boiler where combustion and heat transfer is completed.

A modification of a pile burner is a semi-pile combustion system. The most common semi-pile system seen in North America is an inclined grate system. Wood fuel is fed to the top of a sloped grate, 55 degrees from the horizontal. Wood drying occurs at the top of the grate. As the fuel slides down the grate, it is initially

*This section is based on references (19), (20), (21), (22), and (23).

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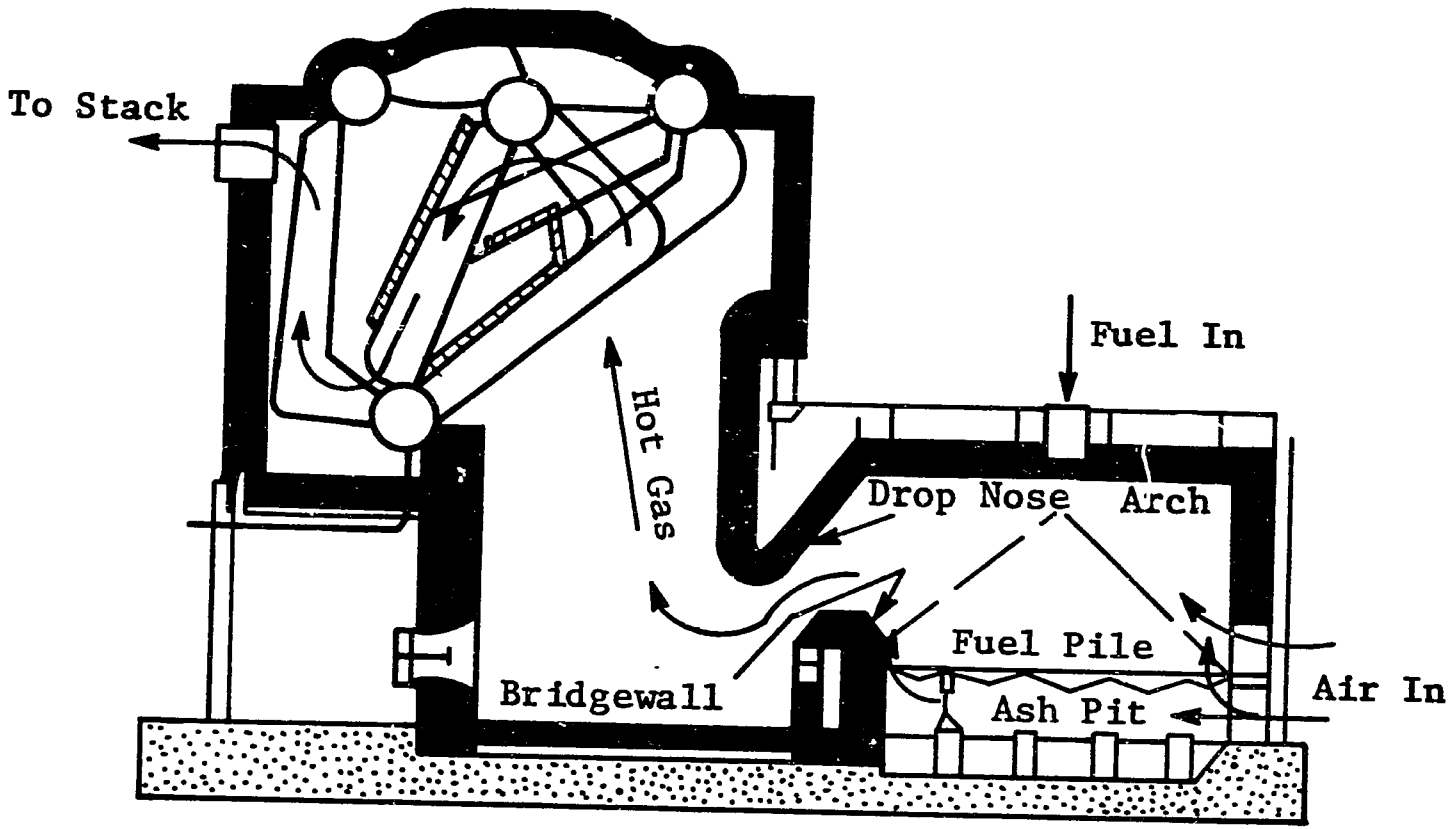


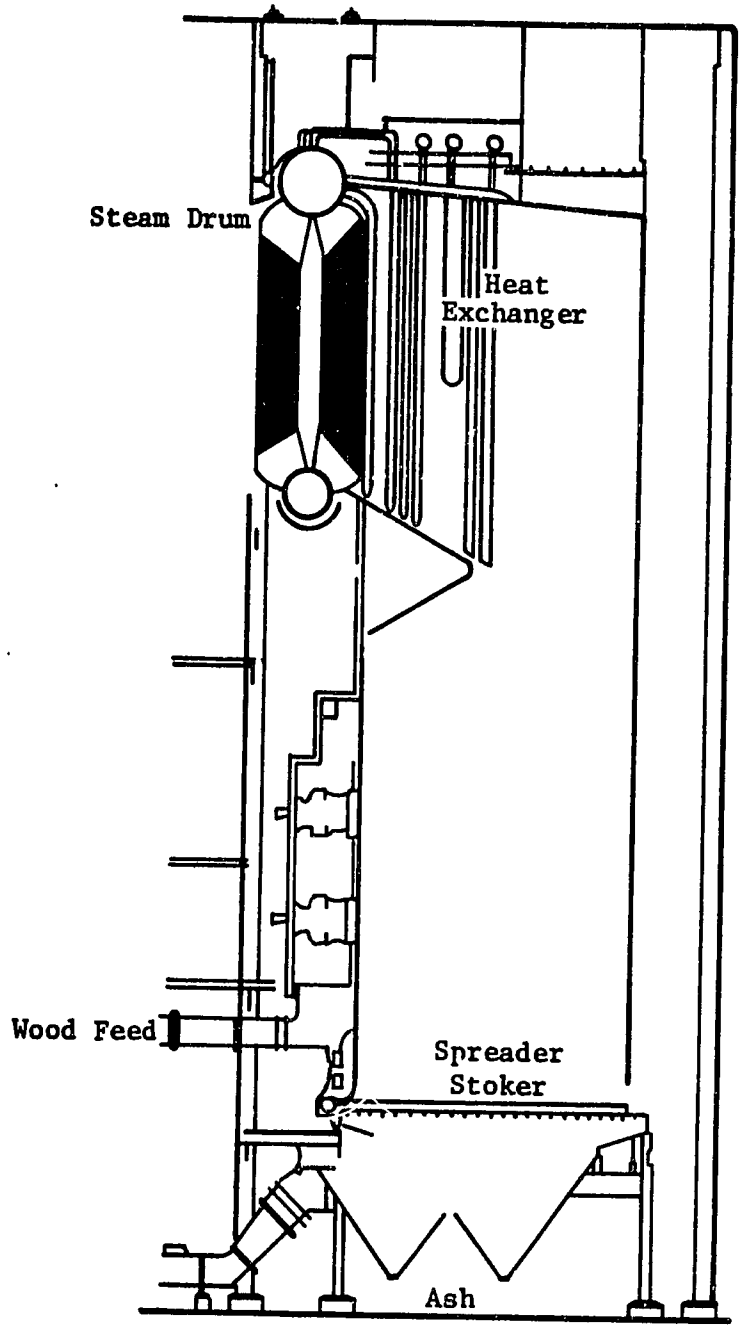
FIGURE 6
TWO-STAGE DUTCH OVEN FURNACE

dried, then volatiles are distilled off, and finally the wood is completely burned as it reaches the flat portion of the grate surface. Again semipile combustion systems are effective for wet wood fuels.

Semi-suspension wood firing systems are more common for electric power systems and for uniform dimension fuel such as wood chips. Wood fuel is usually pneumatically blown into the combustion chamber. Initial combustion occurs as the fuel falls through the upward flowing hot gases. Combustion is completed on water-cooled traveling or vibrating grates. Ash residues are disposed of continuously by the automatic grate system.

Figure 7 describes a typical semi-suspension firing system. Advantages of semi-suspension systems are rapid response to load changes and the ability to burn multiple fuels. If needed, wood fuel can be supplemented with coal with only minor modifications to the fuel feed systems. Operating knowledge of semi-suspension firing systems is sound. The technology is well developed.

Fluidized bed boiler systems have recently been introduced for wood combustion. Fluidized bed boilers consist of a perforated air-distribution plate at the base of the combustion unit, a cylindrical refractory lined furnace containing ports for fuel entry, and a hot gas outlet at the top of the unit. Combustion air is blown up through wood fuel, and an inert material such as sand forms a turbulent fluid-like mixture where combustion takes place. Combustion in



Source: Foster Wheeler, Ltd., Bulletin C76, St. Catherines, Ontario, Canada.

FIGURE 7
TYPICAL MODERN WOOD/BARK FUEL WATER TUBE STEAM GENERATOR (350,000 LBS/HR STEAM)

a fluidized bed unit is very rapid and complete. With very dry fuel however, it is expected that combustion temperatures will likely exceed slagging limits without very high levels of excess air. The alternative to this is the installation of cooling coils in the bed as is done in coal-fired fluidized bed units. Fluidized bed units available today do not have this capability as of yet. Although fluidized bed wood combustion appears to be promising, the technology has not been sufficiently tested to recommend it definitely for the case at hand in the Dominican Republic.

4.1.2 Non-conventional Systems

Non-conventional wood combustion systems consist of pyrolysis, gasification, and densification technologies. We briefly discuss these options here and their applicability to the energy farm option for the Dominican Republic.

Pyrolysis units use wood fuel to produce a combined product of gas, liquid, and solid fuels. Wood is burned in the absence of oxygen. The heat generated gasifies some of the remaining wood to a low Btu gas. Some of the volatiles, also driven off by the heat, are condensed into liquid fuel. Finally, the solid residue left at the bottom of the pyrolysis unit is char, more commonly called charcoal. The relative quantities of each of these fuel products are dependent primarily on the temperature of the combustion process. The higher the temperature, the more gaseous product will be generated.

The gas and liquid products of wood pyrolysis can be burned in boilers. This process is usually considered for existing gas or oil-fired boilers for which there is a need to convert to solid fuels. Retrofit of gas or oil boilers to direct wood firing is very expensive. The use of the gaseous and liquid products of pyrolysis can minimize the boiler retrofit requirements.

Pyrolysis gases can also be used to fire gas turbines. The serious difficulty here is the need to clean the product gas sufficiently to prevent fouling and degradation of turbine blades.

Gasification of wood differs from pyrolysis simply in the fact that gasification temperatures are sufficiently high to yield only a gaseous product. Again the process is very similar to that described for pyrolysis. Wood gasifiers were quite common prior to the introduction of inexpensive petroleum fuels in the 1920's.

The low Btu gas (100-200 Btu/scf) produced from a gasifier can be burned in a boiler, or, when properly cleaned, in gas turbines.

Densification of wood has been effective in cases where wood fuel is very wet and where boiler fuel needs to be very clean. Wood is heated, dried, and extruded into small pellet form. This product is dry, clean, and provides 8500-9000 Btu/lb. The current cost of this product is, however, quite high--$25 to $40/ton. Because of the relatively dry and clean form of the wood product expected in the Dominican Republic, this option is not considered appropriate.

4.2 Selected Option for Conceptual Design

The technology selected for conversion of wood to electricity in the 2 to 50 MW range is a conventional semi-suspension boiler and steam turbine electric generation system. The steam-electric plant is located on or close to the biomass farm and preferably adjacent to a natural water supply. Electric transmission lines connect the plant to the Dominican national power grid.

The semi-suspension boiler system is selected because of its reliability, rapid response to load changes, simplicity of operation, and effectiveness in combustion of dry and uniform fuelwood.

Wood is delivered to the boiler plant in chipped form. This product is expected to be quite clean as a benefit of the manual harvesting and manual feeding of the dispersed chippers on the energy farm.*

Chipped wood is dumped either with automatic truck unloading equipment or with self-unloading trucks. Wood chips are either fed directly by mechanical conveyors to overhead feed hoppers to the boiler, or are moved to storage piles by front-end loaders. A concrete slab covers the entire storage area to prevent intrusion of rock and dirt into the fuel. Storage piles are located under high shed roofs for rain protection. The storage area will hold at least 30 days wood supply for continuous plant operation.

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*Conventional mecahnized harvesting systems tend to pick up some dirt and rock.

Wood from the feed hoppers slides down chutes to the boiler where air jets blow the chips into the boiler combustion chamber.

The semi-suspension boiler system will be field-erected at the site. In support of the main boiler will be a water make-up system, and an ash disposal system. Flue gases will be cleaned of most particulates with a cyclone-removal system. Ash from the cyclone will be deposited with the boiler ash for disposal.

Steam from the boiler drives a three-phase turbine generator connected to the power grid. Operation of the steam and power plant are directed from a control room containing adequate instrumentation and automation to guarantee grid quality electric supply.

Exhaust steam from the turbine passes to a water-cooled condensor before return to the boiler.

4.3 Conversion Costs

The costs of a wood-fired steam electric system as just described will vary significantly with size, with design philosophy,* and with site-specific conditions. In this section we give cost estimates for various size power plants, with uniform design philosophy.

The top of Table V presents capital and operating and maintenance (O/M) cost estimates for various sizes of a wood-fired steam electric conversion system. The estimates for capital and O/M costs

*Highly automated systems will have high capital costs.

TABLE V

COSTS OF WOOD AND OIL-FIRED ELECTRIC POWER PLANTS

	Size	Capital Cost ($)	Capital Cost/Kw ($/Kw)	Annual O/M Cost ($/yr.)	Annual O/M Cost/Kw ($/Kw/Yr.)
WOOD	50 MW	57,500,000	1150	4,600,000	92
	20 MW	27,600,000	1380	2,700,000	135
	5 MW	9,100,000	1820	1,200,000	240
	2 MW	4,400,000	2200	680,000	340
OIL	50 MW	50,000,000	1000	2,200,000	44
	20 MW	24,000,000	1200	1,300,000	65

Sources: (15), (16), and (17).

for 20 MW and smaller plant sizes have been obtained using an exponential scaling factor of 0.8 and 0.6 respectively.(16) Application of the 0.8 and 0.6 scaling factors for capital and O&M costs may be inappropriate in the small size ranges. Quotations from manufacturers would provide better estimates. In the less than 1 MW range, it is suggested that other alternatives for producing energy using wood such as pyrolysis units to generate producer gas and charcoal be examined in a thorough manner before choices are made. Through personal communications, the authors understand that a 200 kW wood-fired facility is being planned for implementation in Panama, a 1.5 to 3 MW facility is being planned in the Philippines, and the Central Planning Authority of Fiji is looking into various wood-fired conversion options in the several hundred kilowatt range and even smaller sizes.

As seen, the cost per installed kilowatt for the 20 MW facility is 20 percent higher than for the 50 MW facility. This shows that, unlike the biomass facility, there are significant capital cost economic-scale benefits for steam-fired systems. Savings are evident both in materials and in efficiencies for the larger systems.

O&M costs also show economy of scale benefits. A power plant requires a certain operating staff. These requirements only increase slightly with the size of the plant.

As seen, the annual O&M cost per kW of installed capacity for the 20 MW plant is 47 percent higher than for the 50 MW plant.

Table V concludes with cost estimates for 20 and 50 MW oil-fired facilities. The capital cost of the oil-fired units is approximately 15 percent less than the respective wood-fired units; the annual O&M costs of oil units are less than half those of the wood-fired units.

In Section 5.0 we use these figures in combination with the biomass farm costs to estimate the cost of electricity from a variety of power plant options.

5.0 ECONOMIC ANALYSIS

In this section the costs of generating electricity from dry forest energy farms in the Dominican Republic are analyzed and interpreted. For wood-fired systems, the three categories of costs are: the cost of the biomass including the use of the land, the planting, tilling, and harvesting of the wood; the cost of chipping and transporting the wood to the electric generation plant; and finally the costs of conversion of the wood fuel into electricity. Transmission and distribution costs are site-specific and thus not included here. These costs have been calculated for four sizes of plants: 50 MW, 20 MW, 5 MW and 2 MW. The size of the biomass farm in each case is scaled to match electric generation plant capacity assuming a fixed productivity for the land.

The cost of electricity from each of these biomass-to-electricity facilities is compared with the cost of electricity from 20 MW and 50 MW oil-fired boiler systems. The cost components of the oil-fired systems are: capital, operating and maintenance, and fuel. To assure accuracy in comparison, the oil-fired facilities are costed as new facilities with identical start-up times to that of the biomass-fired plants.

Finally, electricity costs are compared for three 2 MW biomass facilities under the assumptions of various levels of biomass productivity.

Details on all cost calculations are presented in Appendix A.

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5.1 Assumptions

Table VI summarizes the major assumptions used in the cost analysis. Of significance is the low wood moisture content (30 percent).[18] Dry wood permits higher heater efficiencies and hence lower electricity costs. These boiler efficiencies are presented in the next sub-section.

To determine the cost of electricity from an energy farm, electric generation facility, all costs are converted to Dominican pesos, inflated by 9 percent/year to the year in which monies are spent, and then discounted at 12 percent/year to the electric plant start up year. In addition, oil costs escalate at 2 percent/year above inflation.* The price of electricity is today's price in 1980 Dominican pesos which when inflated and discounted annually over the operating life of the facility, will exactly cover all capital and operating expenses. For simplicity, no provision is made in any of the costs, biomass or oil, for depreciation. Taxes are not expected and have not been considered in the analysis.

5.2 Electricity Costs for Wood- and Oil-fired Systems

Tables VII and VIII present the design parameters for biomass-fired and oil-fired facilities, respectively.

Capital and operating costs for the biomass portion of the wood-fired facility are taken from Table III of Section 3.1. Capital

*Conservative estimate based on author judgment; higher escalation rates make biomass options more attractive.

TABLE VI

ASSUMPTIONS FOR THE ANALYSIS

Biomass	
Wood Moisture	30 percent
Wood Specific Gravity	.8-1.0
Productivity: Low	5 cu. meter/hectare-yr
Medium	10 cu. meter/hectare-yr
High	20 cu. meter/hectare-yr
Dry Wood Energy Content	17×10^6 Btu/ton
Electric Generation Plant	
Load factor when operating	.8
Annual days of operation	330 days
Financial	
Discount rate/capital cost	12 percent/yr
Inflation rate	9 percent/yr
Exchange rate	1.25 pesos/dollar
Oil	
Cost of residual oil	35 $/barrel
Escalation rate (constant dollar)	2 percent/yr
Residual oil energy content	6.3×10^6 Btu/barrel

TABLE VII

DESIGN PARAMETERS FOR WOOD-FIRED SYSTEMS*

	50 MW	20 MW	5 MW	2 MW
Wood Systems				
Land area (tareas)	1,257,000	549,000	168,000	101,000
Biomass Productivity (GTE/tarea-yr)	0.3203	0.3203	0.3203	0.3203
Biomass Production (GTE/yr) (assumes .94 land utilization)	379,000	165,000	50,500	30,300
Average Biomass Transportation Distance (km)	20	15	5	3
Conversion Plant Efficiency**	.24	.22	.18	.12
Electricity Output (kWH/yr)	3.168×10^8	1.267×10^8	3.168×10^7	1.267×10^7

*See Appendix A for derivations of numbers in this table.

**Steam turbines are expected to operate in the neighborhood of 700°F and 650 psia for the larger plants and 500°F and 350 psia for the smaller. Efficiency estimates based on MITRE engineering judgment and discussions with wood-fired boiler manufacturers.

TABLE VIII

DESIGN PARAMETERS OF OIL-FIRED SYSTEMS

	50 MW	20 MW
Oil Systems		
Conversion Plant Efficiency	.32	.31
Oil Consumption (barrels/yr)	536,000	221,000
Electricity Output	3.168×10^8	1.267×10^8

costs consist of all costs prior to electricity production and include land preparation, planting and tilling. Operating costs are those costs occurring after electric plant start-up.

Transportation costs are based on a fixed charge for equipment and linear costs as a function of distance. The average one-way distance for the 50 MW facility is 20 km. For the 20 MW facility the distance is 15 km. In addition to inflation, transportation costs are escalated at 1 percent/year to account for the fraction of increased petroleum fuel costs.

Table IX presents the estimated costs of electricity from various sizes of biomass-fueled plants. Notice that total cost of electricity from a 2 MW facility is nearly twice that from a 20 MW or 50 MW facility. This primarily reflects the lower conversion efficiency and the increased cost per unit output at the smaller plant sizes. Notice also that the biomass production and biomass transportation vary only slightly with change in facility size. The major change is in the per unit electrical conversion costs which nearly triple for a 2 MW facility, as compared to a 50 MW facility.

Table X presents the comparative costs of biomass-fueled and oil-fueled plants. The estimated costs of electricity from 20 MW and 50 MW oil-fired facilities are approximately twice that from identical sized biomass-fueled facilities. A more meaningful comparison is that of costs from the 2 and 5 MW biomass-fueled facilities (10.06

TABLE IX

COSTS OF ELECTRICITY FROM BIOMASS-FUELED PLANTS

SIZE OF PLANT	COST COMPONENTS IN CENTAVOS/kWhr			
	BIOMASS PRODUCTION	BIOMASS TRANSPORTATION	CONVERSION TO ELECTRICITY	TOTAL GENERATION COST OF ELECTRICITY
50 MW	1.96	0.64	3.08	5.68
20 MW	2.14	0.65	4.18	6.97
5 MW	2.62	0.70	6.74	10.06
2 MW	3.94	0.99	9.13	14.06

TABLE X

COMPARATIVE COSTS OF ELECTRICITY FROM BIOMASS-FUELED AND OIL-FIRED FACILITIES

	COST IN CENTAVOS/kWhr							
	WOOD-FIRED				OIL-FIRED			
SIZE OF PLANT	BIOMASS PRODUCTION	TRANSPORTATION	CONVERSION	TOTAL	CAPITAL	O&M	FUEL	TOTAL
50 MW	1.96	0.64	3.08	5.68	1.1	0.9	10.4	12.4
20 MW	2.14	0.65	4.18	6.97	1.3	1.3	10.7	13.3
5 MW	2.62	0.70	6.74	10.06				
2 MW	3.94	0.99	9.13	14.06				

and 14.06 centavos/kWh) with a 50 MW oil-fired facility (12.4 centavos/kWh). Thus, it may be concluded that small (2 to 5 MW) biomass-fueled facilities are roughly in the same range of economics as typical oil-fired (50 MW) facilities in the Dominican Republic. An examination of the three cost components of oil-fired facilities provides further insights. Fuel constitutes 80-84% of the total costs of electricity from oil-fired facilities.

5.3 Effects of Land Productivity on Cost of Electricity

Table XI presents costs of electricity (and its components) from a 2 MW plant assuming 5, 10 and 20 cubic meters/hectare-year of biomass fuel productivity. The transportation costs have been kept constant. Notice that fuel costs have an inverse relationship to land productivity rates. However, since conversion costs constitute so large a fraction of the total costs, productivity has a small effect on total cost.

5.4 Savings of Imported Oil*

A 50 MW oil-fired electricity plant would consume about 536,000 barrels of residual oil each year to generate 3.168×10^8 kWh of electricity. At $35 per barrel this corresponds to about 23.5 million pesos per year. The corresponding biomass facility will likely use about one million pesos per year for imported fuel for chipping and transportation equipment. The difference gives an import savings

*Results presented in this section are based on calculations presented in Appendix A.

TABLE XI

EFFECT OF LAND PRODUCTIVITY ON COST OF ELECTRICITY
(for 2 MW System)

PRODUCTIVITY (cu. meters/ hectare-year)	COST IN CENTAVOS/KwHR			
	WOOD PRODUCTION	TRANSPORTATION	CONVERSION	TOTAL BUSBAR COSTS
5 (Low)	3.94	0.99	9.13	14.06
10 (Med)	1.89	0.99	9.13	12.01
20 (High)	1.06	0.99	9.13	11.18

of approximately 22.5 million pesos per year. On a life-cycle basis, assuming fuel cost increases, this increases to 31.7 million pesos per year in 1980 monetary values.

Using the estimate of 8.6×10^{16} joules of oil consumed in the Dominican Republic in 1977, the oil savings for a 50 MW biomass-fueled facility of 3.6×10^{15} joules is approximately four percent of that year's total petroleum use. Smaller size biomass-fueled facilities will result in proportionately less oil savings.

APPENDIX A

ECONOMIC ANALYSIS

This appendix contains the details of the cost calculations performed for the economic analysis presented in Section 5.0.

The analysis is broken down according to the following:

Wood Fired Systems

- Biomass Farm Development Costs

- Low Productivity Systems
  - 50 MW Facility Analysis
  - 20 MW Facility Analysis
  - 5 MW Facility Analysis
  - 2 MW Facility Analysis

- Medium Productivity Systems
  - 2 MW Facility Analysis

- High Productivity Systems
  - 2 MW Facility Analysis

Oil Fired Systems

- Fuel Costs
- Cost of Electricity Calculations for 50 MW Facility
- Cost of Electricity Calculations for 20 MW Facility

WOOD FIRED SYSTEMS

BIOMASS FARM DEVELOPMENT COSTS FOR MAO SITE

See Table A-1.

LOW PRODUCTIVITY SYSTEMS

Productivity: 5 cu. meter/hectare-year

≈.3203 GTE*/tarea-year

50 MW FACILITY ANALYSIS

Land Requirements

Load Factor = .8

Operating days/year = 330

Plant efficiency for 30% moisture wood = .24 (14221 Btu/KWH)

Fraction of land utilized for wood production = .94

Dry wood energy content = 17×10^6 Btu/ton

50 MW x .8 = 40,000 KW = 40,000 KWH/H

40,000 KWH/H x 24 H/day = 960,000 KWH/day

960,000 KWH/day x 14221 Btu/KWH = 1.365216×10^{10} Btu/day

1.365216×10^{10} Btu/day/ 17×10^6 Btu dry ton = 803.07 dry tons/day

803.07 dry tons/day/ .7 dry tons/GTE = 1147.24 GTE/day

1147.24 GTE/day x 330 days/yr = 378589 GTE/yr

378589 GTE/yr/ .3203 GTE/tarea-yr = 1,181,984 tareas

1,181,984 tareas/.94 = 1,257,429≈1,257,000 tareas

*GTE = Green Ton Equivalents.

TABLE A-1

BIOMASS FARM DEVELOPMENT COSTS FOR MAO SITE (16250 tareas):
(Pesos)

	Year* 0	1	2	3	4	5	6	7	---	---
Site Preparation	15008	15008	15008	15008	15008	---	---	---	---	---
Road Construction	65000	1000	1000	1000	1000	1000	1000	1000	...	...
Fence Construction		3240	---	---	---	---	---	---	---	---
Land Rental	8125	8125	8125	8125	8125	3125	8125	8125	...	...
Planting	---	151352	151352	151352	151352	151352	---	---	---	---
Tending		3777	7554	7554	7554	7554	7554	7554	---	---
Harvesting							4875**	4875	...	...
	88133	182502	183039	183039	183039	38031	21554	21554	...	...
x $(1.09)^{i}$	88133	198927	217469	237041	258374	258536				
x $(1.12)^{5-i}$	155320	313015	305528	297344	289379	258536				

1619122 = Total capital costs discounted to plant start up year

*Money's transacted at end of year

**Assumes productivity of 5 cu meters/hectare-yr. This figure is doubled for each doubling of productivity.

Annual Electricity Output:

50 MW X 1000 KW/MW X .8 X 24 hr/day X 330 days/yr. = 3.168×10^8 kwh/yr.

Biomass Farm Costs Discounted to Plant Start-Up Year:

$$\sum_{i=0}^{5} \text{costs}_i \, (1.09)^i \, (1.12)^{5-i} = 1619122 \text{ pesos (Mao Site)}$$

to scale to 50 MW:

$1{,}619{,}122 \times 1{,}257{,}000/16250 = 1.25245 \times 10^8$ pesos

Costs for Transportation: (20 km)

4.50 pesos/ton X 378589 = 1,703,651 pesos/year

O/M Costs of Biomass Facility

(21,554) X (1,257,000)/16250 = 1,667,285 pesos/year

Cost of Electricity Calculations:

$$\Big[\underbrace{(1.25245 \times 10^8)}_{\text{biomass capital cost}} + \underbrace{(57{,}500{,}000^*)\ (1.25)\ (1.09)^5}_{\text{conversion capital cost}}\Big]$$

$$\underbrace{\sum_{i=6}^{30} \frac{600{,}000)(1.25)(1.09)^i}{(1.12)^{i-5}}}_{\text{Conversion Plant O/M}} + \underbrace{\sum_{i=6}^{30} \frac{(1{,}667{,}285)(1.09)^i}{(1.12)^{i-5}}}_{\text{Harvesting \& O/M (Biomass)}} + \underbrace{\sum_{i=6}^{30} \frac{(1{,}703{,}651)(1.09)^i(1.01)^i}{(1.12)^{i-5}}}_{\text{Transportation}}$$

$$\underbrace{\sum_{i=6}^{30} \frac{p \times 3.168 \times 10^8 \ (1.09)^i}{(1.12)^{i-5}}}_{\text{Income from Electricity}}$$

$$1.25245 \times 10^8 + 1.10588 \times 10^8$$

$$+ (5{,}750{,}000)(27.547) + (1{,}667{,}285)(27.547) + (1{,}703{,}651)(32.576)$$

$$= p \times (3.168 \times 10^8)(27.547)$$

*Capital cost of 50MW plant in U.S. $

$$(1.7113 \times 10^8) + (.55498 \times 10^8) + (2.68983 \times 10^8) = p \times 8.72688 \times 10^9$$

$$\underset{\text{biomass}}{.0196} + \underset{\text{transportation}}{.0064} + \underset{\text{conversion}}{.0308} = .0568 = p$$

20 MW FACILITY ANALYSIS

Land Requirements:

Load factor = .8
Operating days/year = 330
Plant efficiency for 30% moisture wood = .22 (15514 Btu/kwh)
Fraction of land utilized for wood production = .94
Dry wood energy content = 17×10^6 Btu/ton

$$20 \text{ MW} \times .8 = 16{,}000 \text{ KW} = 16{,}000 \frac{\text{kwh}}{\text{h}}$$

$$16{,}000 \frac{\text{kwh}}{\text{h}} \times 24 \frac{\text{h}}{\text{day}} = 384{,}000 \frac{\text{kwh}}{\text{day}}$$

$$384{,}000 \frac{\text{kwh}}{\text{day}} \times 15514 \text{ Btu/kwh} = 5.95737 \times 10^9 \text{Btu/day}$$

5.95737×10^9 Btu/day/17×10^6 Btu/dry ton = 350.43 dry tons/day
350.43 dry tons/day/.7 dry tons/GTE = 500.62 GTE/day
500.62 GTE/day X 330 days/year = 165205 GTE/year ≈ 16500 GTE/year
165205 GTE/year/.3203 GTE/tarea-year = 515781 tareas
515781 tareas/.94 = 548703 ≈ 549,000 tareas

Annual Electricity Output:

20 MW X 1000kw/MW X .8 X 24 hour/day X 330 days/year = 1.267×10^8 kwh/year

Biomass Farm Costs Discounted to Plant Start-Up Year

$$\sum_{i=0}^{5} \text{costs}_i \, (1.09)^i (1.12)^{5-i} = 1619122 \text{ pesos (Mao site)}$$

to scale to 20 MW:

1619122 X 549,000/16250 = 54,701,414 pesos

Costs of Transportation: (15 km)

4.20 pesos/ton X 165205 = 693,861 pesos/year

O/M Costs of Biomass Facility:

(21554) X 549,000/16250 = 728194 pesos/year

Costs of Electricity Calculations:

$$\underbrace{54{,}701{,}414}_{\text{biomass capital cost}} + \underbrace{(27{,}600{,}000)(1.25)(1.09)^5}_{\text{conversion capital cost}}$$

$$\underbrace{\sum_{i=6}^{30} \frac{(2{,}700{,}000)(1.25)(1.09)^i}{(1.12)^{i-5}}}_{\text{conversion plant O/M}} + \underbrace{\sum_{i=6}^{30} \frac{(728194)(1.09)^i}{(1.12)^{i-5}}}_{\text{harvesting + O/M (biomass)}} + \underbrace{\sum_{i=6}^{30} \frac{(693.861)(1.09)^i(1.01}{(1.12)^{i-5}}}_{\text{transportation}}$$

$$= \sum_{i=6}^{30} \frac{p \times 1.267 \times 10^8 \ (1.09)^i}{(1.12)^{i-5}}$$

$$54{,}701{,}414 + 53{,}082{,}526 + (3{,}375{,}000)(27.547) + (728194)(27.547)$$

$$+ (693861)(32.576) = p \times 1.267 \times 10^8 (27.547)$$

$$\underbrace{74{,}760{,}974}_{\text{biomass}} + \underbrace{22{,}603{,}216}_{\text{transportation}} + \underbrace{1.46053 \times 10^8}_{\text{conversion}} = p \times 3.4902 \times 10^9$$

$$\underbrace{.0214}_{\text{biomass}} + \underbrace{.0065}_{\text{transportation}} + \underbrace{.0418}_{\text{conversion}} = .0697 = p$$

5 MW FACILITY ANALYSIS

Land Requirements:

Load factor = 0.8
Operating days/year = 330
Plant efficiency for 30% moisture wood = 0.18 (18961 Btu/kwh)
Fraction of land utilized for wood production = 0.94
Dry wood energy content = 17×10^6 Btu/ton

$5 \text{ MW} \times 0.8 = 4{,}000 \text{ KW} = 4{,}000 \frac{\text{kwh}}{\text{h}}$

$40{,}000 \text{ kwh/h} \times 24 \text{ h/day} = 96{,}000 \frac{\text{kwh}}{\text{day}}$

$96{,}000 \frac{\text{kwh}}{\text{day}} \times 18961 \text{ BTu/kwh} = 1.82025 \times 10^9 \text{ Btu/day}$

1.82025×10^9 Btu/day / 17×10^6 Btu/dry ton = 107.07 dry tons/day
107.07 dry tons/day / .7 dry tons/GTE = 152.96 GTE/day
152.96 GTE/day x 330 days/yr = 50478 GTE/yr
50478 GTE/year / .3203 GTE/tarea-yr = 157,595 tareas
157,595 tareas/.94 = 167654 ≈ 168,000 tareas

Annual Electricity Output:

$5 \text{ MW} \times 1000 \text{ kw/MW} \times .8 \times 24 \text{ hr/day} \times 330 \text{ days/yr} = 3.168 \times 10^7 \text{ kwh/year}$

Biomass Farm Costs Discounted to Plant Start-Up Year:

$$\sum_{i=0}^{5} \text{costs}_i \, (1.09)^i (1.12)^{5-i} = 1619122 \text{ pesos (Mao site)}$$

scale to 5 MW:

1619122 x 168,000/16250 = 16,739,231 pesos

Costs of Transportation:

3.70 pesos/ton x 50478 = 186,769 pesos/year

O & M Costs of Biomass Facility:

(21554) x 168000/16250 = 222835 pesos/year

Cost of Electricity Calculations:

$$\underbrace{16{,}739{,}231}_{\text{biomass capital cost}} + \underbrace{(9{,}100{,}000)(1.25)(1.09)^5}_{\text{conversion plant capital cost}}$$

$$+ \underbrace{\sum_{i=6}^{30} \frac{(1{,}200{,}000)(1.25)(1.09)^i}{(1.12)^{i-5}}}_{\text{conversion plant O \& M cost}} + \underbrace{\sum_{i=6}^{30} \frac{(222{,}835)(1.09)^i}{(1.12)^{i-5}}}_{\text{biomass O \& M cost}}$$

$$+ \underbrace{\sum_{i=6}^{30} \frac{(186{,}769)(1.09)^i(1.01)^i}{(1.12)^{i-5}}}_{\text{transportation}} = \sum_{i=6}^{30} \frac{p \times 3.168 \times 10^7 \ (1.09)^i}{(1.12)^{i-5}}$$

$$16{,}739{,}231 + 17{,}501{,}847 + (1{,}500{,}000)(27.547) + (222{,}835)(27.547)$$

$$+ (186{,}769)(32.576) = p \times 3.168 \times 10^7 \ (27.547)$$

$$\underbrace{22{,}877{,}667}_{\text{biomass}} + \underbrace{6{,}084{,}187}_{\text{transportation}} + \underbrace{5.8822 \times 10^7}_{\text{conversion}} = p \times 8.7269 \times 10^8$$

$$0.0262 + 0.0070 + 0.0674 = 0.1006 = p$$

2 MW FACILITY ANALYSIS

Land Requirements:

Load Factor = .8
Operating days/year = 330
Plant efficiency for 30% moisture wood = 0.12 (28442 Btu/kwh)
Fraction of land utilized for wood production = .94
Dry wood energy content = 17 x 10^6 Btu/ton
2 MW x 0.8 = 1,600 kw = 1,600 kwh/h
1,600 kwh/h x 24 h/day = 38,400 kwh/day
38,400 kwh/day x 28442 Btu/kwh = 1.09217 x 10^9 Btu/day
1.09217 x 10^9 Btu/day / 17 x 10^6 Btu/dry ton = 64.25 dry ton/day
64.25 dry ton/day / .7 dry ton/GTE = 91.78 GTE/day
91.78 GTE/day x 330 days/year = 30,287 GTE/year
30,287 GTE/year / .3203 GTE/tarea-year = 94,559 tareas
94,559 tareas/.94 = 100,594 tareas ≈ 101,000 tareas

Annual Electricity Output:

2 MW x 1000 kw/MW x .8 x 24 hrs/day x 330 day/yr = 1.2672×10^7 kwh/yr

Biomass Farm Costs Discounted to Plant Start-Up Year:

$$\sum_{i=0}^{5} \text{costs}_i \, (1.09)^i (1.12)^{5-i} = 1619122 \text{ pesos (Mao site)}$$

scale to 2 MW:

1619122 x 101000/16250 = 10063466 pesos

Costs of transportation:

3.50 pesos/ton x 30287 = 106005 pesos/yr

O & M Costs of Biomass Facility:

21554 x 101000/16250 = 133966 pesos/yr

Cost of Electricity Calculations:

$$\underbrace{10{,}063{,}466}_{\text{biomass capital cost}} + \underbrace{(4{,}400{,}000)(1.25)(1.09)^5}_{\text{conversion plant capital cost}}$$

$$+ \underbrace{\sum_{i=6}^{30} \frac{(630{,}000)(1.25)(1.09)^i}{(1.12)^{i-5}}}_{\text{conversion plant O \& M}} + \underbrace{\sum_{i=6}^{30} \frac{(133{,}966)(1.09)^i}{(1.12)^{i-5}}}_{\text{biomass O \& M}}$$

$$+ \underbrace{\sum_{i=6}^{30} \frac{(106{,}005)(1.09)^i(1.01)^i}{(1.12)^{i-5}}}_{\text{transportation}} = \sum_{i=6}^{30} \frac{p \times 1.267 \times 10^7 (1.09)^i}{(1.12)^{i-5}}$$

$$10063466 + 8462432 + (850000)(27.547) + (133966)(27.547) +$$

$$(106005)(32.576) = p \times 1.267 \times 10^7 (27.547)$$

$$\underbrace{13{,}753{,}827}_{\text{biomass}} + \underbrace{3{,}453{,}219}_{\text{transportation}} + \underbrace{31{,}877{,}382}_{\text{conversion}} = p \times 3.4902 \times 10^{8}$$

$$\underbrace{0.0394}_{\text{biomass}} + \underbrace{0.0099}_{\text{transportation}} + \underbrace{0.0913}_{\text{conversion}} = 0.1406 = p$$

MEDIUM PRODUCTIVITY SYSTEMS

Productivity: 10 cu. meter/hectare-year

≈.6406 GTE/tarea-year

2 MW FACILITY ANALYSIS

Land Requirements:

Load factor = .8
Operating days/year = 330
Plant efficiency for 30% moisture wood = .12 (28442 Btu/kwh)
Fraction of land utilized for wood production = .94
Dry wood energy content = 17 X 10^6Btu/ton

$$2 \text{ MW} \times .8 = 1{,}600 \text{ kw} = 1{,}600 \frac{\text{kwh}}{\text{h}}$$

$$1{,}600 \text{ kwh/h} \times 24 \text{ h/day} = 38{,}400 \frac{\text{kwh}}{\text{day}}$$

38,400 kwh/day X 28,442 Btu/kwh = 1.09217 X 10^9
1.09217 X 10^9 Btu/day/17 X 10^6 Btu/day ton = 64.25 dry tons/day
64.25 dry tons/day/.7 dry tons/GTE = 91.78 GTE/day
91.78 GTE/day X 330 days/year = 30,287 GTE/year
30,287 GTE/year/.6406 GTE/tarea-yr = 47,279 tareas
47,279 tareas/.94 = 50,297 ≈ 50,000 tareas

Annual Electricity Output:

2 MW X 1000 kw/MW X .8 X 24/hrs/day X 330 days/year = 1.2672 X 10^7 kwh/year

Costs for Transportation:

3.50 pesos/ton X 30287 tons/year = 106,005 pesos/year

Biomass Farm Costs Discounted to Start-Up Year:

$$\sum_{i-0}^{5} \text{costs}_i \, (1.09)^i (1.12)^{5-i} = 1619122 \text{ (Mao site)}$$

to scale to 2 MW:

$$1619122 \times \frac{50000}{16250} = 4{,}981{,}914 \text{ pesos.}$$

O/M Costs of Biomass Facility:

$$\underbrace{4875}_{\text{harvest}} \times 2 + \underbrace{8125}_{\text{rent}} + \underbrace{1000}_{\text{road maintenance}} = 18875$$

$$18875 \times \frac{50000}{16250} = 58077 \text{ pesos/year}$$

Cost of Electricity Calculations:

$$\underbrace{4,981,914}_{\substack{\text{biomass}\\ \text{capital cost}}} + \underbrace{(4,400,000)(1.25)(1.09)^5}_{\substack{\text{conversion plant}\\ \text{capital cost}}} + \sum_{i=6}^{30} \underbrace{(680,000)(1.25)\frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{conversion plant O/M}}$$

$$+ \underbrace{\sum_{i=6}^{30} 58077 \frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{harvesting + O/M biomass}} + \underbrace{\sum_{i=6}^{30} \frac{(106,005)(1.09)^i(1.01)^i}{(1.12)^{i-5}}}_{\text{transportation}}$$

$$= \sum_{i=6}^{30} p \times 1.2672 \times 10^7 \frac{(1.09)^i}{(1.12)^{i-5}}$$

$$4,981,914 + 8,462,432 + (850,000)(27.547) + (58077)(27.547)$$

$$+ (106,005)(32.576) = p \times (1.2672 \times 10^7)(27.547)$$

$$\underbrace{6,581,761}_{\text{biomass}} + \underbrace{3,453,219}_{\text{transportation}} + \underbrace{31,877,382}_{\text{conversion}} = p \times 3.4902 \times 10^8$$

$$\underbrace{.0189}_{\text{biomass}} + \underbrace{.0099}_{\text{transportation}} + \underbrace{.0913}_{\text{conversion}} = .1201 = p$$

HIGH PRODUCTIVITY SYSTEMS

Productivity: 20 cu. meter/hectare-year

≈1.2812 GTE/tarea-year

2 MW FACILITY ANALYSIS

Land Requirements:

Load factor = .8
Operating days/year - 330
Plant efficiency for 30% moisture wood = .12 (28442 Btu/kwh)
Fraction of land utilized for wood production = .94
Dry wood energy content = 17 X 10^6 Btu/ton

$$2 \text{ MW} \times .8 = 1{,}600 \text{ kw} = 1600 \frac{\text{kwh}}{\text{h}}$$

$$1600 \frac{\text{kwh}}{\text{h}} \times 24 \frac{\text{h}}{\text{day}} = 38400 \frac{\text{kwh}}{\text{day}}$$

$$38400 \frac{\text{kwh}}{\text{day}} \times 28442 \text{ Btu/kwh} = 1.09217 \times 10^9$$

1.09217×10^9 Btu/Kwh/17 X 10^6Btu/dry ton = 64.25 dry tons/day
64.25 dry tons/day/.7 dry tons/GTE = 91.78 GTE/day
91.78 GTE/day X 330 days/year = 30287 GTE/year
30287 GTE/year/1.2812 GTE/tarea-year = 23640 tareas
23640 tareas/.94 = 25149 ≈ 25000 tareas

Annual Electricity Output:

2 MW X 1000kw/MW X .8 X 24 hours/day X 330 days/year = 1.2672 X 10^7 kwh/year

Costs for Transportation:

3.50 pesos/ton X 30287 tons/year = 106005 pesos/year

Biomass Farm Costs Discounted to Start-Up Year:

$$\sum_{1=0}^{5} \text{costs}_i (1.09)^i (1.12)^{5-i} = 1619122 \text{ (Mao site)}$$

to scale to 2 MW:

$$1619122 \times \frac{25000}{16250} = 2{,}490{,}957 \text{ pesos.}$$

O/M Costs of Biomass Facility:

$$\underbrace{(4875)}_{\text{harvest}} \times 4 + \underbrace{8125}_{\text{rent}} + \underbrace{1000}_{\text{road maintenance}} = 28625 \text{ pesos for this productivity at Mao Site}$$

$$28625 \times \frac{25000}{16250} = 44{,}038 \text{ pesos/year}$$

Cost of Electricity Calculations:

$$\underbrace{2{,}490{,}957}_{\text{biomass capital cost}} + \underbrace{4{,}400{,}000\ (1.25)(1.09)^5}_{\text{conversion plant capital cost}} + \sum_{i=6}^{30} \underbrace{680{,}000\ (1.25)\frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{conversion plant O/M}}$$

$$+ \underbrace{\sum_{i=6}^{30} 44{,}038\ \frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{harvesting and O/M (Biomass)}} + \underbrace{\sum_{i=6}^{30} \frac{(106{,}005)(1.09)^i(1.01^i)}{(1.12)^{i-5}}}_{\text{transportation}}$$

$$= \sum_{i=6}^{30} p \times 1.2672 \times 10^7\ \frac{(1.09)^i}{(1.12)^{i-5}}$$

$$2{,}490{,}957 + 8{,}462{,}432 + (850{,}000)(27.547) + (44{,}038)(27.547)$$

$$+ (106{,}005)(32.576) = p \times (1.2672 \times 10^7)(27.547)$$

$$3{,}704{,}072 + 3{,}453{,}219 + 31{,}877{,}382 = p \times 3.4902 \times 10^8$$

$$\underbrace{.0106}_{\text{biomass}} + \underbrace{.0099}_{\text{transportation}} + \underbrace{.0913}_{\text{conversion}} = .1118 = p$$

OIL FIRED SYSTEMS

FUEL COSTS

Efficiencies of Oil Fired Units:

50 MW:	32%	(10666 Btu/kwh)
20 MW:	31%	(11010 Btu/kwh)

Heat Content of Oil (Residual): 6.3×10^6 Btu/barrel

Fuel Costs

50 MW:

$[3.168 \times 10^8$ kwh/yr x 10666 Btu/kwh / 6.3×10^6/barrel$]$ x 35.00 $/barrel

= 18,772,160 $/yr.

20 MW:

$[1.267 \times 10^8$ kwh/yr x 11010 Btu/kwh / 6.3×10^6 Btu/barrel$]$ x 35.00 $/barrel

= 7,749,817 $/yr.

Cost of Electricity Calculations for 50MW Facility

$$\underbrace{(50{,}000{,}000)(1.25)(1.09)^5}_{\text{Capital}} + \underbrace{\sum_{i=6}^{30}(2{,}200{,}000)(1.25)\frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{O/M}}$$

$$+ \underbrace{\sum_{i=6}^{30}(18{,}772{,}160)(1.25)\frac{(1.09)^i(1.02)^i}{(1.12)^{i-5}}}_{\text{Fuel}} = \underbrace{\sum_{i=6}^{30}\frac{p \times 3.168 \times 10^8(1.09)^i}{(1.12)^{i-5}}}_{\text{Electricity Income}}$$

$$96{,}163{,}997 + (2{,}750{,}000)(27.547) + (23{,}465{,}200)(38.654)$$

$$= p \times (3.168 \times 10^8)(27.547)$$

$$\underbrace{.011}_{\text{capital}} + \underbrace{.009}_{\text{O/M}} + \underbrace{.104}_{\text{fuel}} = .124 = P$$

Cost of Electricity Calculations for 20 MW Facility

$$\underbrace{(24{,}000{,}000)(1.25)(1.09)^5}_{\text{Capital}} + \underbrace{\sum_{i=6}^{30}(1{,}300{,}000)(1.25)\frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{O/M}}$$

$$+\underbrace{\sum_{i=6}^{30}(7{,}749{,}817)(1.25)\frac{(1.09)^i(1.02)^i}{(1.12)^{i-5}}}_{\text{Fuel}} = \underbrace{\sum_{i=6}^{30} p \times 1.267 \times 10^8 \frac{(1.09)^i}{(1.12)^{i-5}}}_{\text{Electricity Income}}$$

$$46{,}158{,}719 + (1{,}625{,}000)(27.547) + (9{,}687{,}271)(38.654)$$

$$= p \times (1.267 \times 10^8)(27.547)$$

$$\underbrace{.013}_{\text{capital}} + \underbrace{.013}_{\text{O/M}} + \underbrace{.107}_{\text{fuel}} = .133 = p$$

APPENDIX B

DEVELOPMENT PLAN

The plan for an energy farm incorporates a very conservative management philosophy. The native Leucaena and Prosopis are recommended as trees that are well adapted to the site. The giant Leucaena (K-8) is also recommended because it is the same species and exhibits superior growth in tropical climates.[12,24] Site preparation, planting and tending methods are all predicated on minimizing soil erosion, not increasing production rates. The harvesting system is accepted by the local people who will be employed as harvesters. There is a need to test these methods and species on a small-scale before launching a large-scale operation, and there is a parallel need to explore the use of different species, establishment methods and harvesting techniques to gain productivity.

Experimentation

Experimentation should begin at the same time as the demonstration energy farm is established. There are two kinds of needs to be satisfied with a parallel course of experimentation. First, there is a need to improve the knowledge of the establishment methods and species. Second, there is a need to assess the productivity of the remainder of the land available for energy farming. These needs can be accomplished in the following way:

1. Site assessment - using detailed soil mapping, identify prospective site categories that are differentiated by productive capability. The CRIES data offer a starting

point for this effort, but fieldwork is essential to integrate soil type and depth with relief and moisture regime.

Two very important variables on which to base productive capacities appear to be moisture availability and land form. The whole area is called the dry forest, but some areas are drier than others and some slopes and most hill tops are more eroded and contain less topsoil than areas of gentle topography. There are areas of saline soil near Lago Enriquillo and the extreme southern portion of the country that may require special evaluation.

2. Species testing - after production categories are determined and mapped, locate experiment sites to test a range of species to determine those best suited to the sites.

Jennings and Ferreiras identified 21 tree species found in their dry forest inventory, and the genus Acacia was represented three times. Two out of three of these species were commonly used for charcoal production, indicating their relatively high heat value. Another Acacia that might be tried is noted by NAS(13) - Acacia auriculifermis. This species appears to be well suited to a wide variety of soil conditions and thrives under very dry conditions. Two other types of Acacia that should be considered are A. catechu(25) and A. mangium,(13) both fast growing, arid-adapted species.

Albizia lebbeck(25,26) is another legume adapted to arid areas with good fuel characteristics (9300 Btu/lb., .81 to .95 specific gravity) that has been introduced as a fast growing ornamental in the Dominican Republic. Prosopis juliflora(13,27) is described as very successful in arid regions and is native to the Dominican Republic. Other Prosopis which have the characteristics of drought

resistance and high fuel value are to be found outside the country. One is Prosopis pallida,[25] a native of Hawaii. Although Prosopis is very thorny and difficult to handle, it is possible to find and breed thornless varieties. For energy plantations with their need for tending, thornless varieties are very valuable.

Two of the Eucalypts which may have an application in the dry forest are E. tereticarnis and E. camaldulensis. They are not unduly sensitive to alkaline soils and require little moisture. Jacobs[3] describes them as very tolerant of drought and seasonality of precipitation. E. camaldulensis is widely planted outside Australia and requires little moisture (225-65mm/year).

Probably the most important species to test is Leucaena leucocephala, type K-8, developed in Hawaii. Some trees of this type have already been test-planted under very good soil and climatic conditions in the Dominican Republic and very good growth has resulted.*

The species chosen for experimentation should not be restricted to the above-named, but an extensive search of the forestry literature in tropical countries should be made.

As species are tested for growth on different sites within the dry forest area, experimentation with spacing to obtain maximum yield

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*Sr. Italo Russo, Department of Agriculture, Santo Domingo and Sr. Alberto Rodriguez, ISA, Santiago, have planted K-8. Height growth of 6 m the first year has been experienced.

and best form should be done. Since soil moisture is a severe limiting factor, the proper spacing of trees to completely occupy the site but not compete with each other is a critical factor. The testing of species for their ease of establishment and resistance to disease is another important feature of species selection.

Tree improvement - the development of the K-8 strain of *L. leucocephala* was the result of selection from within the species of a particular group of individuals that shared genetic potential for rapid growth. Seed was collected from these individuals, and the strain was isolated so that cross breeding with like species could not occur. Seeds can now be collected from these individuals and their progeny to provide a supply of this valuable type.

The same procedure should be initiated with native species of arid land hardwoods - the *Acacias*, *Prosopis*, *Leucaena*; perhaps *Brusera* and *Caesalpina*. There are thornless varieties of some *Prosopis*.(25) Attempts should be made to breed thornless varieties of *P. juliflora* and the *Acacias*. Many of these species produce seed at an early age (*Leucaena* at 6-9 months), and the results of breeding could be determined very quickly, especially for producing energy crops on short rotations. Seed orchards could be established to provide improved seed in less than five years. A longer term program could be run concurrently to breed or select types that maximize the length of time that coppice growth can be obtained from the same rootstock.

An advantage of working with coppicing species is that a superior individual can be cloned. Exact replicas can be propagated immediately by cutting the past year's branch growth into pieces and planting the pieces almost like seeds. The advantage of this characteristic over sexual reproduction is that one knows exactly what the genetic material is in a cutting, whereas the seed produced by a very well-formed, rapid-growing tree may contain a number of unknown gene characters.

- Methods development - the methods chosen for establishing, tending, and harvesting the energy farm have been characterized as conservative, the principle being to start the project with technologies that minimize risk. In this way, one can gain experience with short rotation tree crops without having to change everyone's thinking at once. The project is much less of a total experiment as well. However, there is ample opportunity to reduce costs and increase production by studying new or different establishment, tending and harvesting methods.

- Site preparation has been predicated largely on the basis of minimizing loss of soil due to erosion. The sensitive sites are on slopes that wash easily, and the least amount of soil disturbance is the objective. Since the reason for site preparation is to eliminate competition from undesirable species, the application of herbicides should be considered seriously. There are a variety of herbicides available in the United States. Among them, Roundup has been used very satisfactorily in preparing weedy and grassy sites for short rotation culture.* A good source to determine experience with Roundup and other herbicides is: Dr. David Dawson, U.S.D.A. Forest Service, Rhinelander, Wisconsin.

Experimentation could be done to plow on the contour, tearing out roots of weed species and creating terraces of topsoil. Where

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*William Reitanen, Ontario Ministry of National Resources, Brockville District, Brockville, Ontario, Canada.

soil is very thin, a method of employing large tractors to crush the existing vegetation to the ground, followed by fire to consume the brush, and release nutrients at the same time as the weed seeds are destroyed could be employed. Herbicide could then be used selectively.

- Planting has been prescribed because it is a proven way to control spacing and establish tree cover quickly. There are a number of ways to mechanize the process, some of which may lend themselves to oxen or mule power. The establishment of the energy farm may be accomplished by seeding, especially since most of the species being considered produce seed plentifully and establish well from seed. A challenge to this method is steep slopes where seeds may wash out before they germinate and their root systems become established.

An interesting seeding technique called the "seed plate" has been developed in Sweden, experimented with and altered substantially because of losses of seed to rodents. Basically, the idea is to drop plastic bags on the ground at the desired spacing, the bags having openings at the top and bottom for root and shoot egress. The bags are flat and contain a growing medium saturated with moisture and one to several tree seeds. The plastic bag helps contain enough moisture to allow the seed to germinate, and the holes allow the root to establish itself in the soil on which it is placed. For steep slope seeding, it could be staked down to prevent washing.

Since all species being considered will sprout, there is a good chance that planting of cuttings will be practical under conditions of adequate moisture and deep soil. A variety of establishment methods must be found and applied to different site conditions.

- Tending is a procedure that foresters have learned is expensive and have tried to minimize because of that expense. On rotations of 20 to 50 years, the cost of capital over those periods is forbidding. For short rotations, however, tending is not only critical biologically, but the investment can be recovered very quickly. It is imperative that weed competition be minimized during the period when the trees are capturing the site. There are a number of ways to do this.

Cultivation to remove the aerial and root portions of competing species may be the most cost-effective method for the Dominican Republic at the present time. Herbicide treatment should be tested, however, to determine the effect on yields of the complete elimination of competition.

The importance of soil moisture to growth in the arid region is obviously significant. Experimentation with drip irrigation should be done with two objectives:

1. to provide the optimum moisture during the early root establishment stage until the foliage shades out weed competition;

2. to obtain maximum yields per unit area.

Trickle irrigation is the most efficient irrigating system because it can be designed to provide only the crop plants with moisture. It is transportable and amenable to farming hillsides. Solar powered irrigation should be investigated. On the negative side, it is also capital-intensive, and a method requiring relatively high (but low technical level of) operating maintenance.

Although the sites visited by the MITRE team appeared not to be lacking in soil nutrients (only moisture), energy farming is demanding of soil nutrients. Whereas traditional forestry and much

of agriculture as practiced by, for example, sugar cane production, leaves organic wastes of the land after harvest, energy farming removes virtually all of the aerial biomass at each harvest. Energy farming uses the chosen plant to capture the energy of the nutrients in the soil and, eventually, the soil will be depleted if nutrients are not returned.

Because nitrogen-fixing species can produce much of the nitrogen needed for their own growth, legumes were recommended as desirable energy farm species. However, the rate at which all nutrients are used by this practice should be determined. As soils are classified and species are selected, trials should establish the rate of nutrient use so future management plans can accommodate the replenishing of the soil with the proper ingredients.

Harvesting has been treated as a means of employing rural people at non-technical jobs. Within that constraint there is opportunity to improve on work methods, tool design, use of draft animals and general work layout. It may be found efficient to prepare bundles of trees, and use a small, tractor-mounted cable yarding device manufactured by the Finns. This would minimize soil disturbance and provide power to transport the trees up slopes to the roads, which are located, as a rule, at higher elevations than the trees.

Methods of harvesting in strips, patches and blocks, so as to avoid baring an entire slope at one time, should be tried in the interest of avoiding the washing of soil that occurs when vegetative cover is missing.

Because of the varied nature of sites within the energy farm area, there will be a need to study and experiment with management planning. This includes the assessment of which areas should be cut at what time. At the present time, rotation age is constrained by the maximum size of trees that can conveniently be harvested by conventional tools. Another look at the whole system should be done to determine the rotation age that maximizes financial return. Objectives other than financial return may be equally important, and studies should be done to design optimum systems according to these objectives.

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